

Effects of Interactive E-Modules on Junior High School Students' Mathematical Communication in Circle Geometry Across Self-Regulated Learning Levels

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ABSTRACT

Mathematical communication skills are one of the most important competencies in mathematics education. However, students' mathematical communication skills are still not optimal, necessitating alternative teaching methods that can support students in developing and conveying their mathematical ideas. This study aims to analyze improvements in students' mathematical communication skills based on the use of interactive e-modules and their level of Self-Regulated Learning (SRL), as well as to determine the interaction between the two. The study employed a quantitative approach with a 2×3 factorial quasi-experimental design. The research subjects consisted of 80 11th-grade students at MAN 1 Lombok Tengah, divided into experimental and control groups. Data on mathematical communication skills were collected through pretests and posttests using a test instrument, while SRL data were collected via a questionnaire. Improvements in mathematical communication skills were analyzed using N-Gain. Inferential analysis employed the Mann-Whitney and Kruskal-Wallis tests, along with follow-up tests using the Bonferroni correction. The results showed no significant difference in the improvement of mathematical communication skills between the experimental and control classes ($p = 0.885$). Conversely, there was a difference in improvement based on SRL levels ($p < 0.001$), with all category pairs showing significant differences after the Bonferroni correction. The analysis results also showed that there was no significant interaction between the use of interactive e-modules and SRL levels on the improvement in students' mathematical communication skills ($p = 0.708$; Partial Eta Squared = 0.009). The findings indicate that the SRL level is associated with variations in the improvement of students' mathematical communication skills, whereas the use of interactive e-modules did not show a significant difference in improvement compared to conventional learning.



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Introduction

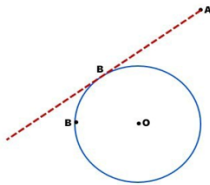
One of the key competency's students must possess in mathematics learning is the ability to communicate mathematically. Mathematics not only helps convey ideas, concepts, and solutions to mathematical problems in a clear and systematic manner, but also helps students develop reasoning, logical thinking, and a deeper conceptual understanding (Yuniarti, 2016). Students can communicate mathematical ideas both orally and in writing, connect mathematical concepts to real-world objects, and describe everyday situations using symbols or diagrams (Lubis et al., 2023). Therefore, mathematical communication is crucial for assessing the success of mathematics learning in schools. The importance of mathematical communication skills is increasingly evident because mathematics learning is not only oriented toward the final answer but also toward the process by which students understand and explain a problem. Students with strong mathematical communication skills can convey ideas, connect various mathematical representations, explain solution strategies, provide reasoning, and evaluate the correctness of their answers. Conversely, students with poor mathematical communication skills tend to struggle with explaining concepts, using symbols, creating mathematical diagrams or models, constructing arguments, and drawing conclusions. According to the NCTM, indicators of mathematical communication skills include the ability to express mathematical ideas orally, in writing, or visually; to understand and evaluate mathematical ideas; and to use mathematical language, notation, and structures to convey ideas and describe mathematical relationships (Na'im & Mukhlis, 2024).

Although important, various studies indicate that students in Indonesia still score low in mathematical communication. Students are less active in discussing their mathematical concepts due to lecture-based teaching methods (Hariati et al., 2022). Additionally, the perception that mathematics is a difficult subject also leads to students being unmotivated and disengaged from the lessons. As a result, students lack the ability to communicate mathematically. Diagnostic test results show that most students fall into the moderate or low categories in mathematical communication, even among high-achieving students. Previous studies have investigated various factors influencing mathematical communication, such as the use of instructional media, self-efficacy, and instructional models. The study (Soleha et al., 2026) demonstrates the influence of the Problem-Based Learning model on mathematical communication skills as viewed through students' self-efficacy. Meanwhile, (Fazira et al., 2025) examines the relationship between mathematical communication skills and students' self-confidence in learning exponents. The results, however, reveal differences and contradictions.

As revealed by observations at a state senior high school (Madrasah Aliyah Negeri) in Central Lombok, students faced several difficulties in answering math problems. Figures 1 a) and 1 b) show a problem and a student's answer regarding a tangent line to a circle. In this problem, students were asked to state whether the provided figure depicted a tangent line. The student failed to present an argument and their opinion regarding the given situation, stating that the provided figure was not a tangent line. They claimed that a tangent line is a line that intersects a circle at two points. This statement is incorrect because the student misunderstood the definition of a tangent line. Furthermore, the student attempted to illustrate the shape of a tangent line, but the drawing provided did not match the problem. The context of the problem states that there is one point that touches the circle. Based on the student's response, the student was unable to explain the idea or solution to a problem or diagram using their own words and was unable to draw conclusions from a mathematical problem.

Perhatikan soal berikut!

Lingkaran dengan pusat O dan panjang jari-jari 6 cm. Titik A berada di luar lingkaran, sehingga jarak $OA = 10$ cm. Dari titik A, dibuat garis singgung yang menyinggung lingkaran di titik B, tentukan panjang garis singgungnya!



1. Apakah gambar representasinya sudah benar? Jika menurutmu benar maka berikan alasannya dan jika tidak berikan alasan serta gambar representasi yang benar.
2. Tuliskan apa yang diketahui dan apa yang ditanyakan dari permasalahan ini.
3. Hitung panjang garis singgung AB dan jelaskan secara singkat mengapa jawaban tersebut masuk akal.

a) Observation Question

1. Representasi gambar secara garis singgung lingkaran adalah garis yang menyinggung lingkaran di dua titik.



2. Diketahui: Pusat lingkaran adalah O
Jari-jari $r = 6$ cm
 $OA = 10$ cm
Ditanyakan: Panjang garis singgung / AB = ...?

3. $AB = OA + OB$
 $= 10 \text{ cm} + 6 \text{ cm}$
 $= 16 \text{ cm}$

Jadi panjang garis singgungnya adalah 16 cm karena jarak atau panjang garis singgungnya harus sama dengan garis singgungnya. Selain panjang dan jarak garis yang lain maka untuk mencari nilainya, kita tambahkan panjang OA dan OB.

b) Student's Answer

Consider the following problem!

A circle with center O has a radius of 6cm. Point A lies outside the circle, with $OA=10$. A tangent is drawn from point A, touching the circle at point B. Determine the length of the tangent segment!

1. Is the diagram an accurate representation of the problem? If you think it is, explain why. If not, explain why and draw a correct representation.
2. State what is known and what is being asked in this problem.
3. Calculate the length of the tangent segment AB and briefly explain why your answer is reasonable

The representation is incorrect because a tangent to a circle is a line that intersects the circle at two points."

Given:

- The center of the circle is O.
- The radius, r , is 6 cm.
- $OA = 10$ cm.

Find:

- The length of the tangent segment AB.

$$\begin{aligned} AB &= OA + OB \\ &= 10 \text{ cm} + 6 \text{ cm} \\ &= 16 \text{ cm} \end{aligned}$$

"So, the length of the tangent segment is 16 cm. This makes sense because the tangent segment is longer. Each side has a different length, so, to find its length, add the lengths of OA and OB."

Figure 1. Observation and Student Answer

The difficulties experienced by the student indicate that the student's mathematical communication skills are still relatively low. This low level of mathematical communication stems from a lack of opportunities for the student to manage their own learning style and express their own opinions. There are many efforts that can be made to improve students' mathematical communication, one of which is by implementing learning using interactive e-modules that contain instructions for students to consciously manage and engage in independent learning activities, as well as provide opportunities for students to explain their opinions. An interactive e-module is a digital learning medium in the form of an interactive module that presents mathematics material in an engaging way with interactive features such as dynamic visualizations, immediate feedback, and easy access at any time, all of which support students' independent learning (Tesi, 2024).

Another aspect believed to influence students' mathematical communication is Self-Regulated Learning. Self-Regulated Learning refers to students' ability to manage their learning process consciously, independently, and responsibly. SRL encompasses the ability to set learning goals, choose strategies, manage time, monitor understanding, utilize learning

resources, control learning activities, and evaluate the learning process and outcomes. Indicators of SRL include independence, self-confidence, discipline, initiative, self-control, and responsibility. Research on SRL also identifies planning, monitoring, and evaluation as crucial components of the process by which students manage their learning activities (Chumdari et al., 2024).

Studies such as those conducted by (Rahmawati & Alaydrus, 2021) and (Apriyanto et al., 2025) indicate that Self-Regulated Learning has a significant impact on improving students' critical thinking skills. This forms the basis for the research into whether Self-Regulated Learning has a similar impact on students' mathematical communication skills. Research conducted by (Mulyani, 2017) also found a relationship between Self-Regulated Learning and mathematical communication skills. These findings indicate that students' ability to plan, monitor, and evaluate the learning process can support their ability to explain ideas, develop strategies, provide reasoning, and draw conclusions from problem-solving.

Previous studies, such as the one conducted by (Zahria, 2024), have shown that interactive e-modules have a positive effect on students' mathematical communication skills; the study (Mulyani, 2017) also found a relationship between Self-Regulated Learning and mathematical communication skills. Furthermore, a study conducted by (Dewi & Bahri, 2024) indicates that interactive e-modules are closely related to the principles of Self-Regulated Learning because they encourage students to learn independently, monitor their learning process, and engage in self-evaluation. However, to date, there have been few studies that specifically examine the effect of using interactive e-modules on improving students' mathematical communication skills regarding circle-related material, as viewed through the lens of Self-Regulated Learning. Previous studies have tended to examine the effect of interactive e-modules on mathematical communication separately or to link SRL with critical thinking skills and other mathematical abilities. Research that simultaneously examines the use of interactive e-modules, SRL levels, and their interaction on the improvement of mathematical communication skills—particularly regarding the topic of tangents to circles—remains limited. Furthermore, research findings on the factors influencing mathematical communication remain inconsistent due to differences in learning media, instructional models, student characteristics, and the subject matter used. The study (Meri et al., 2022) examined the relationship between SRL and mathematical communication skills, while the study by (Harid et al., 2024) demonstrated the use of e-modules in mathematics instruction to facilitate mathematical communication skills. Therefore, this study offers a novel approach by simultaneously testing the use of interactive e-modules and SRL levels to improve students' mathematical communication skills on the topic of tangents to circles, including testing the interaction between the use of interactive e-modules and SRL levels.

The topic of tangents to a circle was chosen because, in studying it, students are not only required to understand the definition but also need to use various representations to explain the concept and understand the properties of tangents. Students need to identify lines that are tangent to a circle, represent situations through drawings or symbols, and understand the relationship between the radius and the tangent at the point of tangency. The study by (Kurniah et al., 2019) shows that solving problems involving tangents to a circle requires the ability to use visual representations, mathematical expressions, and written text. Furthermore, the study by (Lusiana et al., 2019) indicates that when solving problems involving tangents to a circle, students use information in the form of diagrams and symbols and communicate their thought processes. These characteristics of the material provide opportunities to develop mathematical communication skills through activities such as observing representations, explaining ideas,

providing reasons, and drawing conclusions. With the support of interactive e-modules, students can explore representations and the properties of tangent lines more directly through visual and interactive activities.

The use of interactive e-modules is also related to the characteristics of independent learning found in Self-Regulated Learning. E-modules provide students with the opportunity to manage their own learning process through activities such as studying the material, performing tasks, completing exercises, and independently evaluating their understanding (Harid et al., 2024). Meanwhile, Self-Regulated Learning refers to students' ability to manage their learning process independently through activities such as setting goals, selecting strategies, monitoring their understanding, controlling the learning process, and evaluating learning outcomes (Solikah & Astuti, 2025). The relationship between SRL and mathematical communication skills has also been examined in previous studies, although the results have not been entirely consistent (Meri et al., 2022). This serves as the basis for testing whether SRL levels are related to the effectiveness of using interactive e-modules in improving students' mathematical communication skills.

This investigation is important to determine whether the use of interactive e-modules has different effects on students with high, moderate, and low levels of SRL. The results of this study are expected to provide teachers with information regarding the appropriate use of interactive e-modules to improve students' mathematical communication skills in the topic of tangents to circles. Information regarding differences in skill improvement based on SRL levels can also help teachers provide guidance tailored to students' needs. For schools, the results of this study can serve as a basis for developing technology-based learning that takes into account students' academic abilities and self-directed learning. Additionally, these findings can serve as a reference for other researchers to examine the use of digital media, SRL, and mathematical skills in different subjects or educational levels.

Based on the above, this study was conducted to examine the use of interactive e-modules in improving students' mathematical communication skills from the perspective of Self-Regulated Learning. The research questions for this study are as follows: 1) to analyze differences in the improvement of mathematical communication skills between students who learn using interactive e-modules and those who learn conventionally. 2) to analyze differences in the improvement of students' mathematical communication skills based on high, moderate, and low levels of Self-Regulated Learning (SRL) in the circle unit. 3) to analyze the interaction between the use of interactive e-modules and the level of Self-Regulated Learning (SRL) on the improvement of students' mathematical communication skills in the circle unit.

Method

Settings

This study employed a quantitative approach using a quasi-experimental method and a 2×3 factorial design. The quasi-experimental method was chosen because the researcher could not randomize at the individual student level; therefore, randomization was applied to the entire class (intact group). A 2×3 factorial design was used to simultaneously test the effects of instructional treatments (interactive e-modules and conventional instruction), the effects of Self-Regulated Learning levels (low, moderate, and high), and the interaction between instructional treatments and SRL levels on improvements in students' mathematical communication skills.

Participants

The study was conducted at MAN 1 Lombok Tengah during the odd semester of the 2026/2027 academic year. The study population consisted of all 11th-grade students at MAN 1 Lombok Tengah. Sampling was performed using purposive sampling, taking into account the relatively equivalent academic characteristics of the classes based on the previous semester's average math scores as well as the class divisions already established by the school. Based on these considerations, 11th-grade classes FA 2 and FA 3 were selected as the research sample. Class FA 2 was designated as the experimental class, while class FA 3 served as the control class, with a total of 80 students—40 in each class. The experimental class received instruction using an interactive e-module on the topic of tangents to circles, while the control class received conventional instruction on the same topic.

Instruments

The research data consisted of mathematical communication ability scores and Self-Regulated Learning scores. Mathematical communication ability was measured using an essay test administered before and after the intervention, in the form of a pretest and a posttest. The test instrument was designed based on two indicators of mathematical communication ability: 1) representing a situation in the form of a diagram and expressing it in one's own words, and 2) constructing arguments or expressing opinions and providing explanations for answers.

Table 1. Indicators of Mathematical Communication Skills

Indicator	Sample Question
Representing a situation in the form of a diagram and explaining it in one's own words	You are given a problem involving a tangent to a circle. Sketch the situation and explain, in your own words, the given information and the relationships between the elements in the diagram.
Constructing an argument or expressing an opinion and providing an explanation for the answer	Determine the length of a tangent line from a point outside the circle and explain the steps taken to solve the problem as well as the reasoning behind your answer.

Data on Self-Regulated Learning (SRL) was obtained through a questionnaire validated by an expert, namely a Mathematics Education lecturer at UIN Mataram. The instrument was designed based on three aspects: forethought and planning, performance monitoring, and reflection on performance. The questionnaire consists of 36 statements on a 1–4 Likert scale. The scores obtained are used to identify students' SRL levels, which are then categorized as high, moderate, or low based on established criteria.

Table 2. Aspects and Sample Statements of Self-Regulated Learning

SRL Aspects	Example Statements
Forethought and Planning	I plan the learning methods I will use to achieve my learning goals.
Performance Monitoring	I try to stay in control when I encounter difficulties in learning math.
Reflection on Performance	I look for alternative approaches when the learning strategies I use are not successful.

Data Collection

Data collection began with obtaining a research permit from the university, which was then submitted to the Agency for National Unity and Politics (Bangkesbangpol) to obtain a research recommendation. After obtaining the research recommendation, the researcher applied

for a research permit from the school. Next, the researcher coordinated with the vice principal in charge of the curriculum and the math teacher to determine the class and the time for conducting the research. The study was conducted in the experimental and control classes according to the established lesson schedule. The study was conducted in the control and experimental classes according to the established lesson schedule. Each class was allocated 3 JP, allowing the study to be conducted in both classes within a single day.

In the control class, the activity began with students filling out a printed Self-Regulated Learning questionnaire, followed by a pretest on mathematical communication skills. Next, students learned about tangents to circles through explanations and instructions provided by the researcher, with the assistance of the mathematics teacher. Students were given the opportunity to ask questions if there was any material they did not understand. After the lesson ended, students took a posttest on mathematical communication skills.

In the experimental class, the activity began with students completing a Self-Regulated Learning questionnaire provided in print form. Next, the researcher provided instructions on how to access and use the interactive e-module. Students then participated in learning activities according to the stages and activities available in the e-module. The e-module contained material on tangents to circles as well as various learning activities, including a pretest, a posttest, dialogues with AI, exercises, and a form for sharing opinions. During the learning process, students completed each activity in the e-module with guidance from the researcher and the math teacher and were given the opportunity to ask questions if they had difficulty understanding the material or using the available features. After all learning activities were completed, students took the posttest included in the e-module and submitted the results of their conversations with the ChatGPT AI. The research data collection process is presented in [Figure 2](#).

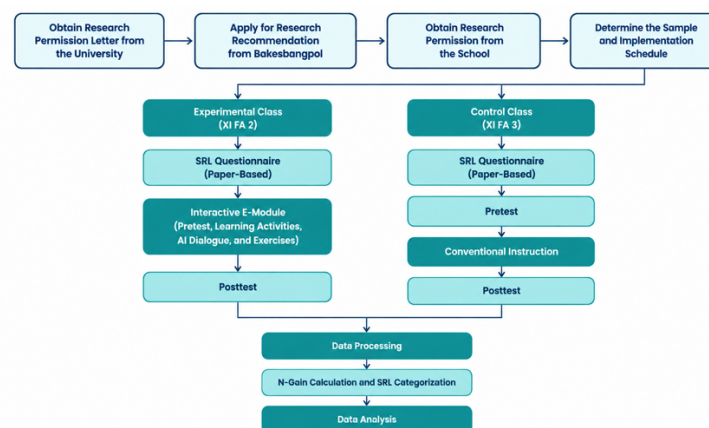


Figure 2. Research Data Collection Flowchart

The data obtained was then analyzed to determine improvements in students' mathematical communication skills and their SRL levels. The pretest and posttest scores for mathematical communication skills were used to calculate the N-Gain as a measure of improvement in mathematical communication skills. Meanwhile, the SRL questionnaire scores were used to classify students into low, moderate, and high categories based on predetermined criteria.

Analysis

Data analysis was conducted using nonparametric statistics because the results of the prerequisite tests indicated that the data did not meet the assumptions of normality and homogeneity. Differences in the improvement in mathematical communication skills between the experimental and control classes were analyzed using the Mann–Whitney U test. Differences in the improvement in mathematical communication skills based on SRL categories were analyzed using the Kruskal–Wallis test, followed by the Mann–Whitney test to compare pairs of categories with Bonferroni correction. Furthermore, the interaction between the use of interactive e-modules and SRL levels on the improvement in mathematical communication skills was analyzed using the Scheirer Ray Hare test in a 2×3 factorial design with a significance level of 0.05.

Results

The research results were obtained from data on students' mathematical communication skills collected through pretests and posttests, as well as Self-Regulated Learning (SRL) data obtained through a questionnaire. Pretest and posttest scores were used to determine the improvement in students' mathematical communication skills through N-Gain values. Based on the SRL grouping results, 11 students (13,75%) were in the low category, 46 students (57,50%) were in the moderate category, and 23 students (28,75%) were in the high category. These results are shown in [Table 3](#)

Table 3. SRL Categories

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	11	13.8	13.8	13.8
	moderate	46	57.5	57.5	71.3
	high	23	28.8	28.8	100.0
	Total	80	100.0	100.0	

Based on [Table 3](#), most students fall into the moderate SRL category, namely 46 students (57.5%), while 23 students (28.8%) fall into the high category and 11 students (13.8%) fall into the low category. This distribution indicates that most students have a moderate level of self-regulation in learning. To provide an overview of the context of the treatment given to the students, the implementation of learning in the experimental and control classes was carried out in stages tailored to the characteristics of each learning activity.

In the experimental class, instruction was conducted using an interactive e-module on the topic of tangents to circles. Before the lesson began, students completed a printed SRL questionnaire. Next, the researcher provided instructions on how to access and use the e-module. Students then followed the learning steps provided in the e-module with guidance from the researcher and the math teacher. The interactive e-module included a pretest, material presentation, exploration activities using GeoGebra, dialogues with artificial intelligence (AI), exercises, reflection, and a posttest. In the initial stage, students took a pretest to assess their baseline mathematical communication skills, then studied the material on tangents to a circle and conducted explorations using GeoGebra. Through these activities, students were able to observe the relationships between the elements of a circle and its tangents in a more interactive way.

After understanding the material and conducting the exploration, students use the AI dialogue feature to ask questions or seek explanations when they encounter difficulties in understanding the material or completing the activities. AI use was carried out under the supervision of researchers and teachers so that students received guidance throughout the learning process. Next, students completed the exercises available in the e-module and reflected on the learning process they had undergone. After all learning activities were completed, students took a posttest to assess their mathematical communication skills following the intervention. Documentation of the learning implementation in the experimental class is presented in Figure 3.

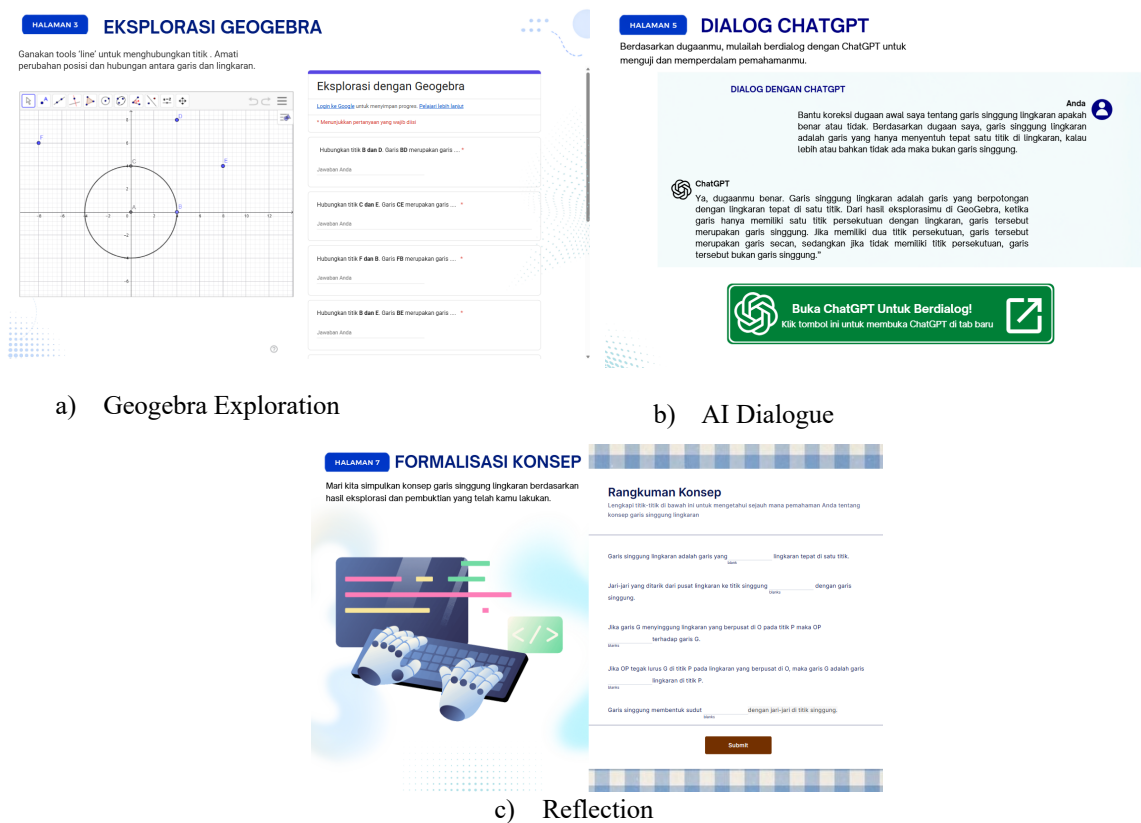


Figure 3. Implementation of the Interactive E-Module in the Experimental Class

The learning process in the control class followed similar steps regarding the completion of the SRL questionnaire and the administration of the pretest and posttest, but utilized conventional teaching methods. After filling out the printed SRL questionnaire, students took the pretest to assess their initial mathematical communication skills. Next, the lesson on tangent lines to a circle was delivered through explanations and guidance from the researcher, with support from the math teacher. During the lesson, students were given the opportunity to ask questions and receive clarification if they had difficulty understanding the material. After the lesson ended, students took the posttest. Thus, the difference in instructional delivery between the two classes primarily lay in the learning media and activities used. The experimental class used an interactive e-module that integrated content, GeoGebra exploration, dialogue with AI, exercises, and reflection, while the control class followed conventional instruction with direct

explanations and guidance. These differences in implementation then served as the basis for assessing improvements in students' mathematical communication skills through N-Gain scores.

The improvement in students' mathematical communication skills based on class and SRL category is demonstrated through N-Gain scores. The results of the descriptive analysis are presented in Table 4.

Table 4. Descriptive statistics of N-Gain by class and SRL category

Class	SRL Category	Numerical	Mean	Standard Deviation	N
Control	Low		.1294	.09141	6
	medium		.6017	.19905	22
	high		.8058	.13075	12
	Total		.5921	.27254	40
Experiment	Low		.2516	.16512	5
	medium		.5768	.18059	24
	high		.8621	.12674	11
	Total		.6164	.24739	40
Total	redah		.1849	.13840	11
	medium		.5887	.18793	46
	high		.8328	.12914	46
	Total		.6034	.25886	23

Based on the results of the descriptive analysis, the average N-Gain for mathematical communication skills in the experimental class was 0.6164, while in the control class it was 0.5921. When examined by SRL category, the average N-Gain for students with low SRL in the experimental class was 0.2516 and in the control class was 0.1294. In the moderate category, the average N-Gain for the experimental class was 0.5768 and for the control class was 0.6017, while in the high category, they were 0.8621 and 0.8058, respectively. Overall, the average N-Gain for students in the low SRL category was 0.1849, in the moderate category 0.5887, and in the high category 0.8328.

Next, a Mann-Whitney test was conducted to determine differences in the improvement of mathematical communication skills between the experimental and control classes. The analysis results showed a significance value of 0.885 (>0.05), indicating that there was no significant difference in the improvement of mathematical communication skills between the two classes.

Table 5. Rank

	Class	N	Mean Rank	Sum of Ranks
n_gain	Control	40	40.13	1,605.00
	Experiment	40	40.88	1,635.00
	Total	80		

The results of the Mann-Whitney U test showed a significance value of $0.885 > 0.05$. Thus, there was no significant difference in the improvement in mathematical communication skills between students in the experimental class and the control class. Furthermore, to determine differences in the improvement of mathematical communication skills based on SRL categories, a Kruskal-Wallis test was conducted.

The results of the Kruskal-Wallis test showed a Chi-Square value of 42.815 with a $p\text{-df} = 2$ and a significance level of < 0.001 . These results indicate that there is a significant difference in the improvement in mathematical communication skills based on SRL categories.

To identify the SRL categories with significant differences, a Mann-Whitney post-hoc test with Bonferroni correction was conducted. Since there were three comparisons between categories, the significance level used was $\frac{0,05}{3} = 0,0167$.

Table 6. Results of the Mann-Whitney U Post-hoc Test with Bonferroni Correction Based on Self-Regulated Learning Categories

Pair	Sig. (2-tailed)	α'	Description
Low-Moderate	< 0,001	0,0167	Significant
Low-High	< 0,001	0,0167	Significant
Moderate-High	< 0,001	0,0167	Significant

Based on Table 6, all pairs of SRL categories have significance values of $< 0,001$, which are smaller than the Bonferroni-corrected significance level of $0,0167$. Thus, there are significant differences in N-Gain between the low and moderate, low and high, and moderate and high SRL categories.

Next, a test was conducted to determine the interaction between the use of interactive e-modules and SRL categories on the improvement of mathematical communication skills. The analysis results are presented in Table 7.

Table 7. Test of Effects/Differences Between Subjects

Source	H	df	Mean Rank	Sig.	Partial Eta-Squared
Class	0.021	1	20.50	.885	.001
Category_SRL	42,815	2	28,17	.000	.349
Class*Category Srl	0.690	2	15.83	.708	.009

Based on Table 7 above, the results of the Scheirer-Ray-Hare test indicate that the class factor does not show a significant difference in the improvement of mathematical communication skills, with a value of $H = 0.021$ and a significance level of $0,885 > 0,05$. Meanwhile, the Self-Regulated Learning category shows a significant difference in the improvement of mathematical communication skills, with a value of $H = 42,815$ and a significance level of $< 0,001$. As for the interaction between class and the SRL category, the results showed a value of $H = 0,690$ with a significance level of $0,708 > 0,05$. Thus, there was no significant interaction between the use of interactive e-modules and the SRL category regarding the improvement in students' mathematical communication skills. The Partial Eta Squared value for the interaction, $0,009$, indicates a small effect size.

These results can further be viewed in the context of implementing instruction using interactive e-modules in the experimental class. The e-module used for the topic of tangent lines to a circle contained integrated content and a series of learning activities, including exploration using GeoGebra, answering questions, dialogues with AI, and learning reflections. Each activity was designed to provide students with opportunities to explore concepts and to articulate and explain mathematical ideas during the learning process. The implementation of the e-module was conducted with guidance from researchers and mathematics teachers, ensuring that students received support if they encountered difficulties in understanding the material or using the available features.

Discussion

Before the implementation of the interactive e-module, mathematics learning activities in the experimental and control classes showed relatively similar conditions. Most students tended to follow the learning flow presented by the teacher or researcher without asking many questions or expressing their opinions. Interaction during learning was still limited because only a small number of students actively asked questions when they encountered difficulties or did not understand the material, while the other students mostly listened to the explanations and followed the instructions given. These conditions indicate that student engagement in mathematics learning—particularly in expressing ideas, asking questions, and communicating mathematical thinking processes—had not yet reached its full potential. Changes in learning activities began to emerge when interactive e-modules were introduced in the experimental class. In the early stages, students showed interest after receiving an explanation on how to access, complete, and use the features available in the e-module. Students appeared more focused on following the learning steps and made an effort to complete each activity presented. The e-module used included GeoGebra exploration activities, answer entry, learning reflections, and dialogues with artificial intelligence.

In part a) of [Figure 3](#), students conducted GeoGebra explorations to observe the relationships between points, lines, and circles. Students were guided to connect the given points, observe the shapes of the resulting lines, and identify how those lines relate to the circles. Their observations were then used as the basis for answering questions on the provided form. This activity provides students with the opportunity to connect visual representations with geometric concepts and to communicate their observations in writing. The use of GeoGebra also offers a different learning experience because students can interact directly with geometric objects and visually observe the relationships between components. This aligns with the ([Putrawangsa & Hasanah, 2018](#)), which explains that digital technology in mathematics education should be used to support mathematical activities, practice skills, and develop students' conceptual understanding. Thus, GeoGebra in this study serves not only as a visual aid but also as a learning environment that enables students to explore geometric concepts.

The use of GeoGebra in the e-module also provides a different learning experience compared to instruction that relies solely on verbal explanations or static images. Students can observe geometric objects more concretely and have the opportunity to explore the relationships between objects. This aligns with the view that digital technology in mathematics education is not merely used as a substitute for conventional media but can function as a tool for engaging in mathematical activities, practicing skills, and developing conceptual understanding. In the context of this study, GeoGebra serves as an exploratory environment that helps students visually observe the relationships between geometric objects. However, these benefits will be more optimal if the exploration is accompanied by guiding questions and tasks that specifically direct students to explain mathematical reasoning.

In part b) of [Figure 3](#), students were given the opportunity to engage in a dialogue with artificial intelligence. Through this dialogue, students could ask questions, request additional explanations, search for relevant information, and develop follow-up questions based on the results of their exploration. Some students asked how to understand concepts, searched for appropriate materials, and clarified the answers they had obtained. These activities demonstrate that students began to take the initiative to seek information and deepen their understanding, rather than simply waiting for explanations from the teacher or researcher. However, the use of artificial intelligence was still carried out under the guidance and supervision of the researcher to ensure that the information obtained aligned with the learning objectives.

Interactions with artificial intelligence are also linked to mathematical communication skills, as students need to formulate questions, explain difficulties, select relevant information, and evaluate the appropriateness of the answers they receive. This aligns with research on (Samura et al., 2025), which indicates that problem-based learning can support mathematical communication skills through activities such as understanding problems, devising strategies, solving problems, and explaining the solution process. Although dialogues with artificial intelligence do not directly replace problem-based learning, these activities share similarities in that they provide students with opportunities to identify information needs, ask questions, and develop explanations. Therefore, artificial intelligence can be used as an exploratory tool as long as students are guided to examine, compare, and re-explain the information they have obtained.

After conducting the exploration and dialogue, students are guided to complete the learning reflection in section c) of Figure 1. Through this activity, students write down the understanding they have gained, the difficulties they encountered, their observations, and the things they still want to know. The reflection activity provides students with an opportunity to review the learning process and evaluate their understanding. This activity relates to Self-Regulated Learning, particularly the aspects of monitoring and evaluating the learning process. Reflection helps students recognize which parts of the material they have understood, identify mistakes, and determine what still needs to be learned. Thus, the e-module not only provides material and exercises but also includes learning stages that encourage students to observe, seek explanations, communicate their understanding, and reflect on the learning process.

A series of exploration, dialogue, and reflection activities demonstrates that the use of e-modules provides a more interactive learning experience in the experimental class. Students not only complete the provided instructions but also experiment with the e-module's features, ask questions, search for relevant information, and document their understanding. This design aligns with the (Putrawangsa & Hasanah, 2018), which states that the integration of digital technology in mathematics education should be directed toward supporting students' mathematical activities and conceptual understanding. Technology should not merely be used to enhance the visual appeal of instructional materials or replace the teacher's explanations; rather, it should be positioned as a tool that helps students explore, develop skills, and build understanding. A similar perspective is evident in the study (Putrawangsa & Hasanah, 2020) regarding sensorimotor-based digital media, which emphasizes the importance of activity design and how students interact with digital devices in mathematics learning.

This situation contrasts with learning in the control class. Most students in the control class tended to listen to explanations and follow the instructions given, while only a small number of students actively asked questions. In contrast, in the experimental class, nearly all students attempted the activities available in the e-module and asked questions more frequently when they encountered difficulties or wanted to confirm the steps they should take. These differences indicate that the use of interactive e-modules has a positive impact on student engagement, particularly in terms of attention, interest, willingness to ask questions, and active participation in activities. These findings align with the (Ratnasari et al., 2018), which explains that the use of digital technology in mathematics learning must be accompanied by changes in teaching practices—shifting from teacher-centered instruction to a learning approach that provides students with opportunities to interact with digital media, explore the material, and actively engage in the learning process. In this study, the e-module provided students with the opportunity to explore GeoGebra, interact with artificial intelligence, and write learning

reflections. This series of activities demonstrates that digital technology can be used to enhance student engagement, provided its implementation is accompanied by guidance and support aligned with learning objectives.

The use of e-modules in this study also aligns with the (Putrawangsa & Hasanah, 2018), which holds that digital technology in mathematics education should not merely serve as a tool for presenting content but should be utilized to support mathematical activities, practice skills, and develop students' conceptual understanding. GeoGebra exploration activities allow students to observe the relationships between points, lines, and circles, while interactions with artificial intelligence provide students with the opportunity to ask questions and seek additional explanations. Subsequent reflection activities help students review their understanding and the difficulties they encountered. Thus, student engagement in the experimental class is evident not only in their attention and enthusiasm but also in their efforts to explore, seek information, and evaluate their learning process.

Nevertheless, increased student engagement during the use of the e-module has not directly indicated a higher level of mathematical communication skills. Engagement in the learning process and mathematical communication skills, as measured by tests, are two interrelated but not identical aspects. Students who actively participate in activities are not necessarily able to immediately present mathematical ideas, explain strategies, construct arguments, and provide reasons systematically. Therefore, changes in student engagement must be complemented by an analysis of mathematical communication skills to quantitatively assess the effectiveness of the e-modules.

Based on observations during instruction, the use of interactive e-modules resulted in positive changes in student engagement. Students in the experimental class appeared more interested, focused, and active in participating in exploration, dialogue, and reflection activities compared to the learning conditions before the e-module was implemented or learning in the control class. However, this increase in engagement cannot yet be interpreted as direct evidence of a higher level of mathematical communication skills. Student engagement during the learning process and skills measured through tests are two interrelated but not identical aspects. Mathematical communication skills require deeper and more sustained mastery, such as the ability to present ideas through appropriate representations, explain strategies, construct arguments, and provide mathematical justifications. Therefore, although the e-module was able to create a more interactive learning environment, its impact on improving mathematical communication skills still needs to be assessed based on the results of quantitative analysis.

Based on the analysis of mathematical communication skills, the use of interactive e-modules has not yet resulted in a significant difference in the improvement of students' mathematical communication skills between the experimental and control classes. The average N-Gain for students' mathematical communication skills in the experimental class was 0,6146, while in the control class it was 0,5921. . Although the experimental class's average was higher, the results of the Mann-Whitney U test showed a significance value of $0,885 > 0,05$, , indicating that the difference in the improvement of mathematical communication skills between the two classes was not significant. Thus, the hypothesis stating that the use of interactive e-modules results in a greater improvement in mathematical communication skills than learning in the control class cannot be accepted. These findings indicate that the interactive e-modules used in this study did not have a statistically significant effect on the improvement of students' mathematical communication skills.

These results are interpreted with the understanding that mathematical communication skills are complex. Students are not only expected to arrive at a final answer but also to be able

to understand, interpret, and convey mathematical ideas through language, symbols, tables, pictures, diagrams, and other representations. According to the NCTM (2000; [Lubis et al., 2023](#)), these skills also include the ability to explain strategies, construct arguments, connect information to mathematical concepts, and communicate the problem-solving process logically and systematically. Therefore, improving mathematical communication skills requires a learning process that provides students with opportunities to express ideas, discuss, provide reasons, respond to opinions, and revise their thinking. The use of independent learning media is not necessarily sufficient to improve these skills if it is not accompanied by planned mathematical communication activities.

In this study, students in both the experimental and control classes received instructions, guidance, and opportunities to ask questions during the learning process. Students in both classes also received explanations when they encountered difficulties in understanding the material or solving problems. These similarities in treatment meant that both classes received relatively comparable learning support. Although the experimental class used interactive e-modules, students in the control class still experienced learning interactions that allowed them to clarify concepts, ask questions, and receive help in completing tasks. This situation may be one reason why the difference in learning media did not result in a significant difference in the improvement of mathematical communication skills.

The findings of this study differ from those of a study titled [\(Zahria, 2024\)](#), which revealed that the use of STEM-based interactive e-modules can improve students' mathematical communication skills. This discrepancy does not necessarily indicate that one study's results contradict the other's, but may reflect differences in context, research design, student characteristics, instructional content, duration of implementation, and the types of activities included in the e-modules. Interactive e-modules equipped with exploration activities, problem-solving, visual representations, feedback, and reflection likely provide a different learning experience compared to e-modules that primarily function as presenters of content and exercises. Thus, the effectiveness of e-modules is determined not only by their digital format or level of interactivity but also by their pedagogical quality and alignment with learning objectives.

This explanation aligns with the study [\(Riski & Andriani, 2020\)](#), which developed an interactive e-module on circle equations based on Realistic Mathematics Education (RME) using GeoGebra. The use of the RME approach and GeoGebra allows students to interact more actively with the context, visual representations, and the process of exploring concepts. Meanwhile, [\(Haeriyah & Pujiastuti, 2022\)](#) developed an interactive e-module using AnyFlip on circle-related material for junior high school students. Both studies demonstrate that interactive e-modules can be designed with different approaches, features, and learning experiences. Other studies also indicate that e-modules with specific contexts can support both independent learning and students' mathematical communication skills [\(Weylin et al., 2023\)](#). Therefore, the term "interactive e-module" cannot be understood as a single, uniform form of media. Differences in content, activity structure, interactive features, problem contexts, and teacher guidance can influence the outcomes of their use.

The lack of significant differences in improvement across classes may also be attributed to the characteristics of the mathematical communication skills being measured. These skills develop through repeated and meaningful practice, not merely through exposure to the material. Students need to be accustomed to translating problems into mathematical models, presenting information in appropriate representations, explaining relationships between concepts, and

providing justifications for each step of the solution. If the activities in the e-module do not specifically guide students through these processes, the use of the e-module may not offer an advantage over learning in the control class. Findings from research on the development of guided inquiry-based e-modules indicate that improvements in mathematical communication skills are more likely to occur when e-modules include inquiry activities, guiding questions, mathematical representations, and structured reflection (Mayang et al., 2026). Thus, digital media must be integrated with instructional strategies that foster students' cognitive engagement and communication.

In contrast to the results based on class, the research findings based on the Self-Regulated Learning (SRL) categories indicate differences in the improvement of mathematical communication skills across SRL categories. The overall average N-Gain for the low SRL category was 0,1849, for the moderate category 0,5887, and for the high category 0,8328. The Kruskal-Wallis test yielded a Chi-Square value of 42,815 with a significance level of $< 0,001$. This indicates that the improvement in mathematical communication skills differs significantly across SRL categories. The results of the follow-up test with Bonferroni correction also showed that all category pairs—low–moderate, low–high, and moderate–high—exhibited significant differences. Thus, unlike the use of e-modules, which did not show significant differences between classes, SRL levels demonstrated a clearer pattern of differences regarding improvements in students' mathematical communication skills.

This pattern of improvement is evident in the average N-Gain, which increases as the SRL category rises. Students with high SRL achieved an average gain of 0,8328, —significantly higher than students with moderate SRL (0,5887) and those with low SRL (0,1849). This difference indicates that students' ability to manage their learning process is related to how they approach and solve math problems. Students who are able to set goals, choose strategies, monitor the learning process, and evaluate their work have more opportunities to recognize errors and improve their problem-solving process. This is relevant to mathematical communication skills because the students in this study were not only asked to obtain the final result but also to explain the steps taken and the mathematical reasoning used.

These findings align with the study (Mulyani, 2017), which demonstrates a correlation between SRL and students' mathematical communication skills. Similar results can also be explained by the perspective that SRL is an active process in which students set goals, select strategies, monitor progress, and reflect on learning outcomes (Zimmerman, 2008). In the context of this study, the SRL questionnaire covers the aspects of forethought and planning, performance monitoring, and reflection on performance. The aspect of forethought and planning relates to students' ability to set goals and plan their learning actions. The aspect of performance monitoring relates to the ability to monitor understanding and progress while working on tasks. Meanwhile, the aspect of reflection on performance relates to the ability to evaluate results and refine the strategies used. These three aspects have a conceptual relationship with the demands of mathematical communication, which require students to explain their processes and evaluate the accuracy of their solutions.

The findings study (Febriyanti & Imami, 2021) also support this interpretation. SRL in mathematics learning is not only related to independent learning habits but also encompasses students' ability to identify learning needs, formulate goals, select learning resources, determine strategies, and evaluate learning outcomes. Students with strong self-regulation skills tend to be more active in seeking information, testing strategies, and correcting mistakes. This process can help students understand the material more deeply and communicate mathematical ideas in a more structured manner. Conversely, students with low SRL may rely more on teacher

guidance, be less consistent in monitoring their problem-solving process, and be less accustomed to reflecting on their mistakes. These conditions may result in a slower improvement in their mathematical communication skills.

Although the SRL categories showed significant differences, the results of the Scheirer-Ray-Hare test indicated that the interaction between class type and SRL category was not significant. The significance value for the interaction was 0.708, which is greater than 0.05, with a Partial Eta-Squared value of 0.009. This means that the effect of the SRL category on improvements in mathematical communication skills does not significantly depend on the type of class. Students with high SRL tended to show greater improvement, whether they were learning using interactive e-modules or participating in the control class. Conversely, students with low SRL tended to show less improvement in both classes. Thus, the pattern of differences based on SRL was relatively consistent across the experimental and control classes.

The average N-Gain patterns for each group also showed no interaction. Students in the experimental class had average N-Gain values of 0,2516, 0,5768, and 0,8621. Students in the control class had low, moderate, and high average N-Gain values of 0,1294, 0,6017 and 0,8058, respectively. Although there were differences in average values among these groups, the differences did not form a statistically significant enough pattern to indicate that the interactive e-module had a different effect on each SRL category. These findings suggest that SRL and the use of e-modules may operate through different mechanisms. SRL relates to students' internal characteristics and strategies for managing the learning process, whereas e-modules function as a medium that provides content, activities, and learning resources.

Theoretically, e-modules have the potential to support SRL because they allow students to access materials flexibly, set their own learning pace, review explanations, and complete activities more independently. However, this potential does not automatically lead to improved mathematical communication skills if students do not yet possess adequate self-directed learning strategies or if the activities within the e-modules are not designed to foster self-regulation. Research on e-modules also indicates that digital media are more effective when supplemented with activities that promote independence, monitoring, feedback, and reflection. Therefore, e-modules should not only include content descriptions and practice questions but also provide learning objectives, strategy guidelines, reflective questions, self-assessments, feedback, and opportunities for students to explain their thought processes.

Overall, the results of this study indicate that improvements in mathematical communication skills were more strongly influenced by differences in SRL categories than by differences in the types of instruction students received. The use of interactive e-modules resulted in a slightly higher average N-Gain compared to the control class, but this difference was not significant. Conversely, students with high SRL achieved greater improvements than those with moderate and low SRL, while the interaction between the use of e-modules and SRL categories was not significant. These findings indicate that learning media should be positioned as part of a broader learning system. The success of their use is greatly influenced by the quality of activities, learning strategies, the intensity of guidance, the characteristics of the material, and students' readiness to manage their own learning process. Therefore, the development of e-modules to improve mathematical communication skills needs to integrate exploration activities, problem-solving, mathematical representations, discussions, written explanations, feedback, and reflection. In addition, teachers need to provide guidance that gradually helps students develop the ability to plan, monitor, and evaluate their learning process.

Conclusion

Based on the research results, the use of interactive e-modules has not shown a significant difference in the improvement of mathematical communication skills between the experimental and control classes. Although the average N-Gain in the experimental class was higher than that in the control class, the average N-Gain for mathematical communication skills in the experimental class was 0.6164, while in the control class it was 0.5921. The results of the Mann–Whitney U test showed a p-value of $0.885 > 0.05$, indicating that the difference in improvement between the two classes was not statistically significant. Thus, the interactive e-modules used in this study did not demonstrate a significant difference in the improvement of mathematical communication skills compared to learning in the control class. When examined by the Self-Regulated Learning (SRL) category, there was a significant difference in the improvement in mathematical communication skills among students with low, moderate, and high SRL levels. The results of the Kruskal–Wallis test showed a Chi-Square value of 42.815 with $p < 0.001$. The average N-Gain for students with low SRL was 0.1849, for those with moderate SRL was 0.5887, and for those with high SRL was 0.8328. These results indicate that students with high SRL achieved a higher average improvement in mathematical communication skills compared to students with moderate and low SRL. The results of the interaction analysis showed that there was no significant interaction between class type and SRL category regarding the improvement in mathematical communication skills. The significance value for the interaction was 0.708 with a partial eta-squared of 0.009. Thus, differences in improvement based on SRL categories did not depend significantly on the use of interactive e-modules or learning in the control class. The pattern of higher improvement in mathematical communication skills among students with high SRL and lower improvement among students with low SRL remained evident in both classes.

Overall, the improvement in mathematical communication skills in this study showed greater variation based on SRL categories than on the type of learning medium used. These findings indicate that the use of interactive e-modules needs to be combined with learning activities that explicitly facilitate students in expressing mathematical ideas, explaining problem-solving strategies, constructing arguments, examining thought processes, and engaging in reflection. Furthermore, students' SRL characteristics should be a key consideration in designing mathematics instruction focused on developing mathematical communication skills. This study has limitations due to its relatively short duration—consisting of a single session in each class with a time allocation of 3 JP. These conditions meant that students' opportunities to adapt to the e-modules and make optimal use of all available features remained limited. Furthermore, the study was conducted only with 11th-grade students at a single school and focused on the topic of tangents to circles; therefore, the results should be interpreted in light of the subjects' characteristics and the research context. Future research is recommended to implement interactive e-modules over a longer period and with more diverse subject matter and student characteristics.

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Declarations

- Conflict of Interest** : The authors declare that there are no conflicts of interest.
- Auhor Contributions** : Author S.S. contributed to the development of research instruments, research design, theoretical framework, data collection, data analysis, presentation of results and discussion, manuscript revision, and coordination of all sections of the article. Author H.R.P.N. contributed to the theoretical development and approval of the final version of the manuscript. Author S.P. contributed to the theoretical development and approval of the final version of the manuscript. The percentage of each author's contribution to the conceptualization, drafting, and revision of this article is as follows: S.S.: 60%, H.R.P.N.: 20%, and S.P.: 20%.
- Data Availability Statement** : The authors declare that the data supporting the findings of this study will be made available by the corresponding author, [S.S.], upon reasonable request.

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