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Article

Debate-Assisted SSI-PBL: Impact on Students' Critical Thinking, Scientific Attitude, and Academic Stress in Chemistry

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A B S T R A C T

Critical thinking, scientific attitude, and psychological well-being are essential outcomes of chemistry learning, yet Indonesian students' scientific literacy remains low and classroom practice rarely addresses these dimensions together. Problem-Based Learning integrated with Socio-Scientific Issues (PBL-SSI) narrows this gap, and scientific debate was added because claim-evidence-rebuttal argumentation is theoretically expected to sharpen reasoning and ease academic pressure, yet empirical evidence on this combined approach remains limited. This quasi-experimental study (nonequivalent control group design) examined the effect of debate-assisted PBL-SSI on critical thinking, scientific attitude, and academic stress among 68 twelfth-grade students (experimental n=36, control n=32) using tests, questionnaires, and reflections. Both classes showed moderate, non-significant gains in critical thinking (p=0.151) and scientific attitude (p=0.652), but academic stress decreased significantly in the experimental class and increased in the control class (Cohen's d=-1.567; p=0.000). Debate-assisted PBL-SSI shows practical but statistically unconfirmed cognitive benefits, while robustly reducing academic stress, supporting holistic chemistry education.

Keywords: *Academic Stress, Critical Thinking, PBL-SSI, Scientific Debate, Scientific Attitude*

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INTRODUCTION

Students' low critical thinking skills in chemistry learning remain an urgent problem that must be addressed systematically. The 2022 PISA results ranked Indonesia 67th out of 81 countries in scientific literacy with a score of 383, reflecting students' limited ability to integrate scientific concepts with real-world contexts and to apply evidence-based problem solving (PISA 2022 Results Factsheets Indonesia PUBE, 2023). This declining trend indicates that the majority of students still have limited understanding of scientific concepts in depth, particularly in connecting these concepts to real-life contexts.

At the school level, *Rapor Pendidikan* (Education Report) data from SMAS XYZ, South Tangerang for the 2023–2025 period show a concerning phenomenon: although reading literacy achievement is in the very good category and relatively stable, critical reasoning ability shows inconsistent fluctuation, and students' psychological well-being tends to decline year by year. The misalignment between students' basic literacy competence and the demands of higher-order thinking in chemistry learning is a clear indicator of academic problems that simultaneously trigger greater psychological pressure on students.

In the context of chemistry learning, the problem becomes more evident because the learning process is still dominated by conceptual and procedural approaches that are mechanistic in nature. Students are trained more to solve routine problems and memorize theory rather than to understand the meaning of concepts in depth. As a result, chemistry is often perceived as an abstract subject with little relevance to daily life, and students' cognitive engagement becomes shallow. This is in line with the findings of (Sutiani et al., 2025), who identified that barriers to students' critical thinking skills are closely related to classroom interaction patterns that have not been conducive to fostering scientific reasoning.

To address this problem, one strategic approach is the integration of Socio-Scientific Issues (SSI) into the Problem-Based Learning (PBL) model. Issues such as plastic pollution, climate change, and renewable energy contain not only scientific aspects but also social and ethical dimensions that encourage students to think more broadly and critically (López-Fernández et al., 2022). The PBL model positions students as active investigative agents through contextual problem solving, and has been proven effective in enhancing students' cognitive engagement and analytical skills (Yu & Zin, 2023). The integration of the two creates a contextual and meaningful learning environment.

However, the complexity of problems in SSI-based PBL also has the potential to increase students' cognitive load, which can trigger academic stress. Academic stress occurs when learning demands exceed students' adaptive capacity, negatively affecting concentration, working memory, and learning achievement (Choi et al., 2023). In this context, scientific debate becomes a relevant reinforcement strategy. Debate not only trains students to construct arguments based on claims, evidence, and rebuttals, but also provides space for students to express ideas and manage emotions constructively. Through debate activities, students learn to face differences of opinion, build self-confidence, and develop scientific attitudes such as objectivity and scientific responsibility (Majidi et al., 2021).

Prior research on debate-assisted learning has mostly examined its contribution to argumentation and communication skills rather than to chemistry-specific critical thinking or psychological outcomes. Majidi et al. (2021) found that structured in-class debate significantly improved students' argumentation skills, indicating that the claim-evidence-rebuttal structure of debate can be trained explicitly through classroom practice. Within SSI-based instruction, Badeo & Duque (2022) reported that SSI approaches produce a large effect on science learning outcomes, particularly in reasoning and evidence evaluation, while (Varlık, 2025) showed that socio-scientific reasoning contributes to stronger problem-solving skills. However, these studies generally isolate debate, SSI, or PBL as single interventions and evaluate them mainly against cognitive or argumentation outcomes, leaving open how debate functions when embedded within SSI-based PBL and how it affects affective and psychological outcomes such as scientific attitude and academic stress.

Although the effectiveness of PBL, SSI, and scientific debate has been widely studied separately, research that integrates all three into a single comprehensive design to examine critical thinking skills, scientific attitude, and academic stress simultaneously remains very limited, particularly in the context of high school chemistry learning in Indonesia. Most previous studies have focused more on cognitive learning outcomes and have neglected psychological aspects such as academic stress. This gap is significant because SSI-based PBL classrooms are cognitively demanding, so understanding whether debate helps students manage the accompanying psychological burden is as important as understanding its effect on learning outcomes. This study aims to fill this gap by analyzing the effect of an SSI-based PBL model assisted by scientific debate on students' critical thinking skills, scientific attitude, and academic stress levels in chemistry learning.

Based on the background above, the research problems in this study are formulated as follows: (1) Can the application of an SSI-based PBL model assisted by scientific debate improve students' critical thinking skills in chemistry learning? (2) Can the application of an SSI-based PBL model assisted by scientific debate improve students' scientific attitude in chemistry learning? (3) Can the application of an SSI-based PBL model assisted by scientific debate reduce students' academic stress levels in chemistry learning? These three research questions guided every stage of the study's design, implementation, and analysis.

Critical Thinking Skills in Chemistry Learning

In the context of science education, critical thinking is understood as an active and reflective process of analyzing, synthesizing, and evaluating information to make rational decisions (Bibi et al., 2025). Ennis (2011) defines it as reflective and reasonable thinking focused on deciding what to believe or do. (Paul & Elder, 2019) view it as a practice of logical reasoning that is indispensable in education.

In chemistry learning, critical thinking skills are crucial given the abstract, complex, and applicative nature of the subject matter, requiring students not merely to memorize concepts but also to analyze chemical phenomena, evaluate evidence, and make decisions based on scientific data (Kusumaningtyas et al., 2025). (García-Carmona, 2025) shows that scientific thinking and critical thinking, although different in purpose, are symbiotic in science education both share cognitive and metacognitive skills such as evidence analysis, logical reasoning, and argument construction.

The development of critical thinking skills in chemistry learning can be optimized through active learning strategies such as PBL integrated with SSI and scientific debate. This integration encourages students to argue based on evidence, evaluate the validity of data, and consider the ethical and social implications of a scientific problem (Badeo & Duque, 2022; Zeidler et al., 2005). In this study, critical thinking skills were measured through five main indicators based on Ennis's framework: the ability to identify problems, analyze arguments, evaluate evidence and source credibility, draw logical conclusions, and formulate and defend rational solutions.

Relevant studies show that the effectiveness of the SSI approach in developing critical thinking has been widely demonstrated. López-Fernández et al. (2022) found that integrating the plastics issue into chemistry learning was effective in developing students' critical thinking, including critical analysis of information, evidence-based chemical argumentation, rational decision-making, and scientific communication. In their systematic literature review, (Pratiwi et al., 2025) also showed that SSI-based chemistry learning has the potential to improve critical thinking, particularly in the aspects of argumentation, evidence evaluation, and problem solving.

Students' Scientific Attitude

Scientific attitude is a psychological disposition manifested in an individual's mindset, attitudes, and actions when interacting with scientific phenomena (Maharani & Muliati, 2025). This attitude includes tendencies toward objectivity, openness to new evidence, critical evaluation of information, and responsibility in communicating scientific knowledge. In science education studies, scientific attitude develops optimally when students are directly involved in the processes of observation, problem formulation, hypothesis testing, and rational conclusion drawing.

Characteristics of scientific attitude relevant to chemistry learning include curiosity, objectivity, openness to different ideas, and scientific honesty in reporting results without data manipulation (Ardana & Artikel, 2025). Critical and reflective attitudes also play an important role in evaluating the validity of arguments, while responsibility for the impact of science ensures students are aware of the ethical implications of applying chemical knowledge (Bórquez-Sánchez, 2025). As an affective aspect, scientific attitude tends to develop gradually and is influenced by psychological factors and long-term learning experiences, so it cannot develop optimally through short interventions alone (Cai et al., 2024).

Academic Stress in the Context of Chemistry Learning

Based on Lazarus and Folkman's transactional theory Cooper & Quick (2018), stress arises when an individual perceives that situational demands exceed the resources available to cope with them. This process is cognitive-evaluative in nature and involves primary appraisal (assessment of the level of threat) and secondary appraisal (assessment of coping capacity). In the educational context, particularly chemistry learning, academic stress is a multidimensional condition involving psychological, cognitive, and physiological pressure resulting from demands perceived to exceed students' responsive capacity (Szota et al., 2024).

Triggering factors for stress originate from internal dimensions such as low self-efficacy and difficulty in emotional regulation (Bandura, 1994; Gratz & Roemer, 2004), as well as external factors such as learning strategies, academic load, and evaluation pressure (Kaslim & Ashaari, 2022). Social support and a conducive learning environment can function as protective factors that reduce the impact of stress. Adaptive coping strategies, particularly problem-focused coping, have proven effective in helping students face complex academic demands (Folkman, 1997). In this study, academic stress was measured using an operationalization of the Perceived Stress Scale (PSS), which integrates perceived stress with aspects of self-control, covering core stress dimensions (uncertainty, loss of control, academic burden, emotional tension) and self-control dimensions (self-efficacy, emotional regulation, perceived control).

SSI-Based Problem-Based Learning (PBL)

The Problem-Based Learning (PBL) model places authentic problems as the primary stimulus within a social constructivist framework. Through the processes of investigation, negotiation of meaning, and collaborative argumentation, students' understanding is built actively and meaningfully. In its development, PBL has often been adapted by integrating critical-thinking-oriented activities such as debate and group work to stimulate students' analytical skills in identifying problems and formulating evidence-based solutions (Yu & Zin, 2023). The application of PBL has been proven to substantially boost students' cognitive engagement and to be effective in chemistry learning (Arisa & Sitinjak, 2022).

Socio-Scientific Issues (SSI), according to Purwandari et al. (2024), are open and controversial in nature because they involve social, moral, and ethical considerations alongside scientific concepts. SSI do not have a single absolute correct answer, requiring students to negotiate scientific knowledge with societal perspectives in the decision-making process. (Herman et al., 2021) affirm that SSI are multidimensional because they view science not as an isolated entity, but as a social practice relevant to real life and the surrounding environment.

Historically, the theoretical trajectory of SSI originated from the research of Zeidler and Sadler in the United States, which subsequently expanded globally to Europe and Asia. In Indonesia, the implementation of SSI in chemistry learning has strengthened over the past decade in response to the demands of the *Kurikulum Merdeka*, which emphasizes scientific literacy and contextual inquiry. The effectiveness of the SSI approach has been demonstrated through various meta-analytic studies; Badeo & Duque (2022) reported a large effect size on improved science learning outcomes, particularly in the aspects of reasoning, evidence evaluation, and scientific decision-making. In addition, SSI integration has been shown not only to deepen scientific literacy but also to foster the 4C competencies (critical thinking, communication, collaboration, creativity) essential for 21st-century students (Reis et al., 2020).

Scientific Debate and the Integration of the Three Components

Scientific debate is an SSI-based learning activity that places argumentation at its core to validate knowledge through empirical evidence. The implementation of structured debate provides an effective framework for actualizing indicators of students' critical thinking in the classroom (Majidi et al., 2021). Theoretically, the implementation of SSI-based debate is grounded in the principle of social constructivism through the negotiation of meaning around societal issues, thereby stimulating the development of logical, systematic reasoning and abstract thinking ability.

The integration of the PBL model, SSI, and scientific debate creates a holistic pedagogical approach designed to foster meaningful and contextual chemistry learning. PBL provides a learning structure that requires students to identify problems, gather information, and formulate solutions both independently and collaboratively. SSI presents problem contexts that connect science with social, ethical, and environmental dimensions. Scientific debate serves as a forum for students to construct evidence-based arguments, defend scientific positions, and evaluate opposing arguments. The combination of these three components creates a learning environment that demands simultaneous cognitive and emotional engagement, which significantly enhances problem-solving ability (Varlık, 2025) and, most importantly, provides collaborative space that can reduce academic stress because students gain greater regulation over their own learning process (Badeo & Duque, 2022).

The conceptual framework of this study positions the SSI-based PBL model assisted by scientific debate as the independent variable (X), which is expected to have a positive effect on critical thinking skills (Y_1) and scientific attitude (Y_2), and a negative effect (reduction) on academic stress levels (Y_3). These three dependent variables were selected because they represent three main dimensions of holistic learning: the cognitive dimension (critical thinking), the affective dimension (scientific attitude), and the psychological dimension (academic stress). This tripartite evaluation approach constitutes the main novelty of this study.

In line with these research problems, this study aims to (1) examine the effect of an SSI-based PBL model assisted by scientific debate on students' critical thinking skills, (2) examine its effect on students' scientific attitude, and (3) examine its effect on students' academic stress levels in chemistry learning. The following section describes the research design and methods used to achieve these objectives.

METHOD

Research Design

This study used a quantitative approach with a quasi-experimental method, adopting a Nonequivalent Control Group Pre-test and Post-test design. This design was chosen because individual randomization was not feasible within an authentic school context, where students were already grouped into pre-existing classes (White & Sabarwal, 2014). The use of a quasi-experimental design in this context is highly relevant for evaluating the impact of educational interventions without disrupting existing classroom structures (Gopalan et al., 2020).

Table 1. Nonequivalent Control Group Pre-test Post-test Research Design

Population	Group	N	Pre-test	Treatment	Post-test
68 twelfth-grade students	Experimental (XII C)	36	O_1	PBL-SSI + Debate	O_2
	Control (XII F-G)	32	O_1	PBL-SSI	O_2

Note: O_1 = Pre-test; O_2 = Post-test; X = Treatment. Source: Developed by the researcher (2026)

Research Site, Time, and Subjects

The study was conducted at SMAS XYZ, South Tangerang, during the even semester of the 2025/2026 academic year, from January to February 2026. The population comprised all twelfth-grade students enrolled in chemistry, consisting of three classes (XII C, XII E, and XII F-G). Because students at the school were already organized into fixed, pre-existing classes and individual random assignment would have disrupted the regular class structure, the sample was determined through cluster random sampling, in which intact classes rather than individual students served as the sampling units. Of the three twelfth-grade classes in the population, two classes (XII C and XII F-G) were drawn as clusters and included in this study, while XII E was not involved. Assignment of the two selected clusters to the experimental and control conditions was then based on their equivalence in academic ability rather than on individual-level randomization, since only intact classes could be compared. This equivalence was validated by comparing the average semester V chemistry scores, where class XII C (71.52) and class XII F-G (72.32) showed comparable initial competence, supporting their treatment as comparable groups prior to intervention. Class XII C (36 students) was then designated as the experimental group and class XII F-G (32 students) as the control group, with a total of 68 students participating. Because assignment occurred at the class rather than the individual level, this design remains a nonequivalent control group (quasi-experimental) design rather than a true experiment with random assignment.

Learning Procedures and Scenario

The experimental class received SSI-based PBL learning assisted by scientific debate, while the control class received SSI-based PBL without scientific debate. The socio-scientific issue context used was the problem of plastic use and pollution, with six debate motions linked to chemistry concepts: polymer structure, plastic degradation, pyrolysis, bioplastics, chemical recycling, and green chemistry. The learning stages included problem orientation, organization, independent and collaborative investigation, development/presentation of results, and reflection.

Table 2. Differences in Learning Scenarios between the Experimental and Control Classes

Learning Stage	Experimental Class (PBL-SSI + Scientific Debate)	Control Class (PBL-SSI without Debate)
Problem Orientation	Video on plastic pollution; identification of chemical, social, and environmental aspects; introduction of 6 debate motions related to chemistry concepts (polymers, pyrolysis, green chemistry)	Video on plastic waste; trigger questions on the chemical properties and impact of plastic; mini-inquiry on household plastic use
Organization	6 groups per debate motion, divided into pro and con teams (3 students/team); scientific data collection	6 discussion groups (5–6 students/group)
Investigation	Literature study (scientific articles, official reports); evidence analysis for arguments; teacher guidance through probing questions	Analysis of plastic usage patterns; group discussion on the chemical properties and degradation of plastic
Presentation of Results	Pro–con scientific debate (3 sessions, 2 motions/session, ±40 minutes/motion); assessment using critical thinking and scientific attitude rubrics	Preparation of analysis reports; poster/digital presentation (3 sessions, 2 groups/session)
Reflection	Reflection on the relationship between chemistry and socio-environmental issues; reinforcement of evidence-based decision-making	Reflection on plastic-use behavior; linking polymer concepts to environmental issues

Source: Developed by the researcher (2026)

Research Instruments

This study used three main instruments that had been piloted with 60 respondents to empirically confirm their validity and reliability. First, the Critical Thinking Skills Test, consisting of reasoned multiple-choice items referring to Ennis (2011) five indicators problem identification, argument analysis, evidence evaluation, conclusion drawing, and formulation of green chemistry solutions produced 19 valid items (r-calculated = 0.328–0.750 > r-table = 0.254) with high reliability (α = 0.864). Second, the Scientific Attitude Questionnaire used a four-point Likert scale to measure the dimensions of curiosity, objectivity, open-mindedness, academic integrity, critical-reflective attitude, and social-environmental responsibility, yielding 11 valid items (r-calculated = 0.305–0.720) with acceptable moderate reliability (α = 0.663). Third, the Academic Stress Questionnaire, developed from the Perceived Stress Scale (PSS), consisted of 8 statement items measuring core stress and self-control dimensions using reverse scoring for negative items; all items were valid (r-calculated = 0.387–0.679) and reliable (α = 0.720), with higher scores representing higher stress levels.

As a supporting instrument, this study also incorporated three open-ended reflection questions administered after the learning process. This qualitative instrument was designed to explore students' experiences of engagement in SSI-based PBL assisted by debate, its impact on problem-analysis ability, and the management of learning challenges they faced. The reflection data were then analyzed descriptively as a triangulation technique to strengthen, clarify, and deepen the interpretation of the quantitative results.

Table 3. Summary of Instrument Validity and Reliability

Instrument	Items Tested	Valid Items	Dropped Items	Cronbach's Alpha
Critical Thinking Test	20	19	1 (Item 5)	0.864 (High)
Scientific Attitude Questionnaire	12	11	1 (Item 2)	0.663 (Moderate)
Academic Stress Questionnaire	8	8	0	0.720 (High)

Note: Valid criterion: r-calculated > r-table (0.254, n=60, a=5%). Source: Processed SPSS Output, 2026

In summary, all three research instruments demonstrated satisfactory psychometric properties for use in this study. The Critical Thinking Skills Test showed high reliability (α = 0.864) with 19 of 20 items valid, the Scientific Attitude Questionnaire showed acceptable moderate reliability (α = 0.663) with 11 of 12 items valid, and the Academic Stress Questionnaire showed high reliability (α = 0.720) with all 8 items valid, as summarized in Table 3. These results indicate that each instrument was sufficiently valid and reliable to measure its intended construct before being administered to the experimental and control classes.

Data Analysis Technique

Data analysis was conducted in stages using IBM SPSS Statistics 27. The analysis began with descriptive statistics to map the mean, standard deviation, and minimum and maximum values of the data obtained. This was followed by prerequisite tests, namely a normality test using Shapiro-Wilk and a homogeneity test using Levene's Test, to ensure that the basic assumptions of parametric statistics were met. Hypothesis testing was then conducted using an Independent Samples t-test to compare the mean scores between the experimental and control classes on the three dependent variables.

Specifically for the critical thinking variable, the effectiveness of the model was measured using N-Gain Score analysis to observe the improvement from pre-test to post-test, categorized into low (≤40%), moderate (41–70%), and high (>70%) levels. The practical strength of the treatment effect was then measured using Effect Size (Cohen's d), grouped into small (d<0.5), moderate (0.5–0.8), and large (d>0.8) categories. To strengthen the interpretation of the quantitative data, qualitative data triangulation was conducted through descriptive analysis of students' reflection sheets to identify response patterns related to their critical thinking experiences, the development of scientific attitude, and their perceptions of learning pressure. The statistical hypotheses tested in this study were H_0: $\mu_1 = \mu_2$ (no difference in means between the experimental and control classes) against H_1: $\mu_1 \neq \mu_2$ (a significant difference in means exists between the two classes) for each research variable at a significance level of $\alpha = 0.05$.

FINDINGS AND DISCUSSION

Critical Thinking Skills

Descriptive Statistics and Prerequisite Tests

The descriptive statistical results show an increase in critical thinking skills in both classes after treatment. The experimental class's mean score increased from 33.93 (pre-test) to 74.60 (post-test), while the control class increased from 31.38 to 70.80. Moreover, the experimental class showed a more even distribution of scores, reflected in a smaller post-test standard deviation (8.49 compared to 12.24 in the control class), indicating that this learning model produced more consistent achievement among students.

Table 4. Descriptive Statistics of Critical Thinking Skills

Group	N	Min	Max	Mean	Std. Deviation
Experimental Pre-test (XII C)	33	13.16	61.84	33.93	12.17
Experimental Post-test (XII C)	33	57.89	93.42	74.60	8.49
Control Pre-test (XII F-G)	31	8.00	54.00	31.38	12.27

Group	N	Min	Max	Mean	Std. Deviation
Control Post-test (XII F-G)	31	39.47	86.84	70.80	12.24

Source: Processed SPSS Output, 2026

The Shapiro-Wilk normality test results show that all data were normally distributed ($p>0.05$) for both the pre-test and post-test of both groups (experimental pre: $p=0.310$; experimental post: $p=0.942$; control pre: $p=0.699$; control post: $p=0.063$). The homogeneity of variance test was also met for both the pre-test ($p=0.82$) and post-test ($p=0.06$), so the assumptions for using the parametric independent samples t-test were satisfied.

Hypothesis Testing, N-Gain, and Effect Size

The independent samples t-test results show a significance value (Sig. 2-tailed) of 0.151, which is above the 0.05 significance level. Therefore, H_0 is accepted and H_1 is rejected, meaning there is no statistically significant difference between the critical thinking skills of students in the experimental and control classes after treatment. Nevertheless, a mean difference of 3.80 shows that the experimental class consistently obtained higher scores.

Table 5. Summary of Hypothesis Testing, N-Gain, and Effect Size for Critical Thinking

Parameter	Experimental Class	Control Class	p-value	Cohen's d
N-Gain Score (Mean)	61.56% (moderate)	56.94% (moderate)	0.151 (NS)	0.363 (small–moderate)
Minimum N-Gain	25.82%	15.41%	–	–
Maximum N-Gain	82.76%	84.33%	–	–

Note: NS = Not Significant. Source: Processed SPSS Output, 2026

Discussion of Critical Thinking Skills

The increase in critical thinking in both classes is theoretically consistent with the characteristics of PBL, which places authentic problems as a trigger for higher-order cognitive activity. SSI integration strengthens the relevance of learning because students not only understand concepts but also connect them to social and environmental realities. Scientific debate further enriches this process by encouraging students to argue based on evidence, in line with (Ennis, 2011) view of critical thinking as a rational and reflective decision-making process.

This result diverges from the theoretical expectation that structured, evidence-based argumentation in debate would give the experimental class a measurable cognitive advantage over PBL alone. The non-significant difference between classes can instead be explained by three main factors. First, PBL as the primary framework provided a dominant contribution to both groups, so the additional effect of scientific debate was not strong enough to produce a statistical gap; because both classes engaged in evidence-based investigation as part of PBL, the debate format added an argumentation channel rather than a wholly new cognitive demand. Second, scientific debate tends to focus more on developing communication and argumentation skills than on deep conceptual content mastery, so its benefits may not fully transfer to a critical thinking test that emphasizes conceptual analysis. Third, the dichotomous (pro–con) structure of debate may limit the exploration of multidimensional solutions, even though this multidimensional characteristic is central to PBL-based learning.

Although not statistically significant, a Cohen's d of 0.363 indicates that the intervention had a real practical effect. This is reinforced by qualitative findings; students reported that learning based on real issues helped them understand concepts more contextually and increased their learning enthusiasm. One student stated that the learning "made chemistry material that was initially boring become interesting because it was connected to the real-life issue of plastic waste." This finding confirms that the implications of learning are not limited to measurable cognitive dimensions, but also encompass the stimulation of motivation and the depth of students' intellectual engagement.

This result partly diverges from previous studies. López-Fernández et al. (2022) and Pratiwi et al. (2025) reported that SSI-based chemistry learning was effective in developing students' critical thinking, particularly in argumentation and evidence evaluation, which is consistent with the improvement observed in both classes of the present study. However, unlike the present finding of no significant between-class difference, those studies did not specifically isolate the additional contribution of a structured debate component, making direct comparison difficult; the discrepancy here suggests that debate's added value may lie more in argumentation practice than in measurable gains on a general critical thinking test. The finding is also consistent with (Yu & Zin, 2023), who noted that PBL alone can substantially strengthen students' cognitive engagement, supporting the interpretation that PBL was the dominant driver of improvement in both groups of this study.

This finding has important implications for future research design. Subsequent studies need to sharpen the distinction in treatment between classes by ensuring that the control class genuinely uses conventional problems free from SSI context, and by providing a more dominant and structured portion of scientific debate in the experimental class. In addition, extending the research duration to at least one full semester is needed so that students move past the initial adaptation period and reach optimal habituation with the SSI-based debate system. The use of class-average-based N-gain (ngc = normalized gain of the average learner), as recommended by (Navarrete et al., 2024) as a more accurate estimator, should also be considered in future research.

Scientific Attitude

Descriptive Statistics and Hypothesis Testing

Descriptive data show a relatively small increase in scientific attitude in both classes. The experimental class mean increased from 38.21 (pre-test) to 38.70 (post-test), while the control class increased from 38.42 to 39.55. The small standard deviation values in both classes indicate that students' scientific attitude was already relatively homogeneous from the outset of learning. Interestingly, the control class showed a slightly higher mean increase (+1.13) than the experimental class (+0.49), although both differences were very small.

Table 6. Descriptive Statistics and Hypothesis Testing for Scientific Attitude

Group	Pre-test Mean (SD)	Post-test Mean (SD)	Δ Mean	t-test Result (p-value)
Experimental (XII C, n=33)	38.21 (4.09)	38.70 (4.58)	+0.49	p = 0.652 (Not Significant)
Control (XII F-G, n=31)	38.42 (3.14)	39.55 (3.36)	+1.13	p = 0.652 (Not Significant)

Source: Processed SPSS Output, 2026

The Shapiro-Wilk normality test results show a normal distribution for all data ($p>0.05$). Although the homogeneity test (Levene, $p=0.049<0.05$) indicated non-homogeneous variance, the t-test using equal variances not assumed still showed no significant difference ($p=0.652$). A mean difference of -0.851 shows that the experimental class's average scientific attitude was slightly lower than the control class's, although this difference was not statistically meaningful.

Discussion of Scientific Attitude

Theoretically, debate was expected to reinforce scientific attitude more strongly than PBL alone because it requires students to construct evidence-based positions and directly confront opposing viewpoints, activities closely aligned with objectivity and openness to evidence. However, this finding indicates that the increase in scientific attitude was not driven solely by the debate activity, but by the underlying PBL framework applied to both groups. Scientific activities in the control class, such as data collection, discussion, and presentation, also contributed comparably. This is consistent with (Maharani & Muliati, 2025), who state that active learning models such as PBL are generally effective in stimulating scientific attitude, regardless of the presence of an additional debate component.

The main factor behind the absence of a statistically significant difference is the inherent nature of scientific attitude as an affective domain that develops gradually through long-term habituation (Cai et al., 2024). The relatively short duration of the study (approximately two months) was a limitation in detecting large quantitative change, as scientific attitude requires gradual value internalization, unlike the acquisition of cognitive knowledge.

Nevertheless, qualitative reflection data show meaningful change. Students reported improved ability to critically analyze statements, construct evidence-based arguments, and understand opposing perspectives objectively. This recognition reflects the growth of students' scientific disposition, encompassing open-mindedness, objectivity, and rational evaluation. Methodologically, this finding shows that short-duration experiments are less sensitive in measuring affective change, so future research is recommended to use a longitudinal design and direct observation methods to capture more substantial development of scientific attitude.

This pattern shows both similarities and discrepancies with prior research. It aligns with (Cai et al., 2024), who argued that affective traits change gradually and are less responsive to short interventions, which explains why neither class showed a large quantitative gain. It diverges, however, from the expectation raised by (Majidi et al., 2021), whose findings on debate's benefit for argumentation skills might suggest a parallel benefit for attitudes such as objectivity and open-mindedness; no such added benefit was detected quantitatively here, suggesting that debate's influence on scientific attitude may take longer to surface than its influence on argumentation skill specifically.

Academic Stress Level

Descriptive Statistics and Hypothesis Testing

The results show a strongly contrasting pattern between the two classes in terms of change in academic stress level. The experimental class experienced a substantial decrease in mean stress level from 20.87 to 13.39 (a difference of -7.48, or a 35.8% decrease), while the control class experienced an increase from 19.67 to 21.97 (a difference of +2.30, or an 11.7% increase). This opposing pattern is a highly significant finding and provides strong evidence for the effectiveness of the applied learning model.

Table 7. Descriptive Statistics and Hypothesis Testing for Academic Stress Level

Group	Pre-test Mean (SD)	Post-test Mean (SD)	Δ Mean	p-value	Cohen's d
Experimental (n=33)	20.87 (3.507)	13.39 (2.957)	-7.48	0.000*	-1.567 (very large effect)
Control (n=31)	19.67 (3.727)	21.97 (4.708)	+2.30	0.000*	–

*Note: *p<0.05. Mean difference between classes = -8.57. Hedges' correction = -1.548; Glass's delta = -1.141.*
Source: Processed SPSS Output, 2026

The Shapiro-Wilk normality test results show a normal distribution for all data ($p>0.05$ in all groups). The homogeneity test showed non-homogeneous variance ($p=0.006$), so the analysis used equal variances not assumed. The t-test showed a highly significant difference ($p=0.000$), with a mean difference between classes of -8.57, meaning the experimental class's stress level was far lower than the control class's after treatment. A Cohen's d of -1.567 indicates a very large effect size, well above the large-effect threshold ($d>0.8$). This is reinforced by a Hedges' correction of -1.548 and a Glass's delta of -1.141, which consistently and convergently confirm that the intervention had a very strong practical effect in reducing students' academic stress.

Discussion of Academic Stress Level

This remarkable finding can be comprehensively explained through several theoretical mechanisms. First, based on Lazarus and Folkman's Transactional Theory of Stress, students in the experimental class tended to perceive learning demands as a challenge that could be overcome, rather than as a threat. This was influenced by the learning characteristics that provided space for exploration, discussion, and active involvement, thereby increasing students' sense of control over the learning process. In contrast, the control class, which worked on similar problems without a structured argumentation forum, lacked the same mechanism for productively expressing and managing academic burden.

Second, collaborative activities in PBL and scientific debate function as protective factors against stress through several pathways. Social support arising from group work helps students obtain interpersonal resources to face academic demands. The structured problem-investigation process also increases students' sense of self-control and self-efficacy in facing complex tasks (Bandura, 1994). In addition, scientific debate specifically trains students' emotional regulation in facing intellectual pressure constructively for example, when receiving rebuttals or defending arguments in public which is a concrete form of adaptive coping strategy (Folkman, 1997).

On the other hand, the increase in stress in the control class can be understood as an accumulation of academic burden without an adequate management mechanism. Without a structured debate forum, students did not have a good opportunity to express and productively analyze academic tension. PBL without debate still carries high cognitive demands, but does not provide the same expressive space to manage emotion and pressure.

Qualitative reflection data strongly reinforce this interpretation. Students in the experimental class reported that although initially nervous and worried about making mistakes during the debate, they gradually managed to adapt. One student stated, "At first I was nervous and afraid the chemistry data would be wrong." Anxiety or obstacles during the debate could be reduced through thorough preparation, including reviewing scientific articles and conducting group simulations. As a result, during the debate activities, classroom dynamics showed a marked escalation in enthusiasm. Students also confirmed that this interaction was effective in fostering a collaborative attitude, particularly in formulating group arguments through an intensive exchange of ideas. These statements concretely illustrate how debate activity functioned as an effective coping-practice arena, transforming a potential source of stress into an empowering learning experience.

These findings on academic stress carry significant weight in the context of Indonesian chemistry education, given that chemistry is often perceived as a frightening subject that triggers high academic anxiety. This study demonstrates that an appropriate learning approach can actually reverse this paradigm: rather than adding to psychological burden, the integration of PBL-SSI with scientific debate proactively builds an internal mechanism within students to manage academic pressure. This is an important theoretical contribution to the development of chemistry learning theory that is oriented not only toward cognitive achievement, but also toward students' psychological well-being as a key foundation of effective learning.

This finding both confirms and extends previous stress research, consistent with (Choi et al., 2023), who found that protective psychosocial factors can moderate the relationship between academic stress and school adjustment and that the cognitive complexity of SSI-based PBL was expected to elevate academic stress. The present study identifies structured debate, embedded within collaborative PBL, as one such protective mechanism specific to chemistry classrooms. The result also diverges from the assumption underlying the introduction of this study: rather than compounding stress, the debate-assisted class experienced a marked reduction, suggesting that a well-structured expressive outlet can offset, rather than add to, the cognitive load associated with SSI-based PBL.

These findings are also relevant to the context of declining student psychological well-being recorded in the SMAS XYZ *Rapor Pendidikan* for the 2023–2025 period. The data from this study provide empirical evidence that appropriate learning-model innovation can be a concrete solution to address students' psychological problems, which have long been overlooked in chemistry learning design. The SSI-based PBL model assisted by scientific debate not only addresses the need to improve academic competence but also contributes to building students' psychological well-being holistically.

CONCLUSIONS

This study evaluated the implementation of debate-assisted Socio-Scientific Issues-based Problem-Based Learning (PBL-SSI) on senior high school students' critical thinking skills, scientific attitudes, and academic stress in chemistry learning. Both the debate-assisted and standard PBL-SSI classes showed moderate improvements in critical thinking and positive changes in scientific attitudes, with no statistically significant differences between groups. However, the debate-assisted class demonstrated a statistically significant reduction in academic stress, suggesting that structured scientific debate may support students' well-being while maintaining comparable cognitive and affective outcomes. The study was limited by its single-school setting, relatively small sample (n = 68), and short intervention period, which may have constrained the detection of higher-order changes. Future research should involve larger, multi-school, longitudinal designs comparing PBL, PBL-SSI, and debate-assisted PBL-SSI. Practically, teachers may integrate structured scientific debate into PBL-SSI to foster a positive classroom climate and manage academic stress, while longer implementation may be necessary to produce additional cognitive and affective benefits.

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