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Improving Students' Critical Thinking Skills on Hydrocarbon Material through Assessment for Learning

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ABSTRACT

Purpose–This study describes the effectiveness of implementing the Assessment for Learning (AfL) approach to improve students' critical thinking skills on hydrocarbon materials.

Methodology–This study is a pre-experimental research with a one-group pre-test-post-test design. The effectiveness of implementing AfL was analyzed based on the pre-test and post-test results of students' critical thinking skills on hydrocarbon materials. Data were analyzed using the completeness criteria of learning objectives, N-gain scores, and mean difference tests.

Findings–The Paired t-test results resulted in a p-value of 0.000 (< 0.05), indicating a significant difference between the pre-test and post-test scores. As many as 100% of students got an N-gain score in the high category. The study results showed that ≥ 85% of students were in the complete category. Thus, implementing AfL has proven effective in improving students' critical thinking skills on hydrocarbon materials.

Significance–This study contributes to the development of chemistry education by demonstrating the effectiveness of implementing AfL in enhancing students' critical thinking skills, particularly in learning about hydrocarbon material.

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INTRODUCTION

Chemistry is a science obtained and developed based on experiments that seek answers to the questions of what, why, and how natural phenomena, especially related to the composition, structure, and properties, transformation, dynamics, and energetics of substances (Dwiningsih & Mangengke, 2021). Hydrocarbon materials are one of the chemical materials taught in high school. In organic chemistry, hydrocarbon materials are fundamental materials that function as a basic concept for further understanding organic chemistry (Purwanto, 2021). Based on the current curriculum's Learning Outcomes and Content Standards, hydrocarbon material must be taught to students thoroughly (Ministry of Education and Culture, 2022).

However, in practice, chemistry learning in schools still faces various challenges. One of the problems often found is students' low critical thinking skills, especially in understanding abstract concepts such as hydrocarbons (Gabriella & Mitarlis, 2021; Sa'adah *et al*., 2020). Understanding how the arrangement of atoms affects the chemical and physical properties of hydrocarbon compounds requires interpretation and inference skills. In studying the structure of hydrocarbons, identifying substituents, and determining the reactivity of molecules, analytical skills are required. Evaluation and explanation skills are needed to assess the correctness of the names of hydrocarbon compounds such as alkanes, alkenes, and alkynes. Interpretation skills are also needed when studying compounds that are isomers of each other. According to Facione (2020), the ability to interpret, infer, analyze, evaluate, and explain is one of the components of critical thinking skills.

Pre-research conducted at one of the high schools in Surabaya City shows quantitative data related to students' critical thinking skills. In the interpretation component, only 46% of students were declared complete; in the inference component, only 10.7% were complete; analysis skills reached 50% of complete students. The results of this pre-study indicate that students' critical thinking skills are still low, so they need to be improved. Observations in the pre-study showed that at the school, learning tends to be teacher-centered, one-way, and focuses on achieving cognitive scores, not on the thinking process and deep understanding. As a result, students are more trained to memorize rather than analyze, evaluate, or conclude scientific information logically and systematically.

Some previous studies have indeed applied innovative approaches to improve students' critical thinking skills in chemistry (Andriani & Gazali, 2025; Kelana et al., 2025). However, the approach tends to be summative, and does not actively involve students in the evaluation and reflection process. To answer these challenges, one potential approach is Assessment for Learning (AfL) (Sudarsono & Muchlis, 2023).

AfL is an assessment aiming to improve teaching and learning (Schellekens et al., 2021). If used consistently, AfL practices show promising results in improving student achievement and learning outcomes worldwide (Volante et al., 2025). The same thing was expressed by Heritage & Wylie (2018), who stated that there is much evidence that AfL can improve student learning when implemented effectively. AfL focuses on monitoring the quality of the learning process and providing continuous feedback to guide learning and teaching, which can positively influence the learning process (Westbroek et al., 2020). Feedback includes not only the substance of hydrocarbon material, but also regarding their learning. Proper feedback can help students understand the strengths and weaknesses related to hydrocarbon materials and how students learn. Based on the results of a pre-research conducted at a high school in the city of Surabaya, it was found that around 81.1% of students had not written down the targets they wanted to achieve before studying chemistry. As many as 62% of students admitted that they often get lecture learning methods from teachers. As many as 67.6% of students have not received teacher feedback after completing formative exams. These findings show that students in the classroom have not obtained learning that approaches AfL.

Various previous studies have shown that the Assessment for Learning (AfL) approach positively impacts learning outcomes and student thinking skills. Research by Ramadhani & Muchlis (2023) confirmed that the application of AfL encourages active participation of learners in the process of reflection and monitoring understanding, to improve critical thinking skills. Furthermore, research by Syah & Muchlis (2025) showed that reflection activities and providing feedback in the AfL approach contributed to improving student learning outcomes in learning chemistry material on the periodic system of elements. Hasanah & Muchlis' (2024) research also proved that AfL significantly affects understanding chemical concepts, because this approach activates students in the learning process through strengthening understanding and self-evaluation. Meanwhile, Utami & Agustini (2024) developed AfL-based learner worksheets on chemical equilibrium material and found that this approach effectively improved students' science process skills. Safithri & Muchlis (2022) also reinforced these findings by applying AfL learning on reaction rate material, which showed that students became more involved and obtained better learning outcomes through formative feedback and reflection. However, there are still research gaps that have not been widely explored. First, most previous studies still focus on improving cognitive learning outcomes, not specifically targeting developing critical thinking skills based on critical thinking indicators such as interpretation, analysis, and inference. Second, the topic of these studies has not touched much on hydrocarbon material, which is one of the most complex and abstract materials in high school chemistry. Third, most of the previous AfL approaches focused more on the effectiveness of learning outcomes, while aspects of students' critical thinking processes during learning have not been explored in depth.

Therefore, this research comes as an effort to fill the gap by developing and implementing an integrated AfL approach to hydrocarbon learning and evaluating its effectiveness in improving students' critical thinking skills based on measurable critical thinking skills components. This study specifically aims to measure the effectiveness of applying the AfL approach in improving students' critical thinking skills in hydrocarbon materials. This research is expected to contribute to the science of chemical education by enriching the study of applying the AfL approach specifically in developing critical thinking skills in hydrocarbon materials.

METHODOLOGY

Research Design

This study is a pre-experimental research using a one-group pretest-posttest design. In this design, AfL was implemented in one experimental group without using a control group. The experimental group was given a pre-test, then treatment in the form of implementing AfL in learning, and ended with a post-test. One of the advantages of this design is that it allows researchers to compare pre-test and post-test scores on the exact measurement and the same subject (Nardi, 2018). This design was chosen due to limited resources and time. Dividing into two equal classes was difficult in the school where the study was conducted. Because the available classes have differences in initial abilities, if used as control and experimental groups, the validity of the research results can be affected by differences in initial characteristics between groups. This design illustrates the relationship between variable X (treatment) and variable O (measurement), which is presented in the following schema:

$$\boxed{O_1 \ldots\ldots X \ldots\ldots O_2}$$

Description:

O1 = test before the AfL implementation trial (pre-test)

X = treatment of hydrocarbon learning with AfL implementation

O2 = test after the AfL implementation trial (post-test)

Participants

The participants in this study were 28 students of class XI at a high school in the city of Surabaya. Students have an average age of 16-17 years and have studied chemical bonding materials, so they are ready to learn hydrocarbon materials. The selection of grade XI students as participants was based on the consideration that students had obtained chemical bonding material in the previous semester at this level. Chemical bonding material is an important prerequisite for understanding the structure and properties of hydrocarbon compounds, so students are considered to have sufficient initial knowledge to learn about hydrocarbon material.

The sampling technique in this study used purposive sampling, which is based on specific criteria or considerations set by the researcher (Sugiyono, 2016). The criteria used are (1) active students in grade XI, (2) have obtained chemical bonding material, and (3) are in a learning environment that allows the application of the AfL approach. This technique was chosen because it is based on the characteristics of pre-experiment research designs that do not require comparisons between groups, but focus on one experimental group that has met specific criteria.

The population in this study was all grade XI students in the school where the research was conducted, who had learned the prerequisite material and were in the same curriculum. This population has similar characteristics in terms of age, curriculum background, and previous chemistry learning experience so that it can support the representativeness of the research results to a similar school context.

Instrument and Data Collection

The data collection method used is the test method, which is data collection through a critical thinking skill test on hydrocarbon materials. The research instrument was a critical thinking skills test sheet on hydrocarbon materials. This test was developed independently by the researcher, adjusted to the characteristics of the material and learning objectives, and refers to the components of critical thinking skills (Facione, 2020), including interpretation, analysis, evaluation, inference, and explanation.

Before use, the test instrument was subjected to validation and reliability tests. The validation process was carried out to assess content validity using the validation sheet format. The validation results were analyzed using Aiken's V formula. They obtained a validity coefficient of 0.85, which is included in the high validity category, so it is feasible for research. An instrument reliability test was also conducted by testing questions for students with characteristics similar to those of the research sample. The data from the trial were analyzed using Cronbach's Alpha formula, and a reliability coefficient of 0.706 was obtained, which indicates that the instrument is reliable and consistent in measuring critical thinking skills.

The test was in the form of a description test with a total of 15 items, each designed for one critical thinking skill component. The details of the learning objectives and critical thinking skills components measured in this test are as follows:

Table 1. Critical Thinking Skills Components and Learning Objectives

Components	Learning Objectives	Sample Questions
Interpretasi	Given several alkane compounds, students can categorize compounds that are isomers appropriately.	Which compounds are isomers of each other from the few compounds below? 1) n-butana 2) 2-methylpropane 3) n-pentana 4) 2-methylbutane 2,2-Dimethylpropane
Analysis	Students can analyze the composition of alkane compounds based on the data provided appropriately.	One of the benefits of alkanes is that they can be used to fuel gas stoves (LPG gas). Straight-chain alkane compounds with four carbon atoms are one of the main components of LPG gas. Analyze what percentage of the mass of carbon and hydrogen is contained in the compound!
Evaluation	Students can evaluate the correctness of the nomenclature of alkane compounds based on IUPAC rules.	Determine if the names of the following compounds are by IUPAC rules. If not, come up with a suitable name! a. 2-methylbutane b. 1-methylbutane c. 3,4-dimethylpentane
Inference	Based on the data from the experiment, students can conclude the experiment on hydrocarbon reactions correctly.	In a welding plant, acetylene gas (C_{2H2}) is used to cut metals. At the time of metal cutting, the flame is yellow with much black smoke, and the cut metal becomes dirtier with soot sticking to its surface. Based on this phenomenon, conclude oxygen

Components	Learning Objectives	Sample Questions
		availability during metal cutting!
Explanation	Presented with facts, phenomena, or arguments related to alkyne isomers, learners can explain their opinions appropriately.	Alkynes are unsaturated hydrocarbons that have triple bonds. One example of an alkyne compound is 2-pentyne. Budi argues that 2-pentine has both a position isomer and a geometric isomer. Do you agree with Budi's opinion? Explain your answer!

With the structure and content as above, this test is designed to provide a comprehensive overview of students' critical thinking skills in understanding and applying hydrocarbon concepts.

Data Analysis

The effectiveness of AfL implementation was measured using mean difference tests, N-gain scores, and the completeness criteria of learning objectives. Before the average difference test is carried out, the test result data (pre-test and post-test) must be tested for normality to determine whether the data is distributed normally or not. A parametric test (Paired t-test) is used if the data is distributed normally. A nonparametric test (Wilcoxon signed test) is carried out if the data is not distributed normally. The average difference test is assisted by using Minitab 18 software with the provision that if the p-value < 0.05, there is a significant difference between pre-test and post-test.

An N-gain score is calculated to determine the improvement of critical thinking skills. The implementation of AfL is said to be effective if it gets a minimum N-gain score in the medium category.

Table 1. N-gain Score Interpretation

N-gain Score	Category
$g \geq 0,7$	High
$0.7 > g \geq 0.3$	Medium
$g < 0,3$	Low

The critical thinking skills test results are said to be complete if they get a score of ≥ 75. The implementation of AfL is said to be effective if as many as ≥ 85% of students in one class are declared complete (classical completeness criteria).

FINDINGS

The pre-test used a critical thinking skill test instrument on hydrocarbon materials. After that, the implementation of AfL in learning hydrocarbon material was carried out in 3 meetings. After that, students are given a post-test. Pre-test and post-test results were used to measure the effectiveness of AfL implementation. Berikut disajikan statistik deskriptif dari hasil pre-test dan post-test.

Table 1. Descriptive Statistics of Pre-Test and Post-Test Results

	N	Minimum	Maximum	Mean	Hours of deviation
Pre-test	28	1.33	40	15	10.0738
Post-test	28	76	94.67	85.0476	4.91384

Based on the Descriptive Statistics Table, it is known that the number of students analyzed was 28. The pre-test results showed a minimum value of 1.33, a maximum value of 40.00, an average of 15.00, and a standard deviation of 10.07. Meanwhile, the post-test results showed a minimum score of 76.00, a maximum score of 94.67, an average of 85.05, and a standard deviation of 4.91.

The comparison of the average score between the pre-test and post-test showed a difference of 70.05, indicating an increase in students' critical thinking skills after applying the AfL approach. In addition, the decrease in the standard deviation value from 10.07 in the pre-test to 4.91 in the post-test showed that the variation in ability between students became more homogeneous after the treatment, which can be interpreted as indicating that the AfL approach has a relatively equal impact on all students.

Furthermore, the pre-test and post-test results were analyzed using the average difference test. Before the average difference test is carried out, a normality test must be carried out first. Table 3 shows the normality test results analyzed using the Minitab 18 software.

Table 2. Normality Test Results

	Mean	StDev	N	RJ	p-value
Pre-test	15	10.7	28	.968	.093
Post-test	85.05	4.914	28	.995	.100

The hypothesis in the normality test is: (1) H0 = normally distributed data; (2) H1 = non-normally distributed data. Decision-making is based on p-values. If the p-value > 0.05, H0 is accepted and H1 is rejected, meaning the data is normally distributed (Muhson, 2016). Based on the normality test results, both pre-test and post-test scores received a p-value of more than 0.05. This means that the pre-test and post-test data are distributed normally. These results make them eligible for the parametric test (Paired t-test). The results of the Paired t-test can be seen in Table 5.

Table 3. Paired t-test Results

t-value	p-value
-37.21	0.000

The results of data analysis using the Paired t-test showed that the t-value was -37.21 with a significance value (p-value) of 0.000. A p-value smaller than 0.05 indicates a significant difference between the pre-test and post-test results. Thus, the null (H_0) hypothesis stating that there is no average difference between the pre-test and post-test scores is rejected, and the alternative hypothesis (H_1) is accepted, which means that there is a significant difference between the two scores. These results indicate that the implementation of AfL in learning can have a significant influence on improving students' critical thinking skills. In other words, implementing AfL effectively improves critical thinking skills, as can be seen from the difference in scores before and after treatment.

Table 4. N-gain Score Calculation Results

Component Critical Thinking Skills	Pre-test score	Post-test score	N-gain score	Category
Interpretation	20.47	88.81	0.86	High
Analysis	11.43	97.85	0.98	High
Evaluation	18.81	73.09	0.67	Medium
Inference	12.14	92.85	0.92	High
Explanation	12.14	72.62	0.69	Medium

The pre-test and post-test results were also analyzed using the N-gain score, which aimed to measure the improvement in students' critical thinking skills after treatment. Based on the results of the analysis of pre-test and post-test critical thinking skills data presented in Table 5, it can be seen that all components of critical thinking skills have increased after the use of AfL-oriented LKPD. The interpretation component increased from an average score of 20.47 to 88.81 with an N-gain value of 0.86 and was in the high category. The analysis component showed the highest increase with an N-gain of 0.98, also in the high category. The inference component increased with an N-gain of 0.92 (high category).

Meanwhile, the evaluation and explanation components have an N-gain of 0.67 and 0.69, respectively, which are classified as medium. However, the N-gain values of both components are still above the minimum limit of effectiveness (i.e. ≥ 0.3). This shows that none of the components are in the low category, so all aspects of critical thinking skills have a significant increase. These results align with research by Ramadhani & Muchlis (2023), which states that students' critical thinking skills are improved through AfL-oriented learner worksheets reviewed from N-gain scores. The following is a recapitulation of the completeness of students' learning objectives.

Table 2. Completeness and N-gain Score Recapitulation

Number of Students	Completeness Pre-test	Completeness Post-test	N-gain Score
28	Not Complete Complete: 0 (0%) Not Complete: 28 (100%)	Complete Complete: 28 (100%) Not Complete: 0 (0%)	High: 28 (100%) Medium: 0 (0%) Low: 0 (100)

Based on the recapitulation in Table 3, as many as 28 students were included in the incomplete category at the time of the pre-test. Then at the time of the post-test, as many as 28 students got the complete category. These results show that as many as ≥ 85% of students in one class are declared complete. Then as many as 28 students got an N-gain score in the high category.

The application or implementation of AfL is contained in activities during learning. In the first step of AfL, which is to clarify the learning objectives and success criteria, students will be given learning objectives that have been set. Then students are asked to write down the targets they want to achieve in learning. In the second step of AfL, which is to engineer practical classroom discussions and other learning tasks that provide evidence of learners' understanding, learners are asked to complete learning tasks designed to reveal learners' understanding of the material and actively participate in class discussions, share opinions, and answer questions asked by teachers or classmates. In the third step of AfL, which is to actively engage students as a learning resource for each other and provide feedback that leads students to a better understanding, representatives of students present their answers to the front of the class. Students present answers from the results of their group discussions or respond to the presenter's answers. At this stage, the teacher will provide feedback as reinforcement. Feedback is not only at this stage, but also at every stage in learning to help learners. In the fourth step of AfL, which is activating students as owners of their learning, students are asked to conduct self-assessment by answering self-reflection questions that the previous teacher has provided to evaluate the effectiveness of the learning strategies that have been carried out. At this stage, feedback is given to help students identify strengths and weaknesses in their learning.

The post-test results showed that as many as 100% of students achieved completeness, exceeding the set classical completeness limit of 85%. This shows that implementing AfL effectively improves students' critical thinking skills on hydrocarbon materials. This is based on the results of research by Ramadhani & Muchlis (2023), who stated that implementing AfL effectively improves students' critical thinking skills.

Individually, some students showed an N-gain score in the high category, such as 18 students with an N-gain score of 0.88 and 22 with an N-gain score of 0.9. Based on observations and test results, these two students consistently wrote down learning targets at the beginning of each learning activity. Writing these targets is in accordance with the principles of AfL, where learners are directed to know what will be achieved and how they will achieve it. A study by Martins van Jaarsveld et al. (2024) found that setting learning goals can increase students' motivation, focus, and perseverance.

Based on observations and test results, students 18 and 22 actively participated in discussion and reflection. Class discussion activities are an important step in learning with an AfL approach. Research conducted by Senarpi & Nath (2023) shows that discussions in the classroom are very helpful in improving students' critical thinking skills. Class discussions are practical for developing high-level cognitive skills such as critical thinking (McKee, 2015). Students often involved in directed and active discussions can better analyze, evaluate, and solve problems (Senarpi & Nath, 2023).

The effectiveness of implementing AfL in improving critical thinking skills is inseparable from the role of feedback provided by teachers. In the context of AfL, the use of teachers' professional assessments, which are then converted into feedback on the quality of individual work, becomes a primary focus (Ningtryas et al., 2025). In this study, feedback is given based on the results of the pre-test and the students' response in completing the money tasks given by the teacher, so that it is individual and adjusted to the level of understanding of each student. Through this feedback, students can identify mistakes and understand their abilities in doing assignments, thereby encouraging improvement and improvement of learning outcomes (Hasanah & Muchlis, 2024). Effective feedback is feedback that students hear, understand, and use to improve themselves (Mandouit & Hattie, 2023).

Observations of the students with the lowest N-gain scores (of 0.74), namely students 3 and 28, showed that they did not write down their learning targets in most meetings. The N-gain score is still in the high category, but it is necessary to analyze why their N-gain score is relatively low compared to the average N-gain score in the class. When confirmed, they admitted they felt "unnecessary" to write it because they "already knew the purpose." Research Pat-El et al. (2024) shows that AfL positively affects motivation to learn from within themselves, so involvement from the early stages is important to support students' enthusiasm for learning.

DISCUSSION

This study's results show that applying the AfL approach can significantly improve students' critical thinking skills on hydrocarbon materials. This increase can be seen from comparing *pre-test* and *post-test* scores, which reflect the development of students' abilities in interpretation, analysis, evaluation, explanation, and inference.

These findings align with the results of research conducted by Ramadhani & Muchlis (2023), which states that AfL encourages the active participation of students in the process of reflection and monitoring understanding, thereby improving students' critical thinking skills. Other studies conducted (Shah & Muchlis, 2025) show that the AfL approach can improve student learning outcomes through reflection and feedback activities during learning. Research Hasanah & Muchlis (2024) shows that AfL positively influences students' chemistry learning outcomes, mainly because this approach actively engages students in the learning process and encourages reflection on concept understanding. Research (Utami & Agustini, 2024) shows that developing AfL-based LKPD can improve students' science process skills and encourage them to actively think and reflect on their learning process. (Safithri & Muchlis, 2022) stated that learning with an AfL approach effectively improves chemistry learning outcomes through active student involvement and constructive feedback.

Based on the results of previous research, it can be concluded that the AfL approach has been widely applied to improve student learning outcomes and encourage active participation in learning. However, most of the research focuses on learning outcomes, not specifically examining improving critical thinking skills, especially in hydrocarbon materials, which have abstract characteristics and require high reasoning skills.

As explained in the introduction, one of the main problems in learning chemistry is students' low critical thinking skills, especially in understanding the concept of hydrocarbons (Gabriella & Mitarlis, 2021; Sa'adah et al., 2020). This material tends to be taught procedurally and memorized, rather than understood conceptually and applicably. The AfL approach in this study directly responds to this urgency by allowing students to explicitly be aware of learning objectives and reflect on their understanding independently.

For example, in the inference component. The inference component improved with an N-gain of 0.92 (high category). The inference component is finding acceptable conclusions based on available data, statements, or information (Facione, 2020). In this question, students are asked to correctly draw conclusions based on data and information related to the properties of alkanes. The data presented are the melting points of straight-chain alkane compounds. Based on this data, students were asked to make conclusions that explained the relationship between the number of carbon atoms and the melting point of the members of the alkane series listed in the data table. At the time of *Pre-test*, one of the students answered the question with the answer that the more C and H atoms, the higher the melting point. This answer is still not precise. The question is how the number of C atoms and the melting point are related. The H atom does not need to be mentioned because the H atom will follow the number of C atoms in the hydrocarbon compound. The stronger the pulling force between molecules, the more energy required to break it down (Higginbotham, 2021). Usually, larger molecules have a higher boiling point and melting point (Higginbotham, 2021). The feedback on the answer sheet is to correct the students' answers. In the results *post-test*, students could draw correct conclusions regarding the relationship between the number of carbon atoms and the melting point of the members of the alkane series. Based on these results, the students were declared to have met the specified learning objectives.

This research makes a scientific contribution to developing 21st-century skill-oriented learning practices, especially critical thinking skills. Theoretically, this research expands the understanding of how AfL can be designed to shape students' thinking during the learning process. Practically, this approach can be used as a model by teachers in designing learning tools that direct learning activities to achieve high-level thinking competencies. Teachers can apply practical recommendations to provide feedback not only in the form of appreciation and correction, but also by triggering diagnostic and constructive sentences, for example, for the question of determining the physical properties of hydrocarbons. When students have answered the inference question, but have not given a reason for the answer, the teacher can give feedback: "Your explanation mentions that hydrocarbons do not dissolve in water, but there is no scientific reason yet. What is the relationship between the polarity of a molecule and its solubility in a particular solvent?".

CONCLUSION

The conclusion is that implementing the AfL approach in learning is efficacious in improving students' critical thinking skills on hydrocarbon materials. This approach has proven effective because it actively engages learners in the learning process through formative feedback, reflection, and involvement in self-assessment. These findings provide positive implications for chemistry teachers integrating the AfL approach into their regular learning.

However, these results need to be read in a specific context. This research was conducted in one of the high schools in the city of Surabaya, with participants as many as 28 grade XI students who have the characteristics of having studied chemical bonding material and are classified as regular classes. Thus, the generalization of these findings cannot be directly applied to all levels or types of schools, for example, schools in rural areas, madrasas, or schools with different levels of student input. Therefore, replication studies are needed in a variety of other learning contexts, such as in schools with different student characteristics, lower grade levels, or in other chemistry topics that are also abstract, such as reaction rates or chemical equilibrium.

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