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Students' Critical Thinking on Thermodynamics: Gender and Conceptual

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ABSTRACT

Purpose of the study: This study aims to analyze senior high school students' critical thinking skills in thermodynamics and explore gender-based differences in these skills.

Methodology: A quantitative approach was employed with purposive sampling involving 132 students (34.1% male, 65.9% female) who had studied thermodynamics with the same teacher. Data were gathered using five essay questions designed to assess critical thinking components, including analysis, evaluation, inference, deduction, and induction. The collected data were analyzed to determine the level of critical thinking skills and potential differences between genders.

Main Findings: The results showed that students' critical thinking skills were generally low across all components: analysis (36.2%), evaluation (30.0%), inference (19.8%), deduction (28.3%), and induction (32.0%). While differences in critical thinking skills between male and female students were observed, they were not statistically significant.

Novelty/Originality of this study: This study provides a detailed analysis of students' critical thinking skills in thermodynamics, highlighting specific weaknesses in key components. It offers a new perspective by examining gender-based differences in critical thinking, which are rarely explored in the context of physics education. The findings serve as a foundation for designing targeted educational strategies to address these deficiencies and improve critical thinking skills in science learning.

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1. INTRODUCTION

Education is a fundamental requirement for humans. Through the education they acquire, humans equip themselves to navigate their existence [1]. The current objective of education is to cultivate persons who possess the skills and abilities necessary to compete effectively in the 21st century [2]. We have unrestricted access to a wide range of information through the internet, yet there needs assurance of the veracity of the news we encounter. There is a proliferation of information from diverse sources, a significant portion of which may need to be updated, complete, or lacking credibility [3]. In order to effectively utilise this knowledge, individuals must assess the data and sources of information. Proficiency in assessing and selecting the appropriate data necessitates applying critical thinking skills [4].

An individual who can think critically only accepts the facts surrounding them, substantiates them, and attempts to demonstrate that the information is valid and accounted for [5]. Critical thinking skills are the most crucial aspect of intellectual development [6]. Critical thinking skills are essential when solving problems and

making decisions that impact an individual. Hence, the acquisition and utilisation of critical thinking skills are crucial and should be employed by students at all educational stages [7].

Developing critical thinking skills is crucial for enhancing learning outcomes, as they are internal factors that play a significant role in the learning process [8]. Critical thinking is especially significant in physics, including the study of thermodynamics, as it enables students to analyze complex phenomena and apply logical reasoning to solve problems [9]. Thermodynamics, which deals with the principles of energy transfer and system interactions, provides a unique context where critical thinking is vital for understanding and applying scientific concepts in real-world scenarios.

Students need to possess strong critical thinking skills as a fundamental asset in order to adapt to the ever-evolving and progressive nature of contemporary society [10]. Thinking involves the mind holding questions and answers while connecting knowledge in a suitable manner. The cognitive process involves manipulating and transforming information during the act of thinking [11]. Critical thinking is the cognitive skill that allows individuals to make decisions or draw conclusions based on logical reasoning supported by empirical evidence [12]. The conclusions made are by assessments based on empirical evidence.

According to various academic journals, critical thinking can be defined differently. Dewey (1909) describes critical thinking as the active, persistent, and thorough examination of a belief or piece of knowledge that is commonly accepted, analyzing the reasons that underlie it and the subsequent conclusions that arise from it [13]. By Dewey's perspective, Glaser (1941) proposed a definition of critical thinking as follows: (1) a disposition towards engaging in profound reflection on issues and phenomena within one's sphere of experience; (2) familiarity with methods of analysis and logical reasoning; (3) the ability to implement these methods [14]. According to Dewey and Ennis (1991), critical thinking is a rational and reflective cognitive process used to make decisions regarding beliefs or actions. Being rational involves holding beliefs and opinions supported by adequate, accurate, and pertinent evidence. On the other hand, being reflective entails carefully and thoroughly considering all possible solutions to a problem before reaching a decision [15].

According to The National Council for Excellence in Critical Thinking, as stated by Theodore M. Tuanakota [16], critical thinking is a disciplined cognitive process that stems from the capacity and skill to conceptualize, apply, analyze, synthesize, and evaluate information acquired through reflective observation, communication, and action [16]. According to Jose [17], analysis, evaluation, inference, deductive, and inductive are among the key indicators of critical thinking skills.

Thermodynamics serves as an ideal subject for evaluating critical thinking due to its reliance on both conceptual understanding and quantitative analysis. The study of thermodynamics challenges students to integrate knowledge from various topics, such as energy conservation and entropy, requiring them to employ higher-order thinking. Understanding how students' critical thinking skills develop in this domain can provide valuable insights for educators and curriculum designers.

The study utilized critical thinking indicators suggested by Jose [17] as a tool for assessing critical thinking. The objective of this study is to examine the critical thinking skills of students. The study also examines students' critical thinking skills according to their gender. The research must be conducted to provide valuable information for educators and other stakeholders, enabling them to enhance critical thinking abilities and create effective learning methodologies. One of the determinants of success in learning is the teacher. Teachers must be innovative in education, which is hoped will produce quality resources.

2. RESEARCH METHOD

This study employs a quantitative descriptive research design to analyze and present the status of critical thinking skills in senior high school students, specifically related to thermodynamics. Quantitative descriptive research is commonly used to collect numerical data, analyze it, and present findings in a clear and interpretable manner [18]. The objective of this research is to observe, analyze, and describe the level of critical thinking among students, and to explore how gender may influence these skills. Conclusions will be drawn based on the phenomena observed during the research process [19].

The research was conducted at a senior high school, involving two science classes, which are taught using the 2013 curriculum. The population for this study consists of 132 students, with 34.1% male and 65.9% female, who have studied thermodynamics under the same teacher. The selection of the sample was done using purposive sampling, ensuring that all students in the sample had been taught thermodynamics using the same teaching approach.

Data collection was carried out using five essay questions designed to assess various indicators of critical thinking skills. These indicators include analysis, evaluation, inference, deductive reasoning, and inductive reasoning. Each essay question is formulated to guide students in demonstrating their critical thinking abilities by addressing different aspects of thermodynamics. The maximum score for each indicator is as follows: 40 for analysis, 44 for evaluation, 23 for inference, 18 for deductive reasoning, and 12 for inductive reasoning, making the cumulative score for all five questions 137 points. The scores are then converted into percentages to represent

each student's critical thinking abilities, with the total possible percentage being 100%. Students were given 120 minutes to complete the test.

The data collected from the essay responses will be analyzed quantitatively. Descriptive statistics, such as mean, median, and standard deviation, will be used to summarize the performance of students on each critical thinking indicator. Additionally, inferential statistics will be employed to examine potential gender differences in critical thinking skills, determining if there are any statistically significant disparities.The indicators utilized in this study comprise:

Table 1. Student Knowledge Desriptor Based on Critical Thinking Skills Indicators

No	Indicator CTS	Definition
1	Analysis	To research ideas, to identify assumptions, reasons and claims, and to collect detailed information from tables, graphs, charts, paragraphs, etc. Thoroughness is the key to analysis. It would be wise to construct further judgments, such as inferences and evaluations of the results of simple analyses.
2	Evaluation	To assess the credibility of claims and strength or evaluation skills can also be applied to form judgments about the quality of inference, analysis, interpretation, explanation, choice, conviction and justification.
3	Inferences	To draw conclusions based on reason and evidence. Inferences can be skillfully drawn from a variety of things including information, data, beliefs, opinions, facts, conjectures, definitions, principle pictures, signs, bahaviors, documents, or testimonies.
4	Deductive	Deductive reasoning moves from an assumed truth of a set of beliefs or premises to conclusions that follow necessity
5	Inductive	Inductive reasoning draws justified probabilistic inferences about what is most likely true or most likely not true, given the information and context at hand

The critical thinking markers employed are used to compile and evaluate student responses. Instead of using a person's maximum score, the scores in this study are determined by the value that each critical thinking indicator yields. This aims to as-certain the general degree of critical thinking proficiency among students. The follow-ing is how the data were calculated [20]:

$$P_i = \frac{x}{X} \times 100\% \quad \ldots (1)$$

Description:
P_i = percentage per indicator (%)
x = student score per indicator
X = maximum score per indicator

The method used to make inferences is predicated on the results of the computa-tions. The following table explains the criteria used to categorize students critical thinking skills [11]:

Table 2. Categorize students critical thinking skills

Percentage (%)	Category
80-100	Very High
61-80	High
41-60	Moderate
21-40	Low
0-20	Very Low

The following is an example of a rubric for evaluating students' critical thinking skills when studying thermodynamics content

No	Soal	Pedoman Penilaian	Keterangan Berpikir Kritis	Jumlah Deskriptor
1	Empat mol gas ideal monoatomic suhunya dinaikkan dari $57°C$ Menjadi $97°C$ pada tekanan Tetap. Jika konstanta gas umum $R = 8{,}31\ J/molK$, maka hitunglah a. Perubahan energi dalam b. Usaha yang dilakukan oleh gas c. Kalor yang diperlukan	*Penyelesaian* *Diketahui:* $n = 4\ mol$ $T_1 = 57 + 273 = 330\ K$ $T_2 = 97 + 273 = 370\ K$ $R = 8{,}31\ J/molK$ *Ditanya:* a. $\Delta U = \cdots ?$ b. $W = \cdots .?$ c. $Q = \cdots ?$ *Jawab:* Untuk menentukanbesarnya usaha dan Kalor maka terlebih dahulu harus di cari perubahan energi dalam a. Perubahan Energi Dalam $\Delta U = \frac{3}{2} nR\,(T_2 - T_1)$	*Analysis(a)* *Analysis (b)* *Analysis (c)* *Analysis(d)* *Evaluasy (a)* *Evaluasy (b)* *Inference(a)* *Interfence (b)* *Deductive(a)* *Deductive(b)* *Inductive(a)*	7 1 1 3 7 1 1 3 3 1 3

Figure 1. An example of rubric for evaluating students critical thinking skills.

3. RESULTS AND DISCUSSION

According to psychologist Glaser [14], critical thinking is an approach that uses the rational use of abilities in situations requiring problem-solving. Ennis [15] char-acterizes the concept as the accurate evaluation of claims and defines it as a logical process and product-oriented phenomenon. According to current conceptualizations, critical thinking is a deliberate, logical process of reflection [21]. Experts disagree about whether incentives, inclinations, and personality features control the development of critical thinking or if it is a learned skill [22]. Jose has honed his critical thinking abilities in analysis, evaluation, inference, and deductive reasoning. There are five thermodynamics-related questions in the distribution of questions. Figure 2 illustrates the critical thinking skills of the students.

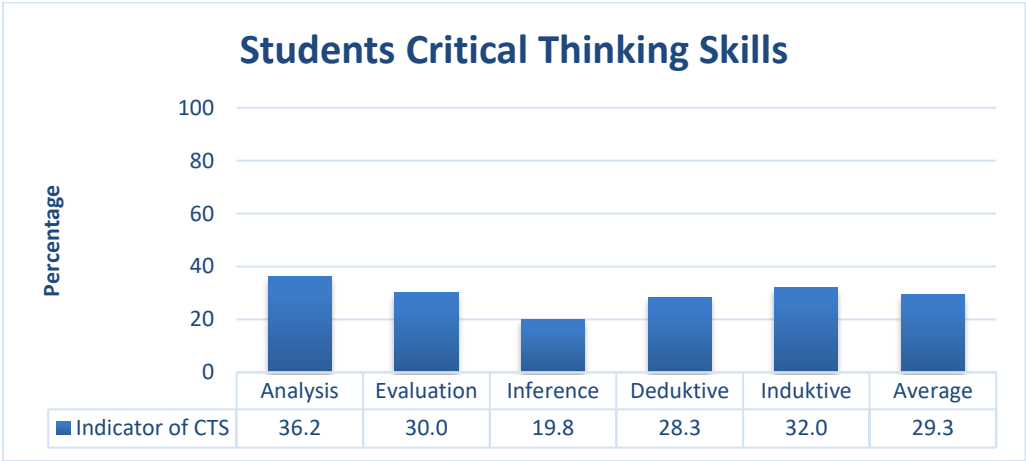

Figure 2. Graph of students' critical thinking skills

The range of values for each indication is relatively wide, as seen in Figure 2. Indicator analysis yielded the highest score percentage (42.2%) compared to other indica-tors, with the critical thinking ability requirement falling into the medium range. With a score of 29.9%, the evaluation indication falls into the low group, with a low cate-gory score of 22.4% in the Inference indicator. The deductive indicator falls into the low range, with a score of 38.9%. The final factor, inductive, needs a better category score of 29.8%. In the low category, the average of all indicators is 22.8%. Students' critical thinking abilities still fall into the low category and require improvement, as seen by their low average scores.

Indicator analysis yielded a poor category average percentage score of 26.3%. Students who can accurately write quantities and symbols, gather comprehensive information, recognize the situation, and solve equations will receive a score in the analytical indicators. In the low group, the indicator evaluation received an average percentage score of 21 percent. Students who can accurately select the units and assess the presented argument will receive a score in the assessment indications.

Inference, which has an average score percentage of 13.4% in the extremely poor group, is the following critical thinking indicator. Students who can decide on a solu-tion to the provided problem and make and determine the results of considerations will receive a score on the inference indicator. In the extremely low group, the deductive indicator received an average score of 29.5%. If students can accurately record the outcomes of the calculation

and give justification for their responses, they will receive a score on the deductive indicator. With an average score percentage of 23.9% in the poor category, the final indicator is inductive. Students who can accu-rately and precisely deduce ideas and write down potential steps to solve the problem will receive a score on the inductive indicator.

The disparities in critical thinking skills between male and female pupils are as fol-lows:

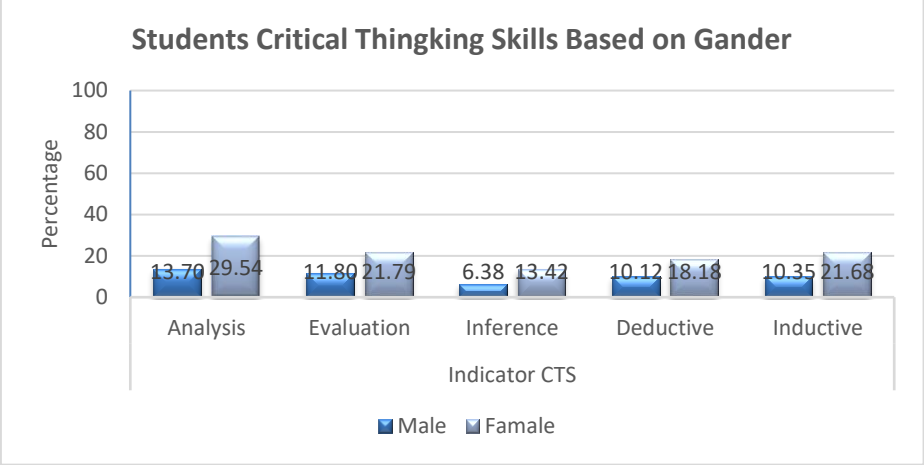

Figure 3. Graph of students' critical thinking skills based on gander

According to the depicted image, it can be inferred that female students exhibit more vital average critical thinking skills than male students across all indicators. The analytical indications reveal that female students' average critical thinking abilities % is 29.54 in the poor category, while male students' average critical thinking capacity is 13.70 in the deficient category. Female students achieved the most significant per-centage of 29.54% on the analysis indicators, while male students achieved 13.70% on the same indicators. Typically, male pupils exhibit inferior cognitive capacities compared to their female counterparts.

While the percentage of female students' cognitive capacities is higher than that of male students, it would be incorrect to consider these findings as evidence that male students are superior to female students [23]. More than merely administering a tex-tual evaluation is required for evaluating critical thinking skills, as critical thinking necessitates engaging pupils in practical tasks[24]. This aligns with Fisher's (2009) assertion that critical thinking is a proficient practice that necessitates analyzing and assessing the outcomes of observations, communication, and other information sources[25]. It involves thinking about assumptions, posing pertinent questions, inferring implications, and engaging in ongoing debates to conclude.

The analysis of students' critical thinking skills on thermodynamics reveals that the inference and evaluation indicators score the lowest, indicating students' difficulties in drawing logical conclusions and assessing thermodynamic processes effectively. These results align with studies highlighting the abstract nature of thermodynamic concepts, such as entropy and the second law, as significant barriers to understanding [26], [27]. On the other hand, the analysis indicator scores relatively higher, reflecting students' ability to interpret data, such as pressure-volume graphs, although they struggle to connect these to underlying principles [28]. Additionally, the deductive and inductive reasoning scores show that students face challenges in applying and generalizing thermodynamic laws to real-world systems, emphasizing the need for instructional methods that integrate conceptual scaffolding and active learning strategies [29], [30]

The analysis of students' critical thinking skills in thermodynamics reveals a significant need for improvement, especially in the inference, evaluation, and inductive reasoning indicators. These areas are essential for understanding complex thermodynamic concepts, such as entropy and the second law of thermodynamics, which are often seen as abstract and challenging for students. The study suggests that while students show better analytical skills such as interpreting pressure-volume graphs. they struggle with applying these skills to deeper, conceptual thermodynamic principles [31], [32]

Interestingly, gender differences were observed, with female students exhibiting stronger critical thinking skills across all indicators compared to male students. This discrepancy is consistent with previous research suggesting that cognitive capacities in critical thinking can vary based on gender, though it should not be used to generalize about the capabilities of either group [32]. In light of these findings, it is recommended to implement instructional methods that integrate conceptual scaffolding and active learning strategies. These strategies could support students in overcoming the challenges they face with abstract concepts in thermodynamics, thus enhancing their ability to engage in critical thinking and problem-solving.

4. CONCLUSION

The research findings show that students' critical thinking skills are generally weak, with low scores across several indicators, including analysis, evaluation, inference, deductive, and inductive reasoning. Female students tend to perform better than their male counterparts, though the difference is small. The lack of applied learning methods that promote critical thinking is a key factor that hinders students' development in this area. The study's results suggest that students' ability to critically assess and evaluate information, particularly in relation to complex topics like thermodynamics, is underdeveloped. For educators, these findings emphasize the need for more active learning strategies that engage students in practical problem-solving and critical analysis. Teaching methods should move beyond simple tests to include collaborative learning activities, real-world case studies, and opportunities for peer feedback. Teachers should be trained in strategies to help foster critical thinking skills, and curricula should be adapted to ensure that critical thinking is woven into the teaching of both theory and practice. Further research could explore alternative assessment methods, such as longitudinal studies or qualitative evaluations, to better understand the development of critical thinking skills and the impact of different teaching approaches. Additionally, the role of technology and interactive learning tools in enhancing critical thinking could be examined further.

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