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# Quantum Learning Boosts Higher-Order Thinking: Enhancing Critical Thinking and Written Argumentation in Secondary Physics

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**ABSTRACT**

**Purpose of the study:** This study aims to examine the effect of the Quantum Learning method on critical thinking skills and written argumentation skills of high school students simultaneously in physics learning, to determine whether this student-centered approach is effective in improving higher-order thinking skills in secondary education.

**Methodology:** This study employed a quasi-experimental non-equivalent control group pretest–posttest design at Kandrian Secondary School. Purposive sampling was used to select 60 eleventh-grade students divided into experimental and control groups. Instruments included essay tests based on Facione's Delphi Report and Toulmin's Argumentation Pattern (TAP), assessed using analytic rubrics. Data were analyzed using SPSS through N-gain, Kolmogorov–Smirnov, Levene's Test, independent and paired samples t-tests, and Cohen's d.

**Main Findings:** The experimental group demonstrated significantly higher improvements in critical thinking and written argumentation skills compared to the control group. N-gain scores were in the moderate category for the experimental class and low for the control class. Independent samples t-test results showed significant differences ($p < 0.05$), while paired samples t-tests confirmed significant pretest–posttest gains. Cohen's d indicated a large effect size of Quantum Learning on both competencies.

**Novelty/Originality of this study:** This study is novel in empirically examining the simultaneous impact of Quantum Learning on both critical thinking and written argumentation skills at the senior high school level. It integrates cognitive and argumentative competencies within a single instructional intervention, advancing existing knowledge by providing combined evidence of effectiveness in a resource-limited secondary education context.



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## 1. INTRODUCTION

Education is no longer solely focused on mastering factual knowledge; it must also develop transversal skills relevant to life and the workplace, such as critical thinking, creativity, collaboration, and communication [1]. These skills, known as Higher Order Thinking Skills (HOTS), are core competencies in modern learning because they enable students to analyze information, solve problems, and make rational decisions in real-world situations [2]-[4]. This approach encourages student interaction, reflection, and engagement in the learning process, so that learning is no longer merely a transfer of information but a process of constructing knowledge that supports the development of higher-order thinking skills [5].

One of the core competencies in HOTS is critical thinking. Ennis defines critical thinking as reflective and rational thinking focused on determining what to believe or do [6]. Furthermore, through the Delphi Report, Facione explains that critical thinking is directed judgment and self-control that results in interpretation, analysis, evaluation, inference, and explanation based on evidence [7]-[9]. These indicators demonstrate that critical thinking is not merely a simple cognitive activity, but a complex process involving reasoning and decision-making. However, various educational studies indicate that students' critical thinking skills are still relatively low, thus becoming a concern in science learning and secondary school education [10]-[12]. Low critical thinking skills impact the quality of learning because students tend to passively receive information, have difficulty evaluating arguments, and are less able to solve problems logically and independently [13]-[15].

In addition to critical thinking skills, 21st-century learning requires students to be able to express and defend ideas logically through written argumentation. In science and language learning, argumentation is seen as an epistemic practice that allows students to construct knowledge through proof, explanation, and evaluation of scientific claims [16]-[18]. The most widely used framework for assessing argumentation quality is the Toulmin Argumentation Pattern (TAP) introduced by Toulmin [19], which includes the components of claim, data, warrant, backing, and rebuttal as the basic structure of scientific reasoning [20]. However, various studies show that students often experience difficulty constructing written arguments; they tend to only express opinions without evidence, do not link scientific concepts as reasons, and rarely provide rebuttals to other arguments [21]. This condition is closely related to critical thinking skills because the argumentation process requires analysis, evaluation of evidence, and drawing rational conclusions, so that the quality of students' arguments is greatly influenced by the level of critical thinking they possess [22].

Although 21st-century education policies emphasize the development of critical thinking and argumentative skills through active learning, practice in high schools is still often dominated by traditional, teacher-centered approaches. Recent studies have shown that lecture-based learning models remain the dominant strategy in many science classes, resulting in suboptimal student cognitive engagement in analysis, evaluation, and reflection [23]. However, a synthesis of recent research confirms that active learning significantly improves higher-order thinking skills compared to conventional methods because it provides space for discussion, problem-solving, and evidence-based argumentation [24], [25]. The mismatch between curriculum demands that expect student-centered learning and learning practices that are still oriented toward delivering material results in limited opportunities for students to develop critical thinking skills and systematically construct scientific arguments. This situation indicates a clear gap between policy and classroom learning implementation, requiring innovation in more participatory and constructive learning strategies [26]-[28]. This condition is particularly evident in physics classrooms, where learning often emphasizes solving numerical problems rather than engaging students in conceptual reasoning and evidence-based explanation. As a result, students may achieve procedural competence but struggle to articulate scientific arguments or critically evaluate physical phenomena.

To address the gap between curriculum demands and classroom learning practices, learning strategies are needed that can activate students cognitively and socially. One relevant approach is Quantum Learning developed by Bobbi DePorter, a learning model that emphasizes the orchestration of various learning interactions to create meaningful, enjoyable, and student-centered learning experiences [29]. Its implementation is structured through the TANDUR stages Trigger, Activate Experience, Name the Concept, Demonstrate Understanding, Use and Reinforce, and Reflect and Celebrate which help students connect prior experiences with scientific concepts, apply their knowledge in practice, and reflect on their learning outcomes. Such an active and contextual learning approach has been shown to enhance student engagement, as students participate in discussions, collaboration, and the exploration of ideas [30]-[32]. In addition, learning that provides opportunities for students to express opinions, defend ideas, and respond to peer arguments has the potential to develop critical thinking skills and the quality of written argumentation because students must analyze evidence, evaluate information, and organize reasoning systematically [29], [33].

Although many international studies place a strong emphasis on developing critical thinking and argumentation skills through various instructional designs, there is a significant gap when it comes to the impact of Quantum Learning methods on both skills simultaneously in senior high school students. First, pedagogical studies have identified effective teaching strategies in fostering critical thinking skills in general secondary education, including structured learning models and explicit learning contexts on decision-making and informed assessment, but without using Quantum Learning as the primary approach [34]. Second, a systematic review of written argumentation shows that although argumentative writing skills are seen as an important competency developed through directed learning in the domains of language and science, research focusing on the direct relationship between specific instructional strategies (e.g., Quantum Learning) and the improvement of written argumentation is still limited explicitly [35]. Third, experimental research conducted with learning technology approaches such as online debates and discussions shows that interventions that combine argumentative discourse with critical thinking exercises can improve written argumentation skills and reflective thinking skills in senior high school students [36]. Fourth, recent literature from Loaiza et al. [37] also emphasized that the development of critical thinking skills requires explicit support for metacognition and argumentative strategies in the science curriculum, indicating the need for more integrated pedagogical interventions. Fifth, cross-disciplinary studies on critical thinking demonstrate the methodological need to connect critical thinking theory with concrete learning practices, but there is still little research that applies and measures the direct impact of specific models beyond general approaches such as problem-solving or collaborative discussion [38]. Overall, the empirical gap is evident in the lack of studies that systematically evaluate Quantum Learning in relation to the combination of critical thinking and written argumentative skills at the high school level, making this research crucial in filling this gap and enriching the evidence base for innovative learning practices in senior secondary education. Despite these findings, limited research has specifically examined the implementation of Quantum Learning in physics classrooms, where the integration of conceptual reasoning, mathematical representation, and scientific argumentation is crucial.

Based on this gap, the novelty of this research lies in the empirical testing of the Quantum Learning method on two interconnected competencies, namely critical thinking and written argumentative skills in high school students, which have generally been studied separately. The urgency of this research is based on the demands of the Independent Curriculum and the need to strengthen HOTS, while learning practices still tend to be traditional and less supportive of argumentative discourse. Therefore, this study aims to analyze the influence of Quantum Learning on students' critical thinking and written argumentation skills simultaneously in physics learning as an effort to present a more effective learning strategy oriented towards 21st century skills.

## 2. RESEARCH METHOD

### 2.1. Research Design

This study used a quasi-experimental approach with a non-equivalent control group pretest-posttest design. This design was chosen because the study was conducted in a naturally formed classroom without individual randomization [39], [40]. Two groups were used in this study: an experimental group treated using the Quantum Learning method and a control group treated with conventional learning by the same teacher in Physics thermodynamics. Critical thinking skills and written argumentation were measured before (pretest) and after (posttest) the treatment to determine differences in learning outcomes between groups.

### 2.2. Population and Sample

The study population was all eleventh-grade students in the current academic year at Kandrian Secondary School, a secondary school serving students from coastal and inland villages. The research sample was selected using a purposive sampling technique, considering the equality of academic ability and the number of students in each class. Two classes were selected as research samples, with one class as the experimental group and one class as the control group. The total number of samples in this study was 60 students, with a relatively balanced distribution across the two groups. The selection of schools in remote areas aims to test the effectiveness of the Quantum Learning method in the context of education with limited resources, so that the results of the study are expected to provide a broader contribution to the development of innovative learning strategies in the 3T (underdeveloped, frontier, and outermost) areas.

### 2.3. Data Collection Techniques

Data in this study were collected through two main techniques: written tests and supporting learning documentation. The written test was used to measure students' critical thinking and written argumentation skills before and after the treatment (pretest–posttest). The critical thinking skills instrument was developed based on Peter A. Facione's critical thinking framework, developed through the Delphi Report [7], which includes indicators of interpretation, analysis, evaluation, inference, and explanation.

Meanwhile, the written argumentation skills instrument was developed by adapting Stephen Toulmin's Toulmin Argumentation Pattern (TAP) framework, which includes claim, data, warrant, backing, and rebuttal components. This model was first introduced in the book, The Uses of Argument, and has been widely adopted in science argumentation research [19].

The instrument, an essay test, was designed to encourage students to analyze contextual problems, construct evidence-based arguments, and provide logical rebuttals. Content validity was assessed by consulting with experts in science education and learning evaluation, while reliability was tested using Cronbach's alpha coefficient.

Table 1. Blueprint of Research Instruments

| Variable | Indicator | Sub-Indicator | N |
|---|---|---|---|
| Critical Thinking | Interpretation | Identifying and clarifying meaning of information | 10 |
| | Analysis | Identifying relationships among statements and evidence | |
| | Evaluation | Assessing credibility of claims and evidence | |
| | Inference | Drawing logical conclusions from data | |
| | Explanation | Justifying reasoning with coherent arguments | |
| Written Argumentation | Claim | Stating a clear position or conclusion | 9 |
| | Data | Providing evidence to support claim | |
| | Warrant | Linking evidence with claim logically | |
| | Backing | Strengthening justification with theoretical support | |
| | Rebuttal | Presenting counter-arguments or alternative views | |

Critical thinking skills are structured into 10 questions (Cronbach's alpha, 0.70) and written argumentation is structured into 9 questions (Cronbach's alpha, 0.69), assessed using an analytical rubric. Each indicator is scored on a scale of 0–4 using the following criteria.:

Table 2. Assessment Rubric

| Score | Critical Thinking Skills | Written argumentation skills |
|---|---|---|
| 4 | Demonstrates complete, logical, and evidence-based interpretation, analysis, evaluation, inference, and explanation. | Complete argument (claim, data, warrant, backing, rebuttal) with logical connections and strong scientific evidence. |
| 3 | Demonstrates most indicators correctly, but there are minor gaps in completeness or depth of analysis. | The argument structure is almost complete, but one component is underdeveloped or weak. |
| 2 | Demonstrates basic understanding, but analysis and justification lack depth or consistency. | Contains only simple claims and data without clear logical connections. |
| 1 | The answer is simply descriptive without clear analysis or evaluation. | Conveys only opinions without supporting evidence. |
| 0 | No answer or irrelevant answer. | No relevant arguments. |

### 2.4. Data Analysis Techniques

Data analysis was conducted quantitatively to determine the effect of the Quantum Learning method on students' critical thinking skills and written argumentation skills. First, descriptive statistical analysis, pretest and posttest data were analyzed to obtain the average value (mean), standard deviation, minimum-maximum score, and percentage of improvement in each group (experimental and control). In addition, the improvement in ability was calculated using the N-gain formula to determine the improvement category (low, medium, high). Then, before conducting the hypothesis test, the data was first tested using the Kolmogorov-Smirnov normality test to determine the data distribution (normal if the significance value is > 0.05) [41], [42]. Then, the homogeneity of variance test (Levene's Test) was used to ensure the equality of variance between groups (homogeneous if the significance value is > 0.05) [43], [44]. To test the difference in ability improvement between the experimental and control groups, an independent Samples t-test was used on the posttest score or N-gain if the data was normally distributed and homogeneous [45], [46]. In addition, a Paired Samples t-test was used to determine significant improvements in each group (pretest-posttest). The magnitude of the effect of the Quantum Learning method was calculated using Cohen's d to determine the strength of the effect (small, medium, or large) [47], [48]. All analyses were performed using SPSS statistical software with a significance level of $\alpha = 0.05$.

## 3. RESULTS AND DISCUSSION

### 3.1. Descriptive Analysis

Descriptive analysis was conducted to describe the profile of students' critical thinking and written argumentation skills before and after treatment in the experimental group (Quantum Learning) and the control group (conventional learning). Parameters analyzed included the mean, standard deviation (SD), minimum-maximum scores, and improvement using the N-gain index.

To determine the initial and final picture of students' critical thinking skills in the experimental and control groups, a descriptive analysis was conducted on pretest and posttest scores. This analysis included the mean, standard deviation (SD), and minimum and maximum scores. The results of this analysis provide information regarding the equivalence of the initial abilities of the two groups and the magnitude of improvement after the learning treatment. Table 3 below presents the descriptive statistics of students' critical thinking skills in the experimental and control groups before and after treatment..

Table 3. Descriptive Statistics of Critical Thinking Scores

| Group | Test | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Experimental | Pretest | 54.20 | 8.45 | 38 | 68 |
| Experimental | Posttest | 78.65 | 7.12 | 62 | 90 |
| Control | Pretest | 53.75 | 7.98 | 40 | 67 |
| Control | Posttest | 65.30 | 8.10 | 50 | 79 |

Table 3 shows that the initial critical thinking skills of both groups were relatively equal (Mean ≈ 54). After treatment, the experimental group experienced a more significant improvement (Mean = 78.65) compared to the control group (Mean = 65.30). The relatively stable standard deviation indicates a fairly homogeneous data distribution. The maximum score increase in the experimental group (up to 90) indicates that the Quantum Learning method encouraged the achievement of higher levels of critical thinking skills.

To more accurately determine the level of improvement in critical thinking skills, an N-gain index was calculated for each group. This calculation was used to categorize the level of improvement into low, medium, or high. Table 4 below presents the results of the N-gain analysis of students' critical thinking skills in both groups.

Table 4. N-Gain Analysis of Critical Thinking

| Group | Mean N-Gain | Category |
|---|---|---|
| Experimental | 0.53 | Moderate |
| Control | 0.24 | Low |

The experimental group's N-gain value of 0.53 falls into the moderate improvement category, while the control group's N-gain of 0.24 falls into the low improvement category. This indicates that Quantum Learning contributes more effectively to improving critical thinking skills than conventional learning.

In addition to critical thinking skills, this study also analyzed students' written argumentation skills through a Toulmin framework-based essay test. Descriptive analysis was conducted to examine the differences in initial and final achievement between the experimental and control groups. Parameters analyzed included the mean value, standard deviation, and minimum and maximum scores. Table 5 below presents the descriptive statistics of students' written argumentation skills in the experimental and control groups before and after the treatment.

Table 5. Descriptive Statistics of Written Argumentation Scores

| Group | Test | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Experimental | Pretest | 50.85 | 9.10 | 35 | 65 |
| Experimental | Posttest | 80.40 | 6.95 | 66 | 92 |
| Control | Pretest | 51.10 | 8.75 | 37 | 64 |
| Control | Posttest | 66.25 | 7.88 | 52 | 81 |

Table 5 shows that the initial written argumentation skills of both groups were nearly identical (mean ≈ 51). After the intervention, the experimental group showed significant improvement with an average of 80.40, while the control group only increased to 66.25. The maximum score range in the experimental group reached 92, indicating that students were able to construct more complete and systematic arguments after the implementation of Quantum Learning.

To determine the effectiveness of the improvement in written argumentation skills, an N-gain analysis was conducted on both groups. This index indicates the extent of improvement after the learning intervention. Table 6 below presents the results of the N-gain analysis of students' written argumentation skills in the experimental and control groups.

Table 6. N-Gain Analysis of Written Argumentation

| Group | Mean N-Gain | Category |
|---|---|---|
| Experimental | 0.60 | Moderate |
| Control | 0.30 | Low |

The N-gain value of 0.60 in the experimental group indicates an increase in the moderate to high category, while the control group's 0.30 value is in the low-moderate category. These findings indicate that the

Quantum Learning approach is more effective in improving the quality of students' written argumentation than conventional methods.

Overall, the descriptive analysis results show that the implementation of Quantum Learning resulted in greater improvements in both critical thinking skills and written argumentation skills compared to conventional learning. This improvement was consistently seen in the higher average posttest scores and N-gain index in the experimental group. These findings provide initial indications that an interactive and reflective learning approach contributes positively to the development of high-order thinking skills in high school students.

### 3.2. Hypothesis Testing

Before hypothesis testing, the data were first analyzed through prerequisite tests, including normality and homogeneity of variance tests. All analyses were conducted using SPSS software with a significance level of $\alpha = 0.05$. The Kolmogorov–Smirnov test was used to determine whether the data were normally distributed. Data were declared normally distributed if the significance value (Sig.) > 0.05. Table 7 below presents the results of the normality test for the post-test data on critical thinking and written argumentation skills.

Table 7. Kolmogorov–Smirnov Normality Test Results

| Variable | Group | Sig. | Conclusion |
|---|---|---|---|
| Critical Thinking (Posttest) | Experimental | 0.087 | Normal |
| Critical Thinking (Posttest) | Control | 0.094 | Normal |
| Written Argumentation (Posttest) | Experimental | 0.072 | Normal |
| Written Argumentation (Posttest) | Control | 0.081 | Normal |

The significance values for all variables in both groups were greater than 0.05, thus concluding that the data were normally distributed. Therefore, the analysis can be continued using parametric tests. The homogeneity of variance test was performed using Levene's Test to ensure equality of variance between groups. Data were considered homogeneous if the significance value was >0.05. Table 8 below presents the results of the homogeneity of variance test.

Table 8. Levene's Test of Homogeneity

| Variable | Sig. | Conclusion |
|---|---|---|
| Critical Thinking (Posttest) | 0.118 | Homogeneous |
| Written Argumentation (Posttest) | 0.126 | Homogeneous |

The significance value for both variables is greater than 0.05, so it can be concluded that the variance of both groups is homogeneous. With the normality and homogeneity assumptions met, an Independent Samples t-test can be conducted. This test is used to determine the difference in ability improvement between the experimental and control groups based on posttest scores. Table 8 below presents the results of the Independent Samples t-test.

Table 9. Independent Samples t-test Results

| Variable | t-value | Sig. (2-tailed) | Conclusion |
|---|---|---|---|
| Critical Thinking | 5.82 | 0.000 | Significant |
| Written Argumentation | 6.47 | 0.000 | Significant |

The significance value of both variables was <0.05, indicating a significant difference between the experimental and control groups. This indicates that the Quantum Learning method significantly improved students' critical thinking and written argumentation skills. A paired samples t-test was then conducted. This test was conducted to determine significant improvements in each group (pretest–posttest). Table 10 below presents the results of the paired samples t-test for the experimental and control groups.

Table 10. Paired Samples t-test Results

| Variable | Group | t-value | Sig. (2-tailed) | Conclusion |
|---|---|---|---|---|
| Critical Thinking | Experimental | 12.41 | 0.000 | Significant Increase |
| Critical Thinking | Control | 4.36 | 0.000 | Significant Increase |
| Written Argumentation | Experimental | 14.02 | 0.000 | Significant Increase |
| Written Argumentation | Control | 5.11 | 0.000 | Significant Increase |

The results showed that both groups experienced significant improvement ($p < 0.05$). However, the t-value in the experimental group was significantly higher than in the control group, indicating that the improvement in the experimental group was stronger. To determine the magnitude of the effect of the Quantum

Learning method, Cohen's d value was calculated. Table 10 below presents the results of the effect size calculation.

Table 11. Effect Size (Cohen’s d)

| Variable | Cohen’s d | Effect Category |
|---|---|---|
| Critical Thinking | 1.25 | Large |
| Written Argumentation | 1.38 | Large |

A Cohen's d value > 0.80 indicates a large effect. This indicates that the Quantum Learning method has a strong influence on improving high school students' critical thinking and written argumentation skills.

The finding that the Quantum Learning method significantly improves students' critical thinking and written argumentation skills aligns with student-centered and constructivist learning theories, which emphasize active student involvement in the learning process. Student-centered learning provides space for students to interact, discuss, and construct meaning through reflective activities, which have been empirically proven to enhance higher-order thinking skills such as problem-solving, analysis, and information synthesis, which active learning approaches like Quantum Learning include [49]. Furthermore, this approach is also consistent with the finding that the integration of critical thinking skills into written argumentation learning enriches students' abilities to formulate claims supported by evidence and evaluate reasons logically, because argumentation is an operational manifestation of critical thinking in a written context. [50].

The results of this study also align with previous research showing that active learning interventions, argument-based discussions, and reflective approaches improve both students' critical thinking and argumentation skills. For example, a study implementing debates via a digital platform reported significantly improved high school students' critical thinking and argumentative writing skills, suggesting that structured argumentative activities can improve both evaluative thinking and written reasoning skills [13]. Furthermore, another study confirmed that dialogue-based argumentative strategies in student-centered classrooms resulted in better written argumentation achievement than traditional learning, supporting the relationship between dialogic processes and improved students' complex thinking skills [51].

The main novelty of this study lies in combining the measurement of two core cognitive skills critical thinking and written argumentation in a single evaluative design using the Quantum Learning method in high schools in a remote school context. Most previous studies often separate these two skills or focus on only one variable, without integrating them within a structured learning framework. The use of Quantum Learning, which combines reflective, collaborative, and active student engagement experiences in a real-life context, demonstrates that this method not only improves individual cognitive function but also the structural quality of students' written arguments, simultaneously representing a novel empirical contribution to the 21st-century learning literature.

The implications of these findings point to a strong need to implement learning strategies that are not solely oriented toward content transfer but also stimulate students' active engagement in the process of analysis, evidence evaluation, and logical argumentation, which ultimately correlate with higher-order thinking skills needed in the 21st century. Approaches such as Quantum Learning can be effective pedagogical models for educators, particularly in remote areas where access to formal learning resources may be limited. However, this study also has limitations, including limited generalizability due to the sample being selected from a single geographic and cultural context, and the use of written instruments that may require the inclusion of other authentic assessments such as oral discussion rubrics or portfolios. Future research should consider a wider variety of populations and hybrid learning designs to strengthen the findings and broaden understanding of the mechanisms of critical thinking and argumentation development across educational contexts.

## 4. CONCLUSION

This study aims to examine the effect of the Quantum Learning method on high school students' critical thinking and written argumentation skills in response to the demands of HOTS development in 21st-century learning. The results show that Quantum Learning significantly improves both skills compared to conventional learning, as evidenced by an increase in the N-gain value in the moderate category, a significant difference in the t-test results, and a large effect size. These findings align with the objectives outlined in the introduction, which is to present a learning strategy capable of simultaneously integrating the development of critical thinking and written argumentation in student-centered learning. Going forward, the results of this study have the potential to be developed through integration with digital learning technologies, project-based approaches, or hybrid learning designs to strengthen students' argumentative and reflective practices. Further research is recommended to involve a broader and more diverse sample, use a pure experimental design or longitudinal study, and combine written assessments with authentic assessments such as portfolios and discussion observations to gain a more comprehensive understanding of the development of students' higher-order thinking skills.

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