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Enhancing students' critical thinking and mathematical self-concept using an autograph-assisted concept attainment model

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Abstract
The low level of students' critical thinking skills and mathematical self-concept is influenced by the use of less effective learning models and the limited integration of technology in mathematics instruction. To address these issues, a concept attainment learning model assisted by Autograph software was implemented. This study aimed to examine whether the improvement of students' critical thinking skills and mathematical self-concept through the concept attainment model assisted by Autograph was better than that achieved through conventional learning. This study employed a quantitative approach with a quasi-experimental method using a nonequivalent control group design. The population consisted of twelfth-grade students at SMA Negeri 1 Tanah Jambo Aye. Data were collected through observations, interviews, tests, and non-test instruments. Test data were analyzed using the Mann–Whitney nonparametric test, while non-test data were analyzed using the independent sample t-test. The findings indicated that students taught using the concept attainment learning model assisted by Autograph demonstrated better improvement in critical thinking skills and mathematical self-concept compared to those taught through conventional learning.

Keywords: authograph software; concept attainment; critical thinking; self concept

Abstrak
Kemampuan berpikir kritis dan self-concept matematis siswa yang masih rendah dipengaruhi oleh penggunaan model pembelajaran yang belum optimal serta minimnya integrasi teknologi dalam proses pembelajaran. Untuk mengatasi permasalahan tersebut, diterapkan model pembelajaran concept attainment yang dipadukan dengan bantuan software Autograph. Penelitian ini bertujuan untuk menganalisis peningkatan kemampuan berpikir kritis dan self-concept matematis siswa melalui penerapan model tersebut dibandingkan dengan pembelajaran konvensional. Penelitian menggunakan pendekatan kuantitatif dengan jenis kuasi eksperimen dan desain nonequivalent control group design. Subjek penelitian terdiri atas siswa kelas XII SMA Negeri 1 Tanah Jambo Aye. Pengumpulan data dilakukan melalui observasi, wawancara, tes, dan instrumen non-tes. Data hasil tes dianalisis menggunakan uji nonparametrik Mann–Whitney, sedangkan data non-tes dianalisis menggunakan uji parametrik berupa uji-t. Hasil penelitian menunjukkan bahwa peningkatan kemampuan berpikir kritis dan self-concept matematis siswa yang belajar menggunakan model concept attainment berbantuan Autograph lebih baik dibandingkan siswa yang memperoleh pembelajaran konvensional.

Kata Kunci: *software* autograph; pencapaian konsep; berpikir kritis; konsep diri

1. INTRODUCTION

Mathematics is one of the fundamental subjects in education and daily life because it plays an important role in the development of science and technology. According to (Rahmaini & Chandra, 2024), mathematics is known as the queen and servant of science due to its contribution to scientific advancement, communication, and information technology. In line with the implementation of the Independent Curriculum, learning is expected to encourage students to develop systematic, logical, and creative thinking skills as part of critical thinking competencies. Critical thinking is considered one of the fundamental skills that students need to possess in the learning process. Through critical thinking, students are able to analyze information, evaluate arguments, and determine appropriate decisions in solving problems. Several studies explain that critical thinking skills can be trained, measured, and continuously developed through effective learning activities (Jannah et al., 2022; Copeland, 2024). In mathematics learning, critical thinking involves cognitive activities such as analyzing, evaluating, interpreting, and making conclusions to solve mathematical problems appropriately (Sosa-Gutierrez et al., 2023; Septiany et al., 2024; Wulandari et al., 2023)

However, the mathematical critical thinking ability of students at SMA Negeri 1 Tanah Jambo Aye is still relatively low. Preliminary observations conducted by the researchers showed that 68.1% of students had not achieved the expected indicators of mathematical critical thinking. Most students experienced difficulties in analyzing problems, evaluating mathematical information, and determining appropriate solution strategies. Interviews conducted during the implementation of the Independent Teaching Campus program also revealed that students tended to depend on teachers' explanations and were not accustomed to exploring alternative learning strategies independently. Consequently, mathematics was often perceived as a difficult and complicated subject, resulting in low learning interest and participation among students.

Besides cognitive abilities, affective aspects such as mathematical self-concept also influence students' learning achievement. Self-concept refers to an individual's perception and assessment of their own abilities formed through experiences and social interactions (Rossi et al., 2022; Suak et al., 2023). In mathematics learning, mathematical self-concept reflects students' perceptions of their abilities, confidence, interests, and enjoyment in learning mathematics (Juniar & Rahayu, 2025; Meriyati et al., 2025). Students with positive mathematical self-concept generally demonstrate better motivation and learning performance than students with negative perceptions of their mathematical abilities. The low level of students' critical thinking skills and mathematical self-concept is also influenced by the limited integration of technology in classroom learning. Learning activities are still dominated by conventional teaching methods, causing students to become passive during the learning process. According to Sitours et al., (2023) insufficient utilization of technology in learning can contribute to low critical thinking skills among students. Therefore, innovative and technology-based learning models are needed to support the development of both cognitive and affective abilities.

Several previous studies have investigated the effectiveness of the Concept Attainment learning model in improving students' conceptual understanding and critical thinking skills The Concept Attainment model emphasizes the process of identifying, comparing, and classifying examples and non-examples of concepts, allowing students to construct their own understanding through analytical thinking processes (Jeong & Evans, 2023; Ananda & Akmal, 2025; Khofifah et al., 2022). These studies indicate that Concept Attainment can facilitate students' cognitive development by encouraging active involvement in the process of concept formation. However, previous implementations of the Concept Attainment model have generally focused on improving conceptual understanding and cognitive learning outcomes without integrating interactive technology as a learning support.

In addition, several studies have examined the use of mathematical software such as Autograph in mathematics learning. The findings indicate that Autograph can facilitate students' understanding of abstract mathematical concepts through dynamic visualization and interactive representations, thereby increasing students' learning motivation and engagement (Mawardin et al., 2025). Nevertheless, previous studies utilizing Autograph have mostly focused on the use of technology as a visualization tool and have not specifically integrated it with a learning model that systematically guides students in analyzing and constructing mathematical concepts.

Furthermore, most previous studies have primarily emphasized cognitive aspects, such as conceptual understanding, problem-solving ability, and learning outcomes, while affective aspects, particularly students' mathematical self-concept, have received relatively limited attention. Mathematical self-concept is an important factor because students' perceptions of their own mathematical abilities, confidence, and interest may influence their participation and persistence in mathematics learning. Therefore, an instructional approach that simultaneously facilitates cognitive processes and supports positive mathematical self-concept development is still needed.

Based on these limitations, a research gap can be identified regarding the integration of the Concept Attainment learning model with technology-based learning media, particularly Autograph software, to improve both cognitive and affective aspects of mathematics learning. Unlike previous studies that investigated the Concept Attainment model and Autograph software separately, this study integrates both approaches within a single learning framework. The integration of Concept Attainment and Autograph is expected to provide opportunities for students to actively analyze mathematical concepts through classification processes supported by dynamic visualization, while simultaneously increasing students' confidence and positive perceptions toward mathematics learning. Therefore, this study offers novelty by implementing an Autograph-assisted Concept Attainment learning model to improve students' mathematical critical thinking skills and mathematical self-concept simultaneously. This study also contributes to the implementation of technology-supported mathematics

learning within the context of the Independent Curriculum at the senior high school level, where both cognitive competencies and students' learning dispositions are emphasized.

Based on the problems and research gaps described above, this study aims to determine whether the Autograph-assisted Concept Attainment learning model can improve students' critical thinking skills and mathematical self-concept better than conventional learning models.

2. METHOD

This study employed a quantitative approach with a quasi-experimental method using a Nonequivalent Control Group Design. The design involved two classes consisting of an experimental class and a control class. The experimental class received learning through the Autograph-assisted Concept Attainment learning model, while the control class was taught using conventional learning methods. The research design is presented in Table 1.

Table 1. Nonequivalent Control Group Design

Class	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	–	O_4

Description:
O_1 : Pretest of the experimental class
O_2 : Posttest of the experimental class
O_3 : Pretest of the control class
O_4 : Posttest of the control class
X : Treatment using the Autograph-assisted Concept Attainment learning model

This study was conducted at SMA Negeri 1 Tanah Jambo Aye during the 2025/2026 academic year. The population of the study consisted of all twelfth-grade students of SMA Negeri 1 Tanah Jambo Aye. The sample comprised 39 students selected using a purposive sampling technique, which were divided into an experimental class and a control class. The research procedure was carried out in several stages. First, the researchers conducted preliminary observations and interviews with students to identify problems related to students' critical thinking skills and mathematical self-concept in mathematics learning. Second, the researchers prepared learning instruments, including lesson plans, test instruments, and self-concept questionnaires. The instruments were developed based on the indicators of mathematical critical thinking skills and mathematical self-concept.

Third, a pretest was administered to both the experimental and control classes to determine students' initial abilities before treatment. Afterward, the experimental class was taught using the Autograph-assisted Concept Attainment learning model, while the control class received conventional learning. In the implementation process, students in the experimental class were encouraged to identify and classify examples and non-examples of mathematical concepts through discussions and learning activities assisted by Autograph software. Meanwhile, students in the control class learned through teacher-centered instruction and conventional problem-solving activities. According to Ningtiyas

et al. (2023), conventional learning is characterized by teacher-dominated instruction, where the teacher plays a central role in delivering learning materials, explaining concepts, and guiding students through problem-solving procedures, while students mainly receive information and follow the given examples. After the learning process was completed, a posttest was administered to both classes to measure the improvement of students' mathematical critical thinking skills.

In addition, students were asked to complete a mathematical self-concept questionnaire to evaluate changes in students' perceptions, confidence, and attitudes toward mathematics learning. Finally, the collected data were analyzed to determine the effectiveness of the Autograph-assisted Concept Attainment learning model compared to conventional learning. The research procedure was carried out in several stages, as illustrated in Figure 1.

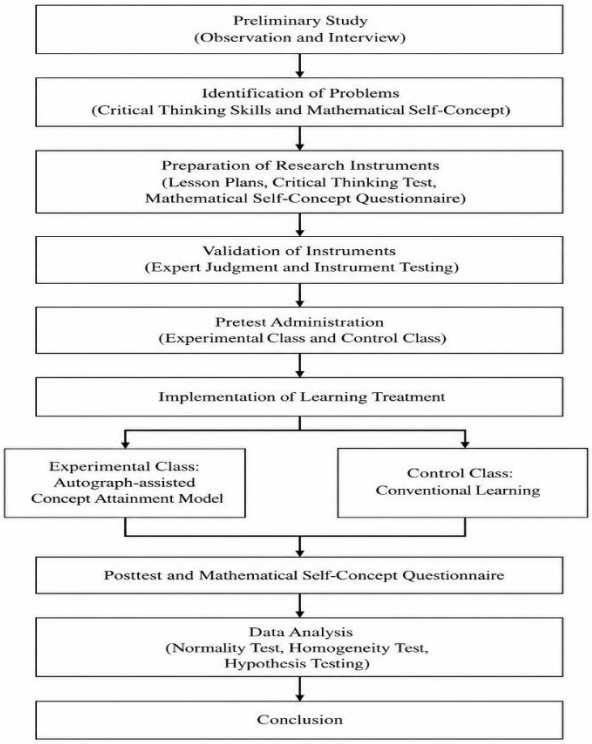

Figure 1. Research Procedure Flowchart

The research procedure was carried out in several stages, as presented in Figure 1. First, the researchers conducted preliminary observations and interviews with students to identify problems related to students' mathematical critical thinking skills and mathematical self-concept in mathematics learning. Second, the researchers prepared learning instruments, including lesson plans, test instruments, and self-concept questionnaires. Before implementation, all instruments were validated to ensure their suitability and accuracy in measuring the intended variables.

The instruments used in this study consisted of test and non-test instruments. The test instrument was used to measure students' mathematical critical thinking skills, while the non-test instrument was used to measure students' mathematical self-concept. The test instrument consisted of essay questions developed based on the indicators of mathematical critical thinking proposed by Hendriana et al. (2018). The indicators included: (1) identifying assumptions provided in the problem; (2) identifying the adequacy of data to solve problems; (3) evaluating relevant arguments in problem solving; (4) expressing data, definitions, and theorems related to problem solving; and (5) answering questions using appropriate reasons, concepts, principles, and rules underlying the answers.

Meanwhile, the non-test instrument consisted of 21 questionnaire statements referring to the indicators of students' mathematical self-concept according to Hendriana et al. (2018). The indicators included: (1) confidence in appearing or speaking in front of the class during mathematics learning; (2) confidence related to receiving attention from teachers and peers in mathematics learning; (3) confidence in understanding mathematics lessons; (4) confidence in completing mathematics assignments and tests; (5) confidence in overcoming difficulties in solving mathematics problems; (6) confidence in asking questions during mathematics learning; (7) confidence in expressing opinions related to mathematics lessons; and (8) responsibility toward mathematics learning activities.

Before being used for data collection, the research instruments were tested to ensure their validity and reliability. The test instrument used to measure students' mathematical critical thinking skills was analyzed through several stages, including validity test, reliability test, difficulty level analysis, and discrimination index analysis. The validity test was conducted to determine the extent to which each item of the instrument was able to measure the intended variable. The validity analysis of the mathematical critical thinking test was performed using the Pearson Product Moment correlation coefficient. The correlation coefficient between each item score and the total score was calculated using the following formula:

$$r_{xy} = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}}$$

Description:

r_{xy}= correlation coefficient of item validity
N= number of respondents
X= item score
Y= total score
$\sum X$= total score of each item
$\sum Y$= total score of all items

The obtained correlation coefficient was then compared with the critical value of the correlation coefficient (r_{table}) at a significance level of 5%. An item was considered valid if $r_{count} > r_{table}$. The interpretation of the validity coefficient was based on the following criteria.

Table 2. Interpretation Criteria of Instrument Validity Coefficient

Correlation Coefficient (r)	Interpretation
$0.80 < r \leq 1.00$	Very high validity
$0.60 < r \leq 0.80$	High validity
$0.40 < r \leq 0.60$	Moderate validity
$0.20 < r \leq 0.40$	Low validity
$0.00 < r \leq 0.20$	Very low validity

After the validity test, the reliability test was conducted to determine the consistency of the mathematical critical thinking skills test instrument. The reliability coefficient was calculated using Cronbach's Alpha formula because the instrument consisted of essay questions with multiple scoring components. The reliability coefficient was calculated using the following formula:

$$r_{11} = \left(\frac{k}{k-1}\right)\left(1-\frac{\sum\sigma_i^2}{\sigma_t^2}\right)$$

Description:

r_{11}= reliability coefficient of the instrument

k= number of test items

$\sum\sigma_i^2$= total variance of each item

σ_t^2= total variance of the test score

The interpretation of the reliability coefficient was determined based on the criteria presented in Table 3.

Table 3. Interpretation Criteria of Instrument Reliability Coefficient

Reliability Coefficient	Interpretation
$0.80 < r_{11} \leq 1.00$	Very high reliability
$0.60 < r_{11} \leq 0.80$	High reliability
$0.40 < r_{11} \leq 0.60$	Moderate reliability
$0.20 < r_{11} \leq 0.40$	Low reliability
$0.00 < r_{11} \leq 0.20$	Very low reliability

Based on the reliability analysis, the mathematical critical thinking skills test showed an acceptable level of consistency and was considered reliable for measuring students' mathematical critical thinking skills. The difficulty level analysis was conducted to determine whether each item was categorized as easy, moderate, or difficult. The difficulty index was calculated using the following formula:

$$P = \frac{X}{X_{max}}$$

Description:
P= difficulty index
X= average score obtained by students on each item
X_{max}= maximum score of each item

The interpretation criteria for the difficulty level are presented in Table 4.

Table 4. Interpretation Criteria of Item Difficulty Level

Difficulty Index	Interpretation
$0.00 < P \leq 0.30$	Difficult
$0.30 < P \leq 0.70$	Moderate
$0.70 < P \leq 1.00$	Easy

The results of the difficulty level analysis indicated that the test items had an appropriate distribution of difficulty levels; therefore, the items were considered suitable for assessing students' mathematical critical thinking skills. The discrimination index analysis was conducted to determine the ability of each test item to distinguish between students with high and low mathematical abilities. The discrimination index was calculated using the following formula:

$$D = \frac{X_A - X_B}{N}$$

Description:
D= discrimination index
X_A= total score of the upper group
X_B= total score of the lower group
N= maximum score obtained by the group

The interpretation criteria of the discrimination index are presented in Table 5.

Table 5. Interpretation Criteria of Item Discrimination Index

Discrimination Index	Interpretation
$0.40 \leq D \leq 1.00$	Very good
$0.30 \leq D < 0.40$	Good
$0.20 \leq D < 0.30$	Fair
$0.00 \leq D < 0.20$	Poor
$D < 0.00$	Very poor

The discrimination index analysis showed that the test items had an adequate ability to differentiate students' mathematical critical thinking abilities and were appropriate for use in the research.

Meanwhile, the non-test instrument in the form of a mathematical self-concept questionnaire was validated based on the suitability of the statement items with the indicators of mathematical self-concept. The questionnaire consisted of 21 statements referring to the indicators proposed by Hendriana et al. (2018). The validity analysis of the questionnaire items was conducted to ensure that each statement was able to

represent the measured construct. The results of the validation process indicated that the questionnaire items were valid and suitable for measuring students' mathematical self-concept.

The data analysis techniques used in this study consisted of descriptive and inferential statistical analyses. Prior to hypothesis testing, the data were tested for normality and homogeneity. If the data met the assumptions of normality and homogeneity, parametric tests were employed. Otherwise, non-parametric tests were used. The data of students' mathematical critical thinking skills were analyzed using the Mann–Whitney test because the data were not normally distributed, while the mathematical self-concept questionnaire data were analyzed using the independent sample t-test.

3. RESULT AND DISCUSSION

3.1 Result

Before analyzing the effectiveness of the Autograph-assisted Concept Attainment learning model, the feasibility of the mathematical critical thinking skills test instrument was examined. The analysis included item validity, reliability, difficulty level, and discrimination index to determine whether each item was appropriate for measuring students' mathematical critical thinking skills. The results of the test item analysis are presented in Table 6.

Table 6. Feasibility Analysis of Mathematical Critical Thinking Skills Test Items

Item	Validity	Reliability	Difficulty Level	Discrimination Index	Decision
1	Valid	High	Moderate	Good	Used
2	Valid	High	Moderate	Good	Used
3	Valid	High	Moderate	Fair	Not Used
4	Invalid	High	Moderate	Poor	Not Used
5	Valid	High	Moderate	Fair	Used
6	Invalid	High	Moderate	Fair	Not Used
7	Invalid	High	Moderate	Fair	Not Used
8	Valid	High	Moderate	Fair	Not Used
9	Valid	High	Moderate	Good	Used
10	Valid	High	Moderate	Good	Used

Based on the results presented in Table 6, the mathematical critical thinking skills test showed good feasibility characteristics. The reliability analysis indicated that the instrument had a high level of consistency. The item validity analysis showed that several items met the validity criteria, while some items did not meet the required criteria. Furthermore, the difficulty level analysis showed that all items were categorized as moderate, indicating that the test items had an appropriate level of difficulty for students. The discrimination index analysis showed that the items had varying abilities in distinguishing students' mathematical critical thinking skills. Based on the overall analysis, five items were selected and used as the final instrument for measuring students' mathematical critical thinking skills.

After the instruments were confirmed to be valid and reliable, the collected data from the experimental and control classes at SMA Negeri 1 Tanah Jambo Aye were analyzed. The analysis was conducted to determine the effectiveness of the Autograph-assisted Concept Attainment learning model compared to conventional learning models in improving students' mathematical critical thinking skills and mathematical self-concept. The results of the pretest and posttest analysis for both variables are presented in the following sections.

Improvement of Students' Mathematical Critical Thinking Skills

The improvement of students' mathematical critical thinking skills was analyzed using the N-Gain score. The results of the N-Gain analysis are presented in Table 7.

Table 7. N-Gain Score of Students' Mathematical Critical Thinking Skills

Class	Average N-Gain Score	Category
Experimental	0.56	Moderate
Control	0.26	Low

Based on Table 7, the average N-Gain score of the experimental class was 0.56, which was categorized as moderate, while the control class obtained an average N-Gain score of 0.26, categorized as low. These results indicate that the improvement in students' mathematical critical thinking skills in the experimental class was better than that of the control class. Before conducting hypothesis testing, the N-Gain data were first tested for normality using the Shapiro–Wilk test. The results of the normality test are presented in Table 8.

Table 8. Normality Test Results of Students' Mathematical Critical Thinking Skills

Class	Statistic	df	Sig.
Experimental	0.629	21	0.000
Control	0.938	18	0.263

Based on Table 8, the significance value of the experimental class was 0.000, while the control class obtained a significance value of 0.263. Since one of the significance values was less than 0.05, the data were not normally distributed. Therefore, hypothesis testing was continued using the non-parametric Mann–Whitney test.

Table 9. Mann–Whitney Test Results of Students' Mathematical Critical Thinking Skills

Mann–Whitney U	Asymp. Sig. (2-tailed)
42.000	0.000

Based on Table 9, the significance value obtained was 0.000, which was less than 0.05. Therefore, the hypothesis was accepted. It can be concluded that the improvement of students' mathematical critical thinking skills through the Autograph-assisted Concept Attainment learning model was significantly better than that of students who received conventional learning.

Improvement of Students' Mathematical Self-Concept

The improvement of students' mathematical self-concept was also analyzed using the N-Gain score. The results are presented in Table 10.

Table 10. N-Gain Score of Students' Mathematical Self-Concept

Class	Average N-Gain Score	Category
Experimental	0.34	Moderate
Control	0.20	Low

Based on Table 10, the experimental class obtained an average N-Gain score of 0.34, categorized as moderate, while the control class obtained an average N-Gain score of 0.20, categorized as low. These results indicate that the improvement of students' mathematical self-concept in the experimental class was better than that of the control class. The normality test results of students' mathematical self-concept are presented in Table 11.

Table 11. Normality Test Results of Students' Mathematical Self-Concept

Class	Statistic	df	Sig.
Experimental	0.947	21	0.293
Control	0.950	18	0.429

Based on Table 11, the significance values of both classes were greater than 0.05, indicating that the data were normally distributed. Therefore, the analysis was continued with a homogeneity test.

Table 12. Homogeneity Test Results of Students' Mathematical Self-Concept

Levene Statistic	df1	df2	Sig.
0.411	1	37	0.526

Based on Table 12, the significance value was 0.526, which was greater than 0.05. Thus, the variance of both groups was considered homogeneous. Since the assumptions of normality and homogeneity were fulfilled, the hypothesis testing was continued using the independent sample t-test.

Table 13. Independent Sample t-Test Results of Students' Mathematical Self-Concept

t	df	Sig. (2-tailed)
0.526	20.854	0.001

Based on Table 13, the significance value obtained was 0.001, which was less than 0.05. Therefore, the hypothesis was accepted. It can be concluded that the improvement of students' mathematical self-concept through the Autograph-assisted Concept Attainment learning model was significantly better than that of students who received conventional learning.

3.2 Discussion

The findings of this study indicate that the Autograph-assisted Concept Attainment learning model had a positive effect on students' mathematical critical thinking skills and mathematical self-concept. The improvement of students' critical thinking skills in the experimental class was higher than that of the control class, as indicated by the higher average N-Gain score and the results of the Mann–Whitney test. This finding suggests that the implementation of the Concept Attainment model assisted by Autograph software can support students in analyzing, evaluating, and solving mathematical problems critically.

The improvement in students' mathematical critical thinking skills can be explained through the characteristics of the Concept Attainment learning model. This model emphasizes the process of identifying, comparing, and classifying examples and non-examples to construct mathematical concepts. Through these activities, students are encouraged to examine information, identify patterns, provide reasoning, and make decisions based on mathematical evidence. These learning processes are closely related to the components of critical thinking, including interpretation, analysis, evaluation, and inference. Therefore, the higher improvement in the experimental class indicates that learning activities involving active concept construction can facilitate students' critical thinking development.

The use of Autograph software further strengthened the implementation of the Concept Attainment model by providing dynamic visualization of mathematical concepts. Abstract mathematical objects that are difficult to understand through conventional representations can be presented visually and interactively through Autograph. This condition allows students to observe mathematical relationships, explore changes in representations, and verify their understanding independently. These findings are consistent with Bruner's constructivist theory, which emphasizes that meaningful learning occurs when students actively construct knowledge through cognitive processes and experiences. Thus, the combination of Concept Attainment and Autograph supports students in building mathematical understanding through exploration and discovery.

The findings of this study are consistent with previous research conducted by Ananda & Akmal (2025),, which found that students who learned through the Concept Attainment model showed better improvement in mathematical critical thinking skills than students who received conventional learning. This study also supports the findings of Subawo et al., (2022), which reported that students' self-concept contributes to their mathematical thinking abilities. Furthermore, the present study extends previous findings by integrating Concept Attainment with Autograph software, while previous studies generally examined the learning model or technology-based media separately. Therefore, this study provides additional evidence that combining an instructional model with appropriate technology can enhance students' cognitive learning processes.

Regarding mathematical self-concept, the experimental class also demonstrated better improvement than the control class. This finding indicates that the Autograph-assisted Concept Attainment learning model not only affects students' cognitive abilities but also supports the development of positive perceptions toward mathematics. During the learning process, students were actively involved in identifying concepts, discussing ideas, presenting arguments, and solving problems collaboratively. These experiences provided opportunities for students to develop confidence, independence, and responsibility in mathematics learning. The improvement of mathematical self-concept can be explained through social constructivist perspectives, which suggest that interaction, active

participation, and successful learning experiences contribute to students' beliefs about their own abilities.

The results regarding mathematical self-concept are also in line with previous studies emphasizing that positive mathematical self-concept is associated with students' confidence, persistence, and willingness to engage in mathematical activities. However, unlike previous studies that mainly focused on the relationship between self-concept and mathematical achievement, this study demonstrates that a technology-assisted learning model can become an instructional strategy to directly support the development of students' mathematical self-concept through meaningful learning experiences.

The findings of this study have several theoretical and practical implications. Theoretically, this study contributes to mathematics education research by strengthening the understanding that the effectiveness of learning models is not only determined by their ability to improve cognitive outcomes but also by their capacity to develop students' affective characteristics. The integration of Concept Attainment and Autograph provides empirical support for constructivist learning principles, where students actively construct knowledge through exploration, visualization, and reflection.

Practically, the findings provide implications for mathematics teachers in designing learning activities that combine appropriate instructional models with technology-based media. The Autograph-assisted Concept Attainment learning model can be considered an alternative approach to create interactive mathematics learning environments that encourage students to think critically and develop positive mathematical self-concept. In addition, the findings may serve as a reference for schools in implementing technology-supported mathematics learning, particularly within the context of the Independent Curriculum, which emphasizes the development of students' cognitive skills and learning dispositions.

4. CONCLUSION

Based on the results of the study, it can be concluded that the Autograph-assisted Concept Attainment learning model was more effective than conventional learning in improving students' mathematical critical thinking skills and mathematical self-concept. The implementation of the learning model encouraged students to actively analyze, classify, and construct mathematical concepts independently, thereby supporting the development of critical thinking skills. In addition, the integration of Autograph software helped students visualize mathematical concepts more clearly and interactively, which contributed positively to students' confidence, motivation, and perceptions of their mathematical abilities. These findings indicate that the Autograph-assisted Concept Attainment learning model can be used as an alternative learning approach to improve both cognitive and affective aspects in mathematics learning, particularly students' critical thinking skills and mathematical self-concept.

5. RECOMMENDATION

This study has several limitations that should be considered in future research. The implementation of the Autograph-assisted Concept Attainment learning model requires adequate time allocation, students' familiarity with technology, and teachers' ability to manage technology-based learning activities. Differences in students' initial abilities, learning experiences, and technological skills may also influence the effectiveness of the learning model. Therefore, future studies are recommended to involve a larger sample size, different educational levels, and various mathematical topics to obtain broader evidence regarding the effectiveness of the model. Further research may also examine the integration of the Autograph-assisted Concept Attainment learning model with other variables, such as mathematical problem-solving ability, creativity, learning motivation, or digital literacy, to provide a more comprehensive understanding of its contribution to mathematics learning.

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