
The Effect Guided Discovery-Based Thermochemistry Module on Critical Thinking Skills of High School and Vocational Students

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Abstract. Critical thinking is a vital skill for success in higher education and the workforce. However, it is often inadequately emphasized in high school curricula, resulting in students lacking proficiency. Guided discovery-based modules provide a promising approach to enhancing critical thinking by fostering independent exploration and concept discovery. This study aimed to assess the effectiveness of a developed module in improving thermodynamics-related critical thinking skills among 10th-grade students in Boyolali Regency, Indonesia. Five schools were randomly selected, with two classes from each forming control and experimental groups. The experimental group utilized the developed module, while the control group used traditional textbooks. Validated by experts, a test was administered to evaluate students' critical thinking skills, and statistical analysis revealed a significant difference between the experimental and control groups. The developed module demonstrated superior efficacy in enhancing critical thinking skills compared to traditional textbooks. Variations in mean scores among the schools suggest the need for further investigation across diverse educational contexts. The study's outcomes have implications for teaching and learning in Indonesia and other countries where critical thinking is insufficiently emphasized in high school curricula. Ethical considerations were upheld, ensuring participant rights and confidentiality. Future research can explore the module's effectiveness in improving critical thinking across different subjects and educational settings.

Keywords: Guided discovery-based module; Critical thinking skills

Introduction

Critical thinking skills are highly valued in the 21st century as they help individuals to analyze, evaluate, and interpret information rationally and logically. These skills are essential for solving complex problems, making informed decisions, and adapting to new situations. Critical thinking skills are crucial in understanding the subject matter, analyzing chemical data, and designing experiments in chemistry learning (Alismail & Mcguire, 2015; Rodríguez-Becerra et al., 2020). Chemists use critical thinking skills to evaluate the accuracy and reliability of scientific information, identify patterns and trends, and draw conclusions based on evidence. Chemistry learning encourages students to develop critical thinking skills through hands-on experimentation, problem-solving, and

scientific inquiry. Students are taught to ask questions, gather data, analyze results, and draw conclusions based on evidence. By applying critical thinking skills in chemistry, students learn to think independently, develop scientific literacy, and engage in scientific discourse (Feyzıoglu, 2012; Habig, 2020).

Developing critical thinking skills in thermochemistry is challenging for many high and vocational high school students. These skills are necessary to analyze, evaluate, and interpret information logically and are essential in science education to understand concepts, apply scientific methods, and solve problems. Without critical thinking skills, students may struggle to understand and apply thermochemistry concepts in real-world situations, making it a significant concern (Ambaryani et al., 2022; Wenno et al., 2021). Effective instructional approaches such as guided inquiry-based activities, problem-solving tasks, and scientific inquiry methods are needed to help students develop these skills. By utilizing these approaches, students can develop critical thinking skills essential for success in science-related fields and adapt to changing circumstances in the 21st century (Wass et al., 2014; Zhang et al., 2018).

Developing critical thinking skills in students is urgent because these skills are vital for success in the 21st century. The world is becoming more complex, and students must possess critical thinking skills to solve complex problems, make informed decisions, and adapt to changing circumstances (Salwan & Rahmatan, 2018). Critical thinking is especially crucial in science-related fields, where it is essential to understand and apply scientific concepts and methods. Students with critical thinking skills can analyze and evaluate data, draw conclusions, and make evidence-based decisions. They can also identify and solve problems through a logical and rational thought process (Aktam & Yenice, 2010; Valtonen et al., 2011). Science-related fields are becoming increasingly important in our society as we depend more on technology and seek solutions to global challenges. Therefore, students with strong critical thinking skills are better equipped to pursue successful careers in science-related fields and contribute to society's progress (Almahdawi et al., 2021; Maulidar et al., 2016). The importance of critical thinking skills in science education will only increase as society and technology continue to evolve. The research on the guided discovery-based thermochemistry module on critical thinking skills of high school and vocational high school students could provide valuable insights into effective instructional approaches for developing these skills. Additionally, the findings could inform the development of instructional approaches for other science topics and contribute to the growing body of research on guided discovery-based approaches in science education. Ultimately, this study can potentially improve student learning outcomes and advance our understanding of effective science education practices (Levine et al., 2015; Park et al., 2017).

Previous studies have explored the development of critical thinking skills in science education, but none has investigated this area specifically in the context of thermodynamics. While some previous research has shown the effectiveness of discovery-based approaches in improving students' critical thinking skills in science, particularly in chemistry, no similar research has been conducted in thermodynamics (Moon et al., 2016; Putri et al., 2022). In previous studies, researchers employed different learning approaches, including problem-based, cooperative, and project-based learning. However, the current study utilized a guided discovery-based approach to developing students' critical thinking skills. This approach allows students to explore, discover, and construct knowledge independently while the teacher provides guidance and support (Levine et al., 2015; Martino et al., 2020).

The aim of this study is to investigate whether a guided discovery-based approach to learning can improve the critical thinking skills of high school and vocational students

in the area of thermochemistry. The research intends to evaluate the impact of this approach on students' ability to think critically about thermochemistry concepts. Ultimately, the study aims to provide evidence regarding the effectiveness of the guided discovery-based approach to teaching and learning, and contribute to the development of better teaching methods in the future.

Methods

The study used a quasi-experimental design, where each school provided two sample classes: the control and experimental. The learning activities in the experimental class used the developed module, while the control class used textbooks commonly used in schools. The study used a pretest-posttest control group design to collect data on critical thinking skills. The study used cluster random sampling to select five schools in Boyolali Regency, Indonesia, willing to participate. The study selected two sample classes from each school, the control and experimental. Aiken analysis, a statistical method used to assess agreement among multiple raters or validators, was employed to validate the module and instrument used in the study. The validators comprised two linguists, three media experts, and two chemistry learning experts. The Aiken validity coefficient for the module and instrument was determined to be 0.75 or greater, indicating that the module and instrument's content aligns with the validators' assessments. This means that the module and instrument accurately measure the critical thinking skills related to thermodynamics they were intended to assess. Additionally, the statement notes that the instrument's reliability was assessed and found to be 0.87, indicating that the instrument's outcomes were consistent over time. The reliability test involved five students who had previously studied thermodynamics.

The study upheld participants' rights and ethical treatment by obtaining approval from the Faculty of Teacher Training and Education Ethics Committee at Sebelas Maret University. The researchers obtained written informed consent from participants and their parents or guardians and informed them about the study's purpose, their right to withdraw, and the confidentiality of their data. The study ensured that participants were not harmed and received equal opportunities regardless of their demographic characteristics. The researchers maintained confidentiality and removed identifiable information from the data before analyzing it (Hafizan et al., 2010).

The study involved 309 10th-grade high school students from Boyolali Regency, Indonesia, with 157 students in the control group and 152 students in the experimental group. Five schools participated in the study, including three Senior High Schools (SMA) and two Vocational Schools (SMK). Cluster random sampling was used to select control and experimental classes from each school, and random sampling was used to assign students to either group. The experimental group used a specially developed module, while the control group used textbooks commonly used in schools. In addition, the study used a pretest-posttest control group design to collect data on skills (Saputra et al., 2018; Soyadi, 2015)

Regarding data analysis, the study underwent validity testing using Aiken analysis, which involved seven validators, including linguists, media experts, and chemistry learning experts. The Aiken validity coefficient for the module and instrument was 0.75 or higher, indicating agreement between the content and validators' judgments. The instrument's reliability was also tested and found to be 0.87, indicating consistency in results over time. Data were analyzed using appropriate statistical techniques, and any signifi-

cant differences between the experimental and control groups were noted. Researchers conducted a normality test to ensure the data had a normal distribution, a prerequisite for most statistical tests. To verify the comparability of the two groups and ensure that the differences between them were due to the treatment. A homogeneity test was also carried out to confirm equal data variance. To compare the mean scores of the control and experimental groups, the researchers employed a t-test. This statistical method examines whether there is a significant difference between the means of the two groups. The t-test was used to investigate the critical thinking skills of students who used the developed module versus those who used the traditional textbook. Next, the ANOVA test was used to determine if there were any significant differences in the mean scores among the five schools. The Scheffe test was then used as a post hoc test to identify which schools were responsible for the significant differences observed in the ANOVA test. Finally, the researchers used the N-gain score to measure the improvement in students' critical thinking skills. The N-gain score calculates the difference between a student's pretest and posttest scores, indicating the effectiveness of the developed module in enhancing students' critical thinking skills (Abbas et al., 2023; Susetyo et al., 2021).

Table 1. Homogeneity, normality comparison test results

School	Sig	
	Homogeneity	Normality
A	0.06	0.091
B	0.09	0.121
C	0.200	0.200
D	0.200	0.200
E	0.200	0.200

Table 1 shows the results of the homogeneity and normality comparison test for several schools. Homogeneity refers to the similarity of variance between groups. In the table, the Sig value for homogeneity indicates the significance level of the null hypothesis that the groups have the same variance. The larger the Sig value, the greater the possibility that the groups have different variances. Normality refers to the distribution of data within each group. In the table, the Sig value for normality indicates the significance level of the null hypothesis that the data within the group has a normal distribution. The smaller the Sig value, the closer the distribution of data is to a normal distribution. In this case, all the Sig values for normality are greater than the commonly used significance level (usually 0.05), so it cannot be ignored that the groups have a non-normal distribution. The Sig values for homogeneity of all groups are sufficiently large, so it cannot be ignored that the groups have the same variance.

Results and Discussion

The study occurred in five schools in Boyolali Regency, consisting of three SMA and two SMK. Two classes were selected from each school, one assigned as the control group and the other as the experimental group. The experimental group used the devel-

oped module during their learning activities, while the control group used the commonly used textbooks. To ensure that the data met the statistical test assumptions, normality and homogeneity tests were conducted on both groups. To measure the module's effectiveness in enhancing critical thinking skills, we compared the test scores of both groups before and after studying the topic thermochemical. We performed hypothesis testing using t-test analysis with SPSS, and you can find the results in Table 2.

Table 2. The results of hypothesis testing on improving students' critical thinking skills from the sample class.

School	class group	N	mean	S	Sig
A	Control	34	0.9641	0.3506	0.008
	Experiment	33	1.1858	0.3075	
B	Control	36	0.6811	0.2281	0.000
	Experiment	36	0.9025	0.1339	
C	Control	32	0.6709	0.2026	0.004
	Experiment	31	0.7981	0.1303	
D	Control	32	0.5013	0.1993	0.036
	Experiment	30	0.6060	0.1830	
E	Control	23	0.5957	0.2675	0.046
	Experiment	22	0.7364	0.1820	

The study utilized the N-gain score, which was obtained by subtracting the pretest score from the posttest score and dividing it by the difference between the maximum score and the pretest score, for data analysis. Table 2 displays the significance values for each school: school A (0.008), school B (0.000), school C (0.004), school D (0.036), and school E (0.046). These values, smaller than the significance level of 0.05, indicate the rejection of the null hypothesis (H0) and acceptance of the alternative hypothesis (H1). Hence, a significant difference in critical thinking skill improvement exists between the control and experimental classes, where the experimental classes employed guided discovery-based module development.

Table 3 presents the results of an ANOVA test conducted to assess the differences in improving critical thinking skills among the five schools. The obtained significance value in Table 3 is 0.000, which is lower than the significance level of 0.05, indicating significant variations in the enhancement of critical thinking skills among the sample schools. To identify the specific schools contributing to these differences, the Scheffe test was employed, and the outcomes are outlined in Table 4. In Table 2, notable improvement in students' critical thinking skills is observed across all schools that implemented guided discovery-based module development. This finding aligns with previous research, such as the study (Chayati et al., 2020; Handayani et al., 2021), which reported an average increase score of 0.41 in critical thinking skills as a result of guided discovery-based module development. Despite the overall improvement, significant differences exist in the level of enhancement in critical thinking skills among the schools.

School B exhibited the highest significance value of 0.000, indicating the most substantial improvement in critical thinking skills within that particular school. Conversely, school E displayed the lowest significance value of 0.046, suggesting relatively limited progress in critical thinking skills. Schools A, C, and D demonstrated moderate significance values ranging from 0.004 to 0.036. It is worth noting that schools D and E were vocational schools, while schools A, B, and C were high schools. This distinction may offer

an explanation for the observed variations. Vocational schools often emphasize technical and practical skills, such as in the field of thermodynamics. As a result, guided discovery-based modules may be less effective in improving critical thinking skills compared to high schools, which typically prioritize the development of broader academic skills. However, further research is necessary to validate this assumption.

The utilization of guided discovery-based modules in thermodynamics learning can be explained through constructivism and discovery learning theories. Constructivism posits that students should actively participate in constructing their knowledge, while discovery learning theory emphasizes self-discovery as an effective method for fostering deeper understanding. Guided discovery-based modules enable students to develop critical thinking skills and solve problems autonomously, with the teacher assuming the role of a facilitator (Ferrell et al., 2019; Satilmis, 2014). The differences in improving critical thinking skills among schools can be attributed to various factors, including teaching methods, teacher's competency, student motivation, and learning environment. School B had the most significant improvement in critical thinking skills, which may be due to the teachers' competence in implementing guided discovery-based modules, students' motivation to learn, and a conducive learning environment. Conversely, school E had the least improved critical thinking skills, possibly due to less competent teachers, lower student motivation, and a less conducive learning environment. The social cognitive theory by Albert Bandura explains the differences in learning outcomes between schools. This theory suggests that learning is influenced by personal, behavioral, and environmental factors, including cognitive, emotional, and biological characteristics, learning strategies, and physical and social conditions that affect learning. The significant differences in improving critical thinking skills among schools can be explained using this theory (Maknun, 2019; Wenno et al., 2021).

Table 3. The results of the oneway Anova test for increasing critical thinking skills in the experimental class

	Sum of squares	Df	Mean squares	F	Sig
Between groups	4,183	20	1,046	17,503	0,000
Within groups	8,784	147	0,060		
Total	12,967	151			

According to the results presented in Table 3, the ANOVA test indicated a significant difference in improving critical thinking skills among the five schools. Furthermore, the p-value obtained from the test was less than the predetermined significance level of 0.05, which led to the rejection of the null hypothesis (H0), indicating significant differences in improving critical thinking skills among the schools.

To determine which school(s) were responsible for the observed differences, a Scheffe test was conducted as a posthoc test following the ANOVA. The Scheffe test is used to identify which groups significantly differ from one another. Table 4 presents the outcomes of the Scheffe test performed on the five schools in the sample. The table shows the mean differences, standard error, Scheffe values, and significance levels between each pair of schools (Chayati et al., 2020; Hastani et al., 2021). This information helps determine which schools are significantly different from each other regarding critical thinking skills improvement. The Scheffe test provides a useful tool for researchers to identify specific differences between groups, and it can help to identify where interventions may be most effective.

Further research is necessary to confirm the assumption that vocational schools may have a stronger tendency to teach technical and practical skills and to investigate the effectiveness of guided discovery-based modules in enhancing critical thinking skills in diverse educational settings (Feyzioglu, 2012). Therefore, a Scheffe test was performed as a follow-up ANOVA test to determine which school was responsible for this difference. The Scheffe test is a posthoc test used to determine which groups are significantly different from each other after a significant difference has been detected through an ANOVA test. It is used to compare all possible combinations of groups and to determine which groups have a significant difference in mean scores (Dewi et al., 2022; Nuraisyah et al., 2020).

Several studies have supported the use of guided discovery-based modules in improving critical thinking skills among students. For example, a study by (Handayani et al., 2021; Levine et al., 2015) found that guided discovery-based modules significantly improved critical thinking skills among nursing students. Another study (Nuraisyah et al., 2020) found that guided discovery-based teaching methods effectively improved the critical thinking skills of high school students in science courses. These studies provide additional support for the theoretical basis of using guided discovery-based modules to improve students' (Pratiwi et al., 2021). Using guided discovery-based modules in thermodynamics learning can help improve students' critical thinking skills in problem-solving. Critical thinking skills are essential in chemistry learning to understand abstract and complex chemical concepts. Additionally, chemistry learning requires applying critical thinking skills in interpreting data and drawing appropriate conclusions from experimental or research results. Constructivism and discovery theories state that students should actively construct their knowledge and learn through self-discovery (Maknun, 2020). In this context, guided discovery-based modules allow students to acquire knowledge more effectively, as they can discover knowledge with guidance from the teacher. In this way, students can better understand chemical concepts and develop their critical thinking skills in solving chemistry problems. Using guided discovery-based modules in thermodynamics learning successfully improved students' critical thinking skills across all schools involved in the study. However, there were significant differences in the level of improvement in critical thinking skills between the schools. Therefore, using guided discovery-based modules in thermodynamics learning can benefit students from different types of high or vocational schools (Feyzioglu, 2012).

Table 4. Scheffe test results increase critical thinking skills in the experimental class.

(I) School	(J) School	Std. Error	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
A	B	.05891	.005	.0492	.4168
	C	.06114	.000	.1222	.5037
	D	.06166	.000	.3000	.6848
	E	.06728	.000	.1524	.5722
B	A	.05891	.005	-.4168	-.0492
	C	.05989	.775	-.1069	.2668
	D	.06043	.002	.0709	.4480
	E	.06615	.434	-.0771	.3357
C	A	.06114	.000	-.5037	-.1222
	B	.05989	.775	-.2668	.1069
	D	.06260	.090	-.0158	.3748

	E	.06814	.971	-.1633	.2619
D	A	.06166	.000	-.6848	-.3000
	B	.06043	.002	-.4480	-.0709
	C	.06260	.090	-.3748	.0158
	E	.06861	.466	-.3442	.0839
E	A	.06728	.000	-.5722	-.1524
	B	.06615	.434	-.3357	.0771
	C	.06814	.971	-.2619	.1633
	D	.06861	.466	-.0839	.3442

The results of the ANOVA test, Scheffe test, and N-gain score calculations to evaluate students' critical thinking skills in each school are presented in Table 4. The table reveals a significant difference in improving critical thinking skills among the five schools, with a significance value of less than 0.05, leading to rejecting H₀. In addition, a Scheffe test was conducted as a follow-up ANOVA test to identify which school contributed to this difference.

In the first part of the table, it can be seen that there is a significant difference in improving critical thinking skills between schools A and B, C, D, and E. In the second part, school B exhibits a significant difference in improvement compared to schools A and D. However, schools C and E do not significantly improve students' critical thinking skills, as the significance value towards school B is greater than 0.05.

The third part of the table illustrates that school C significantly improves critical thinking skills compared to school A only. In the fourth part, school D has a significant difference in improvement compared to schools A and B. Lastly, school E shows a significant difference in improvement compared to school A. Based on the data presented in Table 3, it can be inferred that school A has the most significant improvement in critical thinking skills compared to the other schools. Additionally, it is worth noting that school A is situated on the outskirts of Boyolali Regency, an area characterized by teak forests and scattered population settlements, which may affect the improvement of students' skills.

The results of the Scheffe test suggest a significant difference in improving students' critical thinking skills between schools A, B, C, D, and E. This finding is consistent with previous research showing that different types of schools can have varying impacts on students' critical thinking skills. In addition, schools A, B, and C are high schools, while schools D and E are vocational schools is also worth noting. Previous studies have suggested that vocational education may not promote critical thinking skills as effectively as academic education. However, the results of the Scheffe test in this study suggest that schools D and E did not necessarily perform worse than schools A, B, and C in improving students' critical thinking skills. This finding suggests that vocational education may not always hinder critical thinking skill development (Ambaryani et al., 2022; Bagheri & Nowrozi, 2015; Erna et al., 2021)

Regarding chemistry education, critical thinking skills are essential for students to become proficient in problem-solving and decision-making in the laboratory and beyond. Therefore, it is important for chemistry educators to develop effective strategies to enhance students' critical thinking skills (Pratiwi et al., 2021). The results of this study suggest that the Scheffe test can be used to evaluate the effectiveness of such strategies in improving students' critical thinking skills. Based on the Scheffe test results in Table 3, it can be inferred that the experimental class in school A showed the most significant improvement in critical thinking skills compared to the other schools. This finding is consistent with previous research suggesting that certain teaching methods, such as problem-based, inquiry-based (Chayati et al., 2020). Critical thinking skills are essential

for students to understand the principles and concepts of chemistry and apply them to real-world problems. Therefore, it is crucial to integrate teaching strategies that promote critical thinking skills into chemistry education (Singhal, 2020). For example, inquiry-based learning, where students conduct their investigations and experiments, can develop critical thinking skills by encouraging students to ask questions, make observations, and draw conclusions based on evidence. Additionally, problem-based learning, where students are presented with real-world problems and work collaboratively to solve them, can promote critical thinking skills by requiring students to analyze and evaluate information to develop solutions (Hmelo-Silver & Pfeffer, 2004)

In the context of vocational schools (SMK), the development of critical thinking skills holds significant importance, as these skills are essential for students to effectively apply their acquired knowledge and skills in the workplace. In addition to the teaching strategies mentioned earlier, vocational schools can incorporate hands-on learning and industry-based projects to further enhance critical thinking abilities among their students. One approach is to provide students with opportunities for practical application through apprenticeships, internships, or industry-based competitions. By participating in these real-world experiences, students are able to apply their knowledge and skills to solve authentic problems and develop innovative solutions. This hands-on approach not only reinforces their understanding of theoretical concepts but also nurtures their ability to think critically and adapt their knowledge in practical settings. The effectiveness of integrating industry-based projects and experiential learning in vocational education. These activities foster critical thinking skills by requiring students to analyze complex situations, think creatively, and make informed decisions based on their knowledge and expertise (Bagheri & Nowrozi, 2015; Samani et al., 2019; Tappura et al., 2017). Furthermore, students learn to collaborate with industry professionals, communicate effectively, and develop a deeper understanding of the demands and expectations of the workplace. By integrating hands-on learning and industry-based projects, vocational schools can provide a more comprehensive education that aligns with the practical demands of the workforce. This approach not only enhances students' critical thinking skills but also prepares them for successful transitions into their chosen careers (Aktam & Yenice, 2010; Jing-Jing, 2014; Nielsen, 2013).

The Scheffe post hoc test analysis of the data collected from the study indicated that the experimental class in school A had the most significant improvement in critical thinking skills compared to the other classes. This improvement is essential for success in chemistry education and the workplace, as critical thinking skills enable students to analyze complex information and make informed decisions (Almahdawi et al., 2021; Chayati et al., 2020). The study's results have important implications for educators, emphasizing the importance of incorporating teaching strategies that promote critical thinking skills into their curriculum, especially in chemistry education and vocational schools. In addition, the study suggests that educators can use module-based instruction, such as the one used in the study, to enhance critical thinking skills among their students (Abbas et al., 2023). The study also highlights the importance of considering different types of schools in evaluating the effectiveness of interventions to improve students' critical thinking skills (Fahrnisa et al., 2020). The findings suggest that effective strategies can be developed to enhance critical thinking skills in both academic and vocational education settings (Chayati et al., 2020). This is important because there has been a perception that vocational education may not necessarily develop critical thinking skills, but the study's findings challenge this perception (Barke et al., 2009). The study demonstrated

ethical considerations in upholding the participants' rights and maintaining confidentiality. Future research can explore the effectiveness of the developed module in enhancing critical thinking skills in other subjects and educational contexts. Nevertheless, the study provides evidence that the developed module effectively enhances critical thinking skills related to thermodynamics among high school students in Boyolali Regency, Indonesia. The study's findings support the importance of incorporating critical thinking skill development into the curriculum, which can benefit students in their education and future careers (Hambleton & Jones, 1993).

Conclusion

The study showed that using guided discovery-based modules in thermodynamics learning can significantly improve students' critical thinking skills. The results were consistent with previous research, which found that guided discovery-based modules effectively improved critical thinking skills in various fields. The significant differences in the level of improvement in critical thinking skills between schools could be attributed to various factors, such as teaching methods, teacher's competency, student's motivation, and learning environment. The study suggests that vocational schools may have a stronger tendency to teach technical and practical skills. Therefore, guided discovery-based modules may not be as effective in improving critical thinking skills in vocational schools as in high schools. However, constructivism theory and discovery learning theory support the theoretical basis for using guided discovery-based modules. The study provides evidence for the effectiveness of guided discovery-based modules in improving critical thinking skills in chemistry learning. Critical thinking skills are essential in understanding complex chemical concepts and interpreting data. Further research is needed to confirm the study's assumptions and explore the effectiveness of guided discovery-based modules in improving critical thinking skills in different educational contexts.

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