

EXPLORING JUNIOR HIGH SCHOOL STUDENTS' CRITICAL THINKING PROCESSES IN SOLVING SYSTEMS OF LINEAR EQUATIONS USING GEOGEBRA: A QUALITATIVE CASE STUDY

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ABSTRACT

Critical thinking is an essential cognitive skill in mathematics learning, particularly in solving contextual and non-routine problems. However, many junior high school students still experience difficulties in applying critical thinking when solving systems of linear equations. This study aims to explore the critical thinking processes of students in solving systems of linear equations in two variables (SPLDV) using GeoGebra. A qualitative descriptive approach with a case study design was employed. The participants were 25 ninth-grade students from a junior high school in Surabaya, Indonesia. Based on the results of a critical thinking test, three students were purposively selected to represent successful, less successful, and unsuccessful problem solvers. Data were collected through GeoGebra-assisted problem-solving tasks and semi-structured interviews, and analyzed using Facione's critical thinking framework: interpretation, analysis, inference, evaluation, explanation, and self-regulation. The findings reveal that successful students demonstrated all six critical thinking processes consistently, while less successful students showed partial fulfillment of the indicators. Unsuccessful students failed to demonstrate most critical thinking processes due to weak conceptual understanding and poor problem interpretation. GeoGebra supported visualization and verification of solutions but did not replace conceptual reasoning. These findings highlight the importance of integrating technology with explicit instruction on critical thinking processes in mathematics learning.

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INTRODUCTION

The critical thinking process is a mental activity that allows a person to analyze, evaluate, and logically construct arguments or solutions. According to Siswono (2016), critical thinking is the process of applying thinking skills effectively and systematically to formulate, assess, and implement decisions based on beliefs and actions that are believed to be correct. Facione (2016) states that critical thinking is a purposeful and controlled mental activity, namely proving something, interpreting what something means, and solving a problem by considering evidence, concepts, methods, criteria, and context when making judgments. Critical thinking skills are very important as a means to conduct in-depth investigations. Developing critical thinking processes in mathematics learning has become a primary focus of mathematics education curricula in various countries (Firdaus, 2015). Numerous studies have shown that improving critical thinking processes can contribute to achieving better mathematics learning outcomes. Furthermore, critical thinking also encourages students to think independently and solve various problems, both in the school environment and in everyday life.

Widana (2017) states that higher-order thinking skills (HOTS) questions are a measurement instrument used to assess higher-order thinking skills, namely the ability to think beyond simply recalling, restating, or referring without processing (recite). Higher-order thinking skills require a complex evaluation process because they encompass aspects of data interpretation, analysis, and manipulation. Mathematical problems, such as HOTS problems on systems of linear equations in two variables, typically involve more than just procedural steps; they require a deep conceptual understanding and critical thinking processes to connect various pieces of information, draw logical conclusions, and evaluate solutions. In reality, some students still struggle to develop critical thinking processes, especially in solving mathematical problems. One of the problems in learning mathematics on the topic of systems of linear equations in two variables at the junior high school level is the high level of students' inability to solve word problems. Research conducted by Sihotang (2023) revealed that several student weaknesses include: students do not understand the problem in the problem, the inability to distinguish between the information given and that requested in the problem, students cannot establish concepts for the problem to determine the mathematical model, students do not provide good and complete planning in solving problems, students make calculation errors, and difficulty in drawing conclusions or reconnecting with the problem being solved. These weaknesses indicate that the critical thinking process has not developed optimally in learning. This indicates the need for students' critical thinking processes during the process of solving mathematical problems.

The results of research conducted by Konoras (2022) show that students' mathematical critical thinking skills in solving problems of systems of linear equations in two variables (SPLDV) are still relatively low. The rapid advancement of information and communication technology has intensified the need for students to critically evaluate, analyze, and synthesize information in mathematical problem solving, so that the critical thinking process has become very necessary in the modern era. Students need to improve their critical thinking processes to be able to compare and analyze existing information, thus being able to select the right information and be able to convey arguments based on the information obtained. Critical thinking processes not only improve the quality of life and academic achievement, but also personal skills, self-control, and thinking skills in social life. Critical thinking processes in students are expected to shape individuals who are resilient in facing global developments in science and technology (IPTEK) and solving various problems that arise from these developments. Siswono (2016) argues that the rapid development of information and communication technology, the widespread use of social media, limited natural resources, and the dynamics of uncertain change require critical and creative thinking processes as part of the skills that must be possessed. In the context of modern education, critical thinking processes are essential for students to understand and solve various complex problems, both in everyday social life and in academic learning. One technology that can solve problems with systems of linear equations in two variables is GeoGebra. GeoGebra is useful as a learning tool that supports students in mastering abstract mathematical concepts

through visualizations with various attractive features (Asnawi et al., 2022). Simarmata & Sirait (2020) suggest that GeoGebra serves as a mathematics learning aid that facilitates students' visual understanding of abstract topics and supports a deeper understanding of material concepts through engaging and diverse displays. According to Annajmi (2016), GeoGebra software is basic software that is easy to learn and use for students to develop their understanding independently. GeoGebra is a learning medium that can be utilized to facilitate student understanding through a visual approach to the material presented by educators (Oktaria et al., 2016). Therefore, the use of GeoGebra is highly relevant in the mathematics learning process, particularly in the topic of systems of linear equations in two variables.

Although numerous studies have examined students' critical thinking skills in mathematics, empirical research that specifically investigates the *process* of critical thinking supported by GeoGebra in solving systems of linear equations remains limited. This study addresses this gap by providing an in-depth qualitative analysis of students' cognitive processes based on Facione's framework. The core of the critical thinking process according to Facione (2016) is: (1) Interpretation, which is the process of someone understanding and expressing the meaning of data, (2) Analysis, which is the process of someone identifying information based on the relationship between information and concepts, with questions in the problem, (3) Inference, which is the process of someone identifying and securing the elements needed or required in making rational conclusions, (4) Evaluation, which is the process of someone assessing the credibility of a statement or representation based on questions in a problem, (5) Explanation, which is the process of someone stating and justifying reasoning when providing reasons for justification from evidence, (6) Self-regulation, which is the process of someone monitoring thinking activities and re-examining the results of reasoning that has been done previously.

Of several indicators of the critical thinking process proposed by previous experts, this study refers to the indicators developed by Facione as a reference basis. Facione's version of the indicators was chosen because it is considered easier to apply to measure the critical thinking process of junior high school students in solving systems of linear equations with two variables using GeoGebra. An explanation of these indicators can be seen in **Table 1**.

Table 1 Indicators of Critical Thinking Process

No.	dalege	Descriptions
.1.	Interpretation	Understanding and expressing the meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures, or criteria, as evidenced by the ability to categorize, express the important points of a problem, and classify the meaning of something.
2.	Analysis	Identifying inferential and actual relationships among statements, questions, concepts, descriptions, or other forms of representation, intended to express beliefs, judgments, experiences, reasons, information, or opinions as evidenced by the ability to examine ideas, identify opinions, identify reasons and claims.
3.	Inference	Identifying and securing the elements necessary to draw reasonable conclusions; forming conjectures and hypotheses; considering relevant information and deducing consequences that flow from data, statements, principles, evidence, judgments, beliefs, opinions, concepts, descriptions, questions, or other forms of representation, as evidenced by the ability to question evidence, alternative hypotheses, and draw valid and logically justified conclusions.
4.	Evaluation	Assessing the credibility of statements or other representations that are reports or descriptions of one's perceptions, experiences, situations, judgments, beliefs, or opinions; and to assess the logical strength of actual or intended inferential

No.	dalege	Descriptions
		relationships among statements, descriptions, questions, or other forms of representation, as evidenced by the ability to assess the credibility of claims, assess the quality of arguments.
5.	Explanation	To state and justify reasoning in the form of evidential, conceptual, methodological, criteriological, and contextual considerations that form the basis of one's research results; and to present one's reasoning in the form of convincing arguments, as evidenced by the ability to state results, justification of procedures, and appropriate arguments.
6.	Self-Regulation	Monitoring one's thinking activities, the elements used in those activities, and the results obtained, particularly by applying skills in analysis and evaluation to one's inferential judgments with the aim of questioning, confirming, validating, or correcting one's reasoning or results, as evidenced by self-monitoring or self-correcting abilities.

METHOD

The approach used in this study is a qualitative approach with a descriptive research type. According to Creswell (2018), qualitative research aims to explore and understand the meaning constructed by individuals or groups regarding a social or humanitarian problem. The research procedure begins with determining the research focus, conducting a literature review, compiling research instruments, collecting data in the field using research instruments, and analyzing the collected data. The research design is a case study. In line with qualitative research principles, the researcher served as the primary research instrument, supported by problem-solving tasks and interview guidelines. The supporting instrument used in this study is the Problem Solving Task (TPM) which contains story problems designed to help researchers in understanding students' critical thinking processes in solving two-variable linear equation systems using GeoGebra. The problem-solving tasks were validated by two experts in mathematics education to ensure content validity and alignment with critical thinking indicators.. This research was conducted in grade IX-B of SMPK Angelus Custos 1 Surabaya. The researcher selected three students as research subjects. The first step taken by the researcher in determining the three research subjects was to select all 25 students from class IX-B of SMPK Angelus Custos 1. The research subjects were selected purposively by selecting class IX- B to be given a GeoGebra-assisted critical thinking test (TBK) based on teacher suggestions. The TBK was given to group students based on categories. After completing the critical thinking test, students who met the categories were determined as research subjects. The selection was based on the students' answer categories in solving two- variable linear equation systems and their ability to use the GeoGebra application, students' good communication skills, and the willingness of the selected students. The student answer categories determined in selecting the three research subjects are presented in **Table 2** below.

Table 2 Student Answer Categories

Student Answer	Categories
Students answer all questions correctly or are able to fulfill all critical thinking indicators.	Success
Students answered some of the questions correctly or were only able to fulfill 3 critical thinking indicators.	Less Success
Students cannot answer the questions correctly at all or are only able to fulfill 1 critical thinking indicator.	Failure



RESULT AND DISCUSSION

From the 25 students, the results of the critical thinking test are presented in **Table 3** below.

Table 3 Results of Critical Thinking Test of 25 Students

No.	Names Initials	Critical Thinking Test Results						Categories
		a		b		c		
		True	False	True	False	True	False	
1.	KY	√	–	√	–	√	–	Success
2.	HS	√	–	√	–	√	–	Success
3.	KRG	√	–	√	–	√	–	Success
4.	VA	√	–	√	–	√	–	Success
5.	SC	√	–	√	–	√	–	Success
6.	JA	√	–	√	–	√	–	Success
7.	JCS	√	–	√	–	√	–	Success
8.	EV	√	–	√	–	√	–	Success
9.	EA	√	–	√	–	√	–	Success
10.	KLH	√	–	√	–	–	√	Less Success
11.	KYU	√	–	√	–	–	√	Less Success
12.	AXS	√	–	√	–	–	√	Less Success
13.	ISD	√	–	√	–	–	√	Less Success
14.	JAW	–	√	–	√	–	√	Failure
15.	AKS	–	√	–	√	–	√	Failure
16.	GR	–	√	–	√	–	√	Failure
17.	EG	–	√	–	√	–	√	Failure
18.	FE	–	√	–	√	–	√	Failure
19.	FAE	–	√	–	√	–	√	Failure
20.	LI	–	√	–	√	–	√	Failure
21.	JF	–	√	–	√	–	√	Failure
22.	HV	–	√	–	√	–	√	Failure
23.	AN	–	√	–	√	–	√	Failure
24.	PGS	–	√	–	√	–	√	Failure
25.	RY	–	√	–	√	–	√	Failure

The results of the critical thinking test showed that 9 students were classified as successful, 4 students were classified as less successful, and 12 students were classified as unsuccessful. After conducting analysis and discussions with partner teachers, three students were selected as research subjects: one student with the successful category with the initials KY (S1), one student with the less successful category with the initials KLH (S2), and one student with the unsuccessful category with the initials JAW (S3). The three students who became research subjects were given a GeoGebra-assisted Problem Solving Task (TPM) which was then followed by an interview. The interview was conducted to reveal the critical thinking process of the research subjects that was not written on the TPM answer sheet. The critical thinking process of the research subjects studied, as expressed by Facione, included interpretation, analysis, inference, evaluation, explanation, and self-regulation.

At the problem understanding stage, the subject successfully (S1) demonstrated the complete and

consistent implementation of the interpretation process. S1 was able to determine the core of the problem, fully express known and requested information, and relate the problem to relevant SPLDV concepts. This ability was evident in S1's ability to explain the problem context using his own language, although some editors still took the problem directly from the problem. This finding indicates that S1 moved beyond literal comprehension and constructed a conceptual representation of the problem, which served as a foundation for subsequent analytical reasoning. This aligns with Facione's (2016) view that interpretation is the foundation of critical thinking, as errors at this stage will impact subsequent stages. Therefore, S1's success in understanding the problem is a primary prerequisite for successful overall SPLDV problem solving. The use of GeoGebra at this stage is not yet technical, but serves as cognitive anticipation, helping students imagine that the SPLDV solution will be represented as the intersection of two lines. This reinforces the initial understanding of the purpose of problem solving. This ability demonstrates the fulfillment of the interpretation process according to Facione (2016), namely the ability to understand and express the meaning of a problem accurately. This finding aligns with Polya's (2004) opinion, which states that successful problem-solving is highly dependent on students' accurate understanding of the problem from the outset. Siswono (2016) also emphasized that students with high critical thinking skills are able to sort out important information and connect it to appropriate mathematical concepts. Thus, undergraduate students' abilities at this stage demonstrate a strong foundation of critical thinking.

At the planning stage, S1 demonstrated systematic implementation of the analysis and inference process. S1 was able to identify significant data, select relevant information, and ignore information that did not directly impact the formation of the mathematical model. In addition, S1 was able to explain the reasons for choosing a solution strategy, namely assuming variables, forming SPLDV, and solving it using GeoGebra. The inference process was evident when S1 drew logical conclusions from initial information, such as concluding that prices or variables are constant under certain conditions, and deducing the appropriate form of mathematical modeling. The conclusions drawn were not merely intuitive, but based on an analysis of the relationships between information.

GeoGebra at this stage functions as a strategy support tool, not as a substitute for critical thinking, so that students remain actively involved in the analysis and inference process. This finding reflects the analysis process, namely identifying relationships between concepts, and the inference process, namely drawing initial conclusions regarding the most appropriate solution strategy; running well by S1. Facione (2016) states that inference is demonstrated through the ability to select alternative solutions based on relevant information. This finding is also in line with Stanic (1989) who views problem solving as a skill, where students are able to choose effective strategies based on conceptual understanding. In addition, Annajmi (2016) states that GeoGebra can support the planning process by helping students explore various possible solutions visually.

During the planning implementation phase, S1 demonstrated effective evaluation and explanation. S1 not only carried out the solution procedure but also evaluated the accuracy of the information, the system of equations, and the validity of the solution obtained. This was demonstrated through the habit of proving by substituting values

into the equation. Furthermore, S1 was able to explain the solution steps in a coherent, logical manner, and with clear mathematical reasoning. This explanation reflected a deep conceptual understanding, not merely procedural skills. GeoGebra plays a significant role at this stage, especially in visualizing the intersection points of two lines as a solution to the SPLDV, thereby strengthening students' confidence in the results obtained. This finding reinforces the view that the use of dynamic technology such as GeoGebra can improve the quality of critical thinking when used reflectively and integrated with conceptual understanding. In line with Scriven's (2008) view, critical thinking demands clarity, consistency, and strong evidence in reasoning. The use of GeoGebra by undergraduate students also strengthens the validity of the solution, as stated by Simarmata & Sirait (2020) that technology-based visualization can help students verify the correctness of mathematical solutions.

In the reexamination stage, S1 demonstrated the comprehensive implementation of the self-regulation process. S1 reexamined all stages of completion, from writing the initial information, forming the SPLDV, to validating the results through proof. This action demonstrated reflective awareness and intellectual responsibility for one's own work. This self-regulation ability is an important characteristic of students categorized as successful, as it demonstrates that students are not only oriented towards the final answer, but also on the accuracy of the process. Facione (2016) emphasized that self-regulation is a key characteristic of mature critical thinking. This finding is also in line with Ennis (2011), who stated that critical thinking always involves an overview or review of the entire process and results of one's thinking. Thus, S1 has fulfilled all of Facione's critical thinking process indicators.

At the problem understanding stage, the subject's less successful (S2) demonstrated the implementation of the interpretation process, although it was still inconsistent. In a relatively simple problem, namely TPM number 1, S2 was able to identify the core of the problem, express known information, and relate it to the SPLDV that would be used in solving the problem. However, in a more complex problem, TPM number 2, S2 had difficulty understanding the overall context of the problem, particularly information that was gradual or involved changing conditions. S2 failed to identify the core of the problem as a whole and failed to express known information. These limitations indicate that S2's understanding is still partial and tends to rely on the wording of the question. S2 was not yet fully able to reconstruct the problem in his own words, so the interpretation process did not occur fully. This indicates that the interpretation process has emerged, although it is not yet fully complete. According to Glaser (1941), recognizing a problem is the first step in critical thinking. However, S2's limited understanding resulted in the information obtained not being fully integrated. Nevertheless, S2 demonstrated the interpretation process in solving the problem.

At the planning stage, S2 demonstrated limited analytical and inference skills. S2 was able to identify some important data, but was unable to fully connect the data to form a complete solution strategy. S2 was also unable to articulate precise reasons related to the data used in the solution. The conclusions drawn tended to be limited and did not cover the entire problem. GeoGebra at this stage functioned more as a procedural tool, rather than as a means of conceptual reflection. S2 entered the mathematical model into GeoGebra without full confidence in the model's validity, so the role of critical thinking was not optimal. This indicates that the analysis process emerged partially, while inference was still weak. Facione (2016) stated that failure in inference can lead to a lack of direction in the solution plan. This finding aligns with Jacob & Sam (2020), who stated that students with moderate/less successful critical thinking tend to have difficulty constructing strong inferences. At the implementation stage of the plan, S2 was able to follow the steps in a systematic manner, but the evaluation and explanation provided were still limited. S2 rarely performed independent proofs and tended to accept GeoGebra results without in-depth verification. S2 was not yet able to carry out problem solving on more complex problems and was not yet able to state the appropriate reasons for the solutions he had worked on. This indicates that the evaluation and explanation processes were not fully fulfilled. Siswono (2016) emphasized that critical thinking requires logical consistency in every step of the solution. In the reexamination stage, S2 demonstrated low levels of self-regulation. Reexamination was minimal and did not include a comprehensive evaluation of the process and results. This indicates that S2's self-regulation skills still need to be developed. Facione (2016) stated that self-regulation often does not emerge optimally in students with moderate critical thinking processes. Therefore, S2 has not yet met all of Facione's critical thinking process indicators.

Failure students (S3) demonstrated limitations in critical thinking processes across almost all of Polya's stages. At the problem-understanding stage, S3 had difficulty identifying the core of the problem and was unable to articulate known information used in problem-solving. The understanding formed was incomplete and unintegrated. Bell (1978) stated that a condition becomes problematic if an individual is unable to comprehend the situation at hand. This finding aligns with Sihotang (2023), who stated that the inability to distinguish between

known and questionable information is a key characteristic of students with low critical thinking skills. This indicates that S3 did not perform the correct interpretation process. At the planning stage, S3 was unable to identify significant data and was unable to identify relevant information from the data used in the solution process. This was due to S3's inability to interpret the previous process, such as inability to gather important information in the problem and a poor understanding of the SPLDV concept. According to Polya (2004), without a clear plan, problem-solving cannot proceed effectively. This indicates incomplete analysis and inference processes. During the planning implementation stage, S3 was unable to perform a single correct step. He simply performed haphazard solutions without any underlying rationale and without understanding the mathematical meaning, thus failing to achieve the evaluation and explanation process. During the review stage, S3 failed to re-examine all of his work. This demonstrates a lack of self-regulation within S3. Therefore, S3 has not demonstrated Facione's critical thinking process.

CONCLUSION

This study reveals that students' success in solving systems of linear equations using GeoGebra is strongly associated with the completeness of their critical thinking processes. Successful students demonstrated all six indicators of critical thinking, while less successful and unsuccessful students showed fragmented or absent processes. GeoGebra functioned effectively as a visualization and verification tool, but its benefits depended on students' conceptual understanding and reasoning ability. These findings emphasize that technology integration in mathematics learning must be accompanied by explicit instruction in critical thinking processes. Future research should involve larger samples and experimental designs to develop GeoGebra-based instructional models that explicitly train each indicator of critical thinking. First, students in the successful category, at the problem understanding stage, were able to identify the core of the problem, articulate known information, clarify questions, link related information, and relate the problem to the material to be used in solving the problem. GeoGebra utilization at this stage was not yet operational, but served as cognitive anticipation, helping to establish an initial understanding that the SPLDV solution was represented by the intersection of two lines. During the planning stage, students are able to perform analysis and inference by identifying significant data, examining the reasons related to the data found, and utilizing them in the problem-solving process. Furthermore, they are able to identify and secure relevant information to mitigate the consequences of data confusion, and are able to draw reasonable conclusions using previously collected information. GeoGebra serves as a supporting tool in designing a solution strategy, not a substitute for critical thinking. During the plan implementation stage, students are able to perform evaluation and explanation processes by assessing the level of trustworthiness of previously collected information, assessing the credibility of claims and the quality of arguments, implementing problem-solving using previously collected information, and providing sound reasoning related to the conclusions of the designed solution. GeoGebra plays a significant role in visualizing SPLDV solutions, thereby strengthening confidence in the validity of the results obtained. In the review stage, students are able to carry out self-regulation by monitoring and evaluating work results by reviewing each stage of problem-solving. This demonstrates reflective awareness and intellectual responsibility for the problem-solving process and results.

Second, subjects are less successful in solving two-variable linear equation systems with the help of geogebra. At the problem understanding stage, students interpret relatively simple problems by identifying the core of the problem, revealing known information, and relating it to the SPLDV that will be used in solving the problem. However, for more complex problems, they experience difficulty understanding the overall context of the problem and are unable to identify and express the core of the problem as a whole. The use of GeoGebra at this stage has not had a significant impact on deepening conceptual understanding. At the planning stage, they conduct limited analysis and inference processes, identifying significant data but not all of it. They are unable to examine the

reasons related to the data they have found and utilize in the problem-solving process. They are also less able to identify and secure relevant information to reduce the consequences of data confusion and are unable to draw reasonable conclusions by utilizing previously collected information. GeoGebra tends to be used as a procedural tool without prior conceptual confidence in the model being built. At the planning implementation stage, the evaluation and explanation process is still limited, where they are unable to access the level of trustworthiness of the previously collected information as a whole, are unable to assess the credibility of claims and the quality of the arguments that have been made. They are able to implement problem solving by utilizing previously collected information, but not to the entire core of the problem and are unable to state the appropriate reasons related to the conclusions of the solutions that have been designed. They tend to accept the results from GeoGebra without conducting in-depth verification and are not yet able to provide strong mathematical reasons for the solutions obtained. At the re-examination stage, the self-regulation process is carried out, but it is not able to monitor and evaluate the results of the work by reviewing each stage that has been carried out in solving the problem as a whole.

Third, subjects failed to solve two-variable linear equation systems using geogebra. At the problem-understanding stage, they are unable to interpret, identifying the core of the problem, and identifying known information that can be used in problem-solving. At the planning stage, they are unable to analyze and infer, identifying significant data, analyzing the reasons for the data they have found and using in the problem-solving process, identifying and securing relevant information to mitigate the consequences of data confusion, and drawing reasonable conclusions from previously collected information. This inability to understand the problem and their poor mastery of the SPLDV concept prevent them from identifying relevant data or developing a solution strategy. During the plan implementation stage, they failed to evaluate and explain the problem. They were unable to assess the level of trustworthiness of previously collected information, assess the credibility of claims and the quality of discarded arguments, implement problem-solving strategies utilizing previously collected information, and articulate sound reasoning for the conclusions of their proposed solutions. The steps taken were haphazard, lacking a clear conceptual basis and meaningful mathematical explanations. GeoGebra failed to provide optimal assistance due to its lack of adequate conceptual understanding. During the review stage, they failed to engage in self-regulation, monitoring and evaluating their work by reviewing each step taken in solving the problem. This lack of review demonstrates a lack of reflective awareness of the problem-solving process and outcomes. It is recommended that further research involve a wider range of subjects to obtain a more comprehensive picture of critical thinking processes. Furthermore, the development of GeoGebra-assisted learning tools specifically designed to train each indicator of students' critical thinking processes should be further investigated to better understand the extent to which GeoGebra can be used to enhance critical thinking processes.

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