JPPIPA 12 (7) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Supporting Sustainable Development Goal 4 Through Scientific Argumentation: A Mixed-Methods Study of High School Students' Argumentation Skills on Acid–Base Concepts

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Received: June 15, 2026
Revised: July 29, 2026
Accepted: August 17, 2026
Published: August 17, 2026

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DOI: 10.29303/jppipa.v12i7.16032

Abstract: Scientific argumentation is an essential competency in 21st-century science education because it enables students to construct claims supported by evidence and scientific reasoning. This study aimed to analyze the scientific argumentation skills of senior high school students on acid–base concepts and identify the factors influencing these skills. A mixed-methods approach with a sequential explanatory design was employed involving 216 Grade XI students from SMA Negeri 1 and SMA Negeri 5 Jambi City, Indonesia. Quantitative data were collected using an essay test based on Toulmin's Argumentation Pattern (TAP), while qualitative data were obtained through classroom observations, questionnaires, and interviews with teachers and students. Quantitative data were analyzed using descriptive statistics, one-way ANOVA, and Tukey HSD tests, whereas qualitative data were analyzed using the Miles and Huberman interactive model. The findings revealed significant differences in students' argumentation skills among the six classes ($F = 21.63$, $p < 0.001$). Students from SMA Negeri 1 generally demonstrated higher levels of argumentation, predominantly at Levels 4 and 5 of the Toulmin framework, whereas students from SMA Negeri 5 were distributed across Levels 1 to 5, indicating greater variation in argumentation quality. The qualitative findings showed that conceptual understanding, active participation in classroom discussions, critical thinking skills, and a learning environment that encourages scientific dialogue were the primary factors influencing students' argumentation skills. These findings highlight the importance of integrating learning activities that explicitly foster claim–evidence–reasoning construction to strengthen students' scientific argumentation and support quality science education.

Keywords: Acid base; Argumentation ability; Argumentation factors; Mixed methods; Toulmin argumentation pattern

Introduction

Education plays a fundamental role in developing high-quality human resources capable of responding to the challenges of the twenty-first century (Galimova et al., 2025). Rapid advances in science and technology have transformed the competencies required of students, shifting educational goals from merely acquiring knowledge to developing higher-order thinking, problem-solving, collaboration, creativity, and communication skills (Edwin et al., 2025). Consequently, science education is expected not only to help students understand scientific concepts but also to prepare them to make informed decisions based on scientific evidence. In Indonesia, these expectations are reflected in the implementation of the Independent Curriculum, which emphasizes student-centered learning, inquiry, scientific literacy, and competency development (Lestari et al., 2021). Therefore, science learning should facilitate students in constructing knowledge through investigation, reasoning, and scientific communication rather than memorizing scientific facts (Saido et al., 2018).

How to Cite:
Wahyuning, S. B., Effendi, M. H., Syahri, W., & Kriswantoro. (2026). Supporting Sustainable Development Goal 4 Through Scientific Argumentation: A Mixed-Methods Study of High School Students' Argumentation Skills on Acid–Base Concepts. *Jurnal Penelitian Pendidikan IPA*, *12*(7), 762–771. https://doi.org/10.29303/jppipa.v12i7.16032

Among the competencies required in science learning, scientific argumentation has become one of the most essential skills because it enables students to explain phenomena, justify conclusions, evaluate evidence, and defend scientific ideas logically (Allchin & Zemplén, 2020). Scientific argumentation is more than expressing opinions; it involves constructing claims supported by valid evidence and logical reasoning (Faize et al., 2018). Through argumentation, students learn to distinguish scientific explanations from personal beliefs, evaluate alternative viewpoints, and communicate scientific ideas effectively (Maisarah et al., 2025). Previous studies have consistently shown that argumentation contributes significantly to conceptual understanding, critical thinking, scientific literacy, and decision-making abilities. Consequently, the development of students' argumentation skills has become an important objective in contemporary science education.

Scientific argumentation has been widely discussed in science education through Toulmin's Argumentation Pattern (TAP), which provides a systematic framework for evaluating the quality of arguments. According to Toulmin (2003), an argument consists of six interconnected components: claim, data (evidence), warrant, backing, qualifier, and rebuttal. Among these components, claims, evidence, and warrants represent the essential structure of a complete scientific argument because they demonstrate students' ability to formulate conclusions, support them with empirical evidence, and explain the logical relationship between the evidence and the conclusion. Students who fail to integrate these components generally produce incomplete arguments that rely on opinions rather than scientific reasoning.

Chemistry is one of the science disciplines that strongly requires scientific argumentation because many chemical concepts involve abstract representations, scientific models, experimental evidence, and logical reasoning (Susanto et al., 2026). Students are expected not only to understand theoretical concepts but also to explain observations, analyze experimental results, justify conclusions, and solve contextual problems using scientific evidence. However, chemistry learning often remains focused on algorithmic problem-solving and memorization, limiting students' opportunities to develop argumentation skills. As a result, many students can answer computational questions correctly but struggle to explain why their answers are scientifically valid.

Among chemistry topics, acid–base concepts represent one of the most fundamental yet challenging areas for senior high school students. Acid–base theories require students to understand multiple scientific perspectives, including the Arrhenius, Brønsted–Lowry, and Lewis theories, while interpreting experimental observations and relating macroscopic, submicroscopic, and symbolic representations (Saputri & Suprihatiningrum, 2023). Furthermore, acid–base concepts are closely connected to everyday phenomena, including food acidity, cleaning products, environmental issues, and biological systems. This contextual nature makes acid base learning highly suitable for examining students' scientific reasoning and argumentation.

Acid base learning also provides rich opportunities for inquiry-based and laboratory learning. Students frequently conduct experiments using litmus paper, universal indicators, pH meters, and natural indicators to classify solutions according to their chemical properties (Epinur et al., 2024). These experimental activities generate authentic evidence that students should use to construct scientific explanations (Fitria et al., 2025). Therefore, argumentation becomes an integral part of learning because students are required to formulate claims, interpret evidence, and justify their conclusions based on experimental observations rather than intuition or memorized.

Previous studies conducted in several public senior high schools in Jambi and Muaro Jambi have consistently reported that students' scientific argumentation skills remain relatively low across various chemistry topics, including reaction rates, thermochemistry, stoichiometry, redox reactions, and chemical bonding. These studies found that many students experienced difficulties in providing appropriate evidence, connecting evidence with scientific concepts, and explaining their reasoning logically. Such findings indicate that improving students' argumentation skills remains a significant challenge in chemistry education.

Although previous studies have contributed valuable insights into students' argumentation abilities, most of them primarily described students' argumentation levels without investigating the quality of individual argumentation components or the factors responsible for students' weaknesses. Furthermore, studies focusing specifically on acid–base concepts remain limited despite the conceptual complexity and contextual relevance of this topic (Jiménez-Liso et al., 2020). Consequently, there is still insufficient understanding of how students construct claims, select evidence, and formulate warrants when solving acid–base problems information (Martin et al., 2024).

Another limitation of previous studies is that they rarely examine the factors influencing students' scientific argumentation comprehensively. Students' ability to argue scientifically is influenced not only by conceptual understanding but also by classroom discussions, inquiry experiences, teacher guidance, assessment practices, and learning environments (Dianti et al., 2023). Without identifying these contributing factors, it is difficult to design effective instructional

interventions that can improve students' argumentation skills (Triana et al., 2026). Therefore, investigating both students' argumentation performance and its influencing factors is necessary to obtain a more comprehensive understanding of the problem.

The novelty of this study lies in its integrated analysis of students' scientific argumentation on acid–base concepts by combining Toulmin's Argumentation Pattern with an investigation of the internal and external factors influencing argumentation performance. Unlike previous studies that mainly categorized argumentation levels, this research analyzes the quality of claims, evidence, and warrants while simultaneously identifying the factors underlying students' responses. This integrated perspective provides a more comprehensive description of students' reasoning processes and offers deeper insights into why students experience difficulties in constructing scientifically valid arguments (Hasnunidah et al., 2025).

The findings of this study are expected to contribute theoretically and practically to chemistry education. Theoretically, the study enriches the literature on scientific argumentation by providing empirical evidence regarding students' argumentation patterns in acid–based learning (Utami et al., 2022). Practically, the findings may serve as a reference for teachers in designing inquiry-based learning activities, argumentation-oriented assessments, and classroom discussions that promote evidence-based reasoning (Mikeska & Lottero-Perdue, 2022). In addition, the results support the implementation of the Independent Curriculum by strengthening students' critical thinking, scientific literacy, and communication skills as key competencies for twenty-first-century learning (Stehle & Peters-Burton, 2019).

Based on the issues outlined above, this study aims to investigate the scientific argumentation skills of Grade XI senior high school students in Jambi City on acid–base concepts and to identify the factors influencing these skills. The study was conducted at SMA Negeri 1 and SMA Negeri 5 Jambi City, focusing on the three essential components of Toulmin's Argumentation Pattern—claims, evidence, and warrants—to provide a comprehensive understanding of students' scientific reasoning in chemistry learning.

Method

This study employed a mixed-methods approach using a sequential explanatory design, in which quantitative data were collected and analyzed in the first phase, followed by qualitative data to explain and enrich the quantitative findings (Sugiyono, 2014). The quantitative phase aimed to assess students' scientific argumentation skills on acid–base concepts, whereas the qualitative phase explored the factors influencing these skills through classroom observations, questionnaires, and semi-structured interviews with teachers and students (Dewi et al., 2025).

The study was conducted at SMA Negeri 1 and SMA Negeri 5 Jambi City during the second semester of the 2025/2026 academic year. The participants consisted of all Grade XI students from six science classes: F8, F9, and F10 at SMA Negeri 1 Jambi City and F1, F2, and F3 at SMA Negeri 5 Jambi City, comprising a total of 216 students (36 students per class). Participants were selected using purposive sampling based on recommendations from chemistry teachers, who considered students' academic characteristics, learning styles, and previous learning achievement (Benjamin, 2024).

The research employed both test and non-test instruments. The test instrument consisted of an argumentative essay test developed to assess students' ability to construct three essential components of Toulmin's Argumentation Pattern (TAP), namely claims, evidence, and warrants, within the context of acid–base concepts. The instrument was adapted from the assessment rubric was administered after students had completed the acid–based learning unit (Murni et al., 2022). Each response was scored using the established rubric to determine students' argumentation performance (Rodríguez-Mora et al., 2022). The non-test instruments included classroom observation sheets, teacher and student activity observation sheets, student questionnaires, and semi-structured interview guidelines (Larasati et al., 2025). To preserve the authenticity of the classroom context, acid–base instruction was conducted entirely by the chemistry teachers following the school's regular lesson plans and instructional practices (Asli et al., 2023). The researcher did not participate in the teaching process and acted solely as a non-participant observer, documenting students' argumentation behaviors, classroom interactions, and learning activities throughout the instructional process.

Students' scientific argumentation was evaluated based on the three core components of Toulmin's Argumentation Pattern: claim, evidence, and warrant. The total argumentation score was converted into percentages and interpreted using five performance categories adapted from Toulmin's rubric: Very Low, Low, Moderate, High, and Very High. These categories were applied consistently throughout the study to facilitate interpretation of students' argumentation performance.

Research Design

Mixed Methods – Sequential Explanatory Design

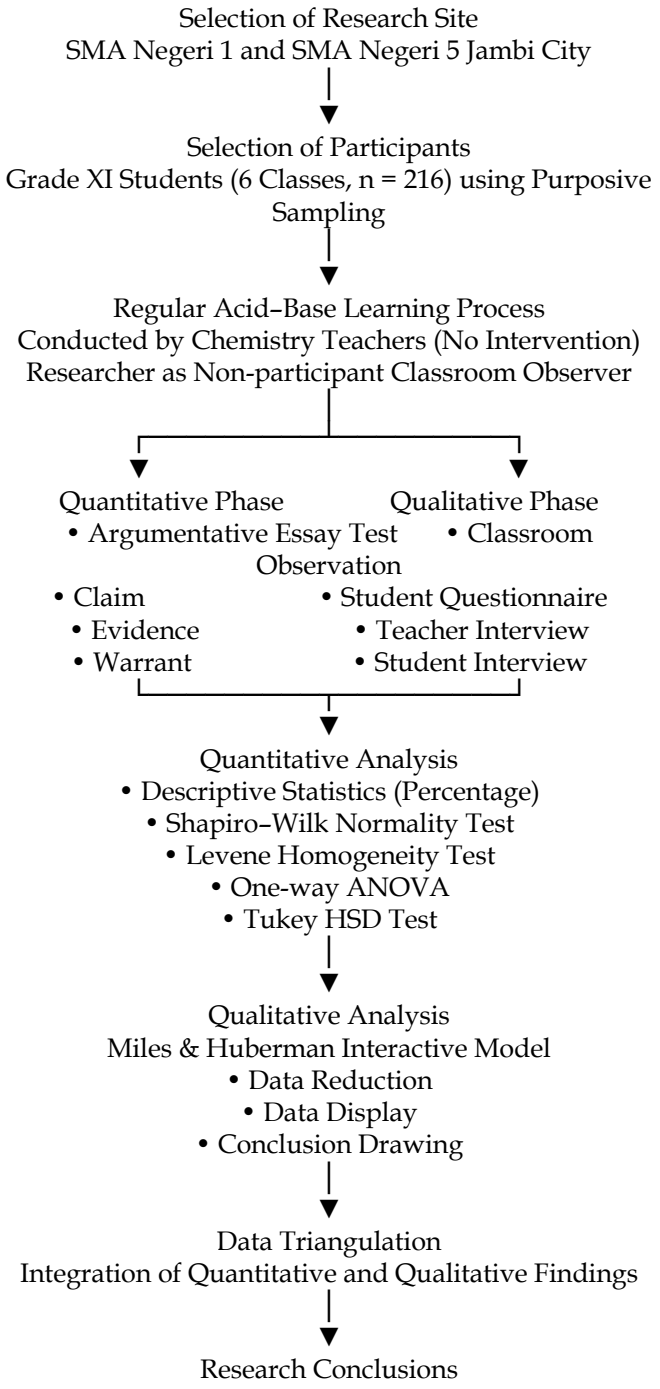

Figure 1. Research procedure of the sequential explanatory mixed-methods design

Quantitative data were analyzed descriptively by calculating the percentage distribution of students' argumentation scores for each argumentation component and overall performance (Haudek & Zhai, 2024). Prior to inferential analysis, the data were tested for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test (Montero, 2026). Differences in students' argumentation performance among the six classes were analyzed using one-way analysis of variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) post hoc test when significant differences were identified. Qualitative data obtained from classroom observations, questionnaires, and interviews were analyzed using the Miles and Huberman interactive model, which includes data reduction, data display, and conclusion drawing. Finally, methodological triangulation was employed by comparing quantitative and qualitative findings to obtain a comprehensive understanding of students' scientific argumentation skills and the factors influencing them.

Result and Discussion

Students' Argumentation Ability Based on Pretest and Posttest Results

The scientific argumentation test results were converted into percentage scores (0–100) to facilitate interpretation and statistical analysis. The percentages were calculated from the raw scores obtained using the Toulmin-based argumentation rubric (Satriya & Atun, 2024). Higher percentage scores indicate better scientific argumentation performance.

The descriptive results indicate that students' percentage scores increased after completing the acid base learning unit in all classes at both schools. The average pretest and posttest percentage scores are presented in Tables 1 and 2.

Table 1. Average pretest and posttest scores of class XI SMA Negeri 1 Kota Jambi

Class	Pretest (%)	Posttest (%)
XI F8	21.57	86.39
XI F9	20.65	87.41
XI F10	22.04	84.44

Table 2. Average pretest and posttest scores of class XI SMA Negeri 5 Kota Jambi

Class	Pretest (%)	Posttest (%)
XI F1	28.98	77.31
XI F2	28.15	68.61
XI F3	22.13	68.89

Based on Table 1, Students at SMA Negeri 1 Jambi City obtained posttest percentage scores ranging from 84.44% to 87.41%, whereas students at SMA Negeri 5 Jambi City obtained scores ranging from 68.61% to 77.31%. These findings indicate that, after completing the acid–based learning unit, students at SMA Negeri 1 generally demonstrated stronger scientific argumentation performance than those at SMA Negeri 5. Since the present study did not involve an instructional intervention, these results describe students' argumentation performance following regular classroom instruction rather than the effectiveness of a particular teaching model. A descriptive summary of

students' posttest percentage scores is presented in Table 3.

Table 3. Descriptive statistics of posttest results of students' argumentation ability

School	N	Mean	Standard Deviation	Minimum	Maximum
State Senior High School 1, Jambi City	108	86.08	10.93	50.00	100.00
State Senior High School 5, Jambi City	108	71.60	11.78	33.33	93.33

Based on Table 3, the mean percentage score of students at SMA Negeri 1 Jambi City (86.08) was higher than that of students at SMA Negeri 5 Jambi City (71.60). The standard deviations of both schools were relatively similar, indicating comparable score variability within each school. Nevertheless, the higher mean score and higher minimum score at SMA Negeri 1 suggest that students in this school generally demonstrated better and more consistent scientific argumentation skills.

Distribution of Argumentation Ability Levels

Students' scientific argumentation was classified into five performance categories based on the converted percentage scores derived from the Toulmin Argumentation Pattern rubric: Very Low, Low, Moderate, High, and Very High. The percentage distribution of students across these categories is presented in Table 4.

The results indicate that students at SMA Negeri 1 Jambi City were predominantly classified in the High and Very High categories, whereas students at SMA Negeri 5 Jambi City showed a more heterogeneous distribution across all five categories. Although a considerable proportion of students at SMA Negeri 5 achieved High and Very High levels, a larger percentage remained in the Moderate and Low categories, suggesting that some students still experienced difficulties in constructing complete scientific arguments, particularly in providing appropriate evidence and logical warrants.

Table 4. Presents the percentage distribution of posttest argumentation levels

Class	Level 1 (%)	Level 2 (%)	Level 3 (%)	Level 4 (%)	Level 5 (%)
F8 (SMA 1)	2.31	1.39	12.04	24.54	59.26
F9 (SMA 1)	0.46	0.93	12.04	44.91	41.20
F10 (SMA 1)	0.93	0.93	22.22	24.07	51.39
F1 (SMA 5)	7.87	8.80	18.52	18.52	46.30
F2 (SMA 5)	14.35	10.65	25.93	15.74	33.33
F3 (SMA 5)	7.41	15.28	25.00	30.09	22.22

Table 4 shows that, in general, the percentage of students at Level 1 and Level 2 is very low across all six grades, with the percentage increasing at higher levels. Grades F8, F9, and F10 at SMA Negeri 1 consistently show dominance at Level 4 and Level 5, while Grades F2 and F3 at SMA Negeri 5 still show a fairly large proportion at Level 1 to Level 3 (ranging from 32.66–47.69%). This pattern is consistent with the results of inferential statistics which indicate that the argumentation skills of SMA Negeri 1 students are generally higher and more homogeneous than those of SMA Negeri 5 Jambi City.

Hypothesis Testing: Differences in Argumentation Ability between Classes

Prior to hypothesis testing, the posttest percentage scores were examined for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test. The data satisfied the assumption of homogeneity (Levene's test, p = 0.905) (Bestari et al., 2025). One-way ANOVA was subsequently conducted to compare students' scientific argumentation performance among the six classes.

Table 5. One-Way ANOVA test results for six classes

Source of variance	Sum of squares	Df	Mean square	F	Sig.
Intergroup	13240,196	5	2648,039	21,634	0,000
In group	25704,361	210	122,402	-	-
Total	38944,557	215	-	-	-

The one-way ANOVA revealed a statistically significant difference in students' scientific argumentation scores among the six classes, $F(5, 210) = 21.634$, $p < 0.001$. Subsequent Tukey HSD analysis showed that Classes F8, F9, and F10 (SMA Negeri 1) formed a homogeneous group with no significant differences among them. In contrast, Class F1 (SMA Negeri 5) represented an intermediate group, whereas Classes F2 and F3 showed significantly lower argumentation performance than the three classes from SMA Negeri 1. These findings indicate that the most substantial differences in scientific argumentation occurred between students from the two schools rather than among classes within the same school.

Qualitative Data: Observation, Questionnaires, and Interviews

Observations of learning at SMA Negeri 1 Jambi City showed that argumentative activities emerged through discussions, Q&A sessions, and learning reflections actively facilitated by teachers. Students demonstrated the ability to express opinions, provide reasons, and respond to peers' opinions, although participation was not evenly distributed across all students. Similar conditions were observed at SMA Negeri 5 Jambi City through discussions, presentations, and quizzes, but the activeness and quality of student argumentation appeared to vary more among individuals compared to SMA Negeri 1.

The recapitulation results of the questionnaire for students at SMA Negeri 1 Jambi City showed an average score of 2.62 out of a maximum scale of 4, which is classified as moderate/sufficient. The indicator with the highest score was students' difficulty in answering essay questions that require explanation (3.02), while the indicator with the lowest score was the inclusion of supporting evidence when answering questions (2.36). At SMA Negeri 5 Jambi City, the average questionnaire score of 2.46 was in the "Occasional" category, with the lowest score being the use of evidence or logic to support or challenge arguments (2.29). The questionnaire findings at both schools consistently showed that the evidence and warrant components were still the aspects that needed the most strengthening compared to the claim component.

Interviews with students corroborate these findings, with some students admitting they are more accustomed to multiple-choice questions than argumentative essay questions, and are able to determine the correct answer but struggle when asked to explain scientific reasoning or present supporting evidence. Interviews with teachers indicate that learning evaluations are still dominated by objective questions and essays focused on the final outcome, while specific argumentative exercises are not routinely conducted due to time constraints and limited practical argumentative assessment instruments.

Factors Influencing Students' Argumentation Skills

The integration of test results, observations, questionnaires, and interviews revealed that the differences in students' argumentation abilities between SMA Negeri 1 and SMA Negeri 5 in Jambi City were influenced by a combination of several factors, as follows.

Table 6. Factors influencing students' argumentation skills

Factor	Explanation
Concept mastery	Students with better learning outcomes and understanding of acid-base concepts tend to be more able to logically connect data to claims (Andrian et al., 2025). This finding aligns with Osborne (2010) and McNeill & Krajcik (2012) who found that conceptual mastery is an important foundation for building claim-evidence-reasoning relationships.
Activeness in learning and argumentative experiences	Students of SMA Negeri 1 were more active in group discussions, presentations, and Q&A sessions than students of SMA Negeri 5. This is in line with Vygotsky (1978) social constructivism and the findings of Osborne et al. (2004) that an active discussion environment improves the quality of scientific argumentation.
Critical thinking skills	Students at a high level of argumentation tend to be accustomed to analyzing information before responding, while students at a low level rely more on memorization. Facione (2015) and Zohar & Nemet (2002) emphasize the close relationship between critical thinking and argumentative quality.
A learning environment that supports argumentation	Learning that provides space for scientific dialogue, group discussions, and presentations of work results has been proven to encourage students to construct, test, and evaluate arguments scientifically (Driver et al., 2000; Simon et al., 2006)

Students' relatively good argumentative abilities in acid-base material can also be attributed to the characteristics of the material that are close to everyday life, such as the use of vinegar, antacids, soap, and detergents, as well as the color changes of natural indicators (Fransiska, 2023). The closeness of the material to everyday experiences makes it easier for students to connect scientific concepts with real phenomena, thus supporting the development of arguments (Sadler & Zeidler, 2005). In addition, the practicum activities testing the properties of acids and bases provide opportunities for students to obtain empirical data as a basis for argumentation, in line with the findings of Sampson & Blanchard (2012) and Hofstein & Lunetta (2004) that laboratory activities contribute greatly to the development of argumentation and scientific reasoning skills.

Overall, the findings of this study indicate that argumentation skills are not only determined by cognitive aspects such as concept mastery, but are also influenced by learning experiences, social interactions, and the learning strategies implemented by teachers in the classroom. Therefore, developing students' argumentation skills requires a learning approach that explicitly trains the components of claim, evidence, and warrant, for example through the Claim-Evidence-Reasoning (CER) approach, Argument-Driven Inquiry (ADI), or problem-based learning that involves discussion, practicum, and critical evaluation of arguments.

Implications of Findings in Chemistry Learning

The finding that the evidence and warrant components consistently scored lower than the claim components in both schools has important implications for high school chemistry teaching practices. Teachers need to design learning activities that are not solely focused on final answers but also train students to consistently include supporting data and explain the relationship between the data and the proposed claim. This can be achieved by routinely using essay questions based on the claim-data-reason pattern, not just during the final assessment (Putri et al., 2025).

The difference in achievement between SMA Negeri 1 and SMA Negeri 5 in Jambi City also indicates that the intensity of discussions, presentations, and teacher-facilitated practicums significantly contributes to the quality of students' argumentation. Schools with a higher frequency of scientific discussions and practicums tend to produce students with higher and more homogeneous levels of argumentation. Therefore, school policies to provide adequate time and facilities for chemistry discussions and practicums are an important supporting factor that needs to be considered by education policymakers at the school level and the education office.

Furthermore, the results of this study emphasize the importance of developing evaluation instruments specifically designed to measure students' argumentation skills, considering that teachers at both schools admitted to not yet having practical argumentation assessment instruments for routine use. The development of an essay test instrument based on the Toulmin argumentation pattern, as used in this study, can be an alternative that teachers can adopt in chemistry learning evaluation activities, especially in materials that have a strong connection to everyday life phenomena such as acids and bases.

Conclusion

Based on the findings of this study, students from the two participating senior high schools demonstrated different levels of scientific argumentation ability on acid–base concepts. Students from SMA Negeri 1 Jambi City generally exhibited stronger scientific argumentation than those from SMA Negeri 5 Jambi City, as reflected in their higher posttest percentage scores and a greater proportion of students in the High and Very High argumentation categories. In contrast, although many students at SMA Negeri 5 also achieved high levels of argumentation, a considerable proportion remained in the Moderate, Low, and Very Low categories, indicating that students' scientific argumentation ability varied across schools and had not yet developed uniformly. The findings further indicate that students who demonstrated stronger conceptual understanding, actively participated in classroom discussions, and had greater opportunities to justify their ideas using scientific evidence were more likely to construct complete arguments consisting of claims, evidence, and warrants. Conversely, limited conceptual understanding, low participation in scientific discussions, and insufficient opportunities to practice evidence-based reasoning were identified as the main factors constraining students' argumentation performance. These findings suggest that chemistry instruction should provide more systematic opportunities for students to develop scientific argumentation through inquiry-based learning, classroom discussions, laboratory investigations, and assessment tasks explicitly designed to foster the integration of claims, evidence, and warrants. Such learning experiences are expected to strengthen students' scientific reasoning and contribute to the development of higher-order thinking and scientific communication skills required in twenty-first-century science education. This study found that the scientific argumentation abilities of Grade XI students on acid–base concepts differed between the two participating senior high schools in Jambi City. Students from SMA Negeri 1 Jambi City generally demonstrated higher scientific argumentation performance than those from SMA Negeri 5 Jambi City, particularly in constructing claims, evidence, and warrants based on Toulmin's Argumentation Pattern. The findings also indicate that students' argumentation skills were influenced by both internal factors, including conceptual understanding, critical thinking, motivation, and participation in classroom discussions, and external factors, such as instructional practices and opportunities to engage in evidence-based argumentation. These results highlight the importance of integrating argumentation-oriented learning activities and assessments into chemistry instruction to strengthen students' scientific reasoning and communication skills. Future research is recommended to investigate scientific argumentation using a broader and more diverse sample of schools, examine the effectiveness of specific argumentation-based instructional models, and explore the development of all components of Toulmin's Argumentation Pattern, including backing, qualifier, and rebuttal, to provide a more comprehensive understanding of students' scientific argumentation.

Acknowledgments

The authors would like to thank the Chemistry Education Study Program, Jambi University, for its support during this research. The authors also thank the principals, chemistry teachers, and students of SMA Negeri 1 Kota Jambi and SMA Negeri 5 Kota Jambi for their participation in this study.

Author Contributions

Conceptualization, S.B.W. and M.H.E.; methodology, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration, funding acquisition, S.B.W.; validation, M.H.E., W.S., and K. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

References

Allchin, D., & Zemplén, G. Á. (2020). Finding the Place of Argumentation in Science Education: Epistemics and Whole Science. *Science Education*, *104*(5), 907–933. https://doi.org/10.1002/sce.21589

Andrian, A., Solekhah, M., & Fitriani, N. (2025). Analisis Butir Soal Berbasis Multiple Representasi Kimia untuk Mengukur Pemahaman Konsep Siswa pada Materi Asam Basa. *Prosiding Seminar Nasional Pendidikan Kimia*, *4*(`1), 58–71. Retrieved from https://proceedings.radenfatah.ac.id/index.php/snpk/article/view/2109

Asli, S., Basheer, A., & Hugerat, M. (2023). Acid-Base Chemistry and Societal, Individual, and Vocational Aspects of Students' Learning. *Creative Education*, *14*, 943-960. https://doi.org/10.4236/ce.2023.145060

Benjamin, A. E. W. (2024). Studying the Student's Perceptions of Engagement and Problem-Solving Skills for Academic Achievement in Chemistry at the Higher Secondary Level. *Education and Information Technologies*, *29*, 8347–8368. https://doi.org/10.1007/s10639-023-12165-x

Bestari, I. A. P., Atmadja, A. T., Tika, I. N., & Suastra, I. W. (2025). Conditional Critical Thinking Gains: ATI Study of Homo Complexus in PBL–SSI Biology Education. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *11*(3), 1139–1155. https://doi.org/10.22219/jpbi.v11i3.42549

Dewi, C. A., Muhali, M., & Joselevich, M. (2025). Claim-Evidence-Reasoning-Based Interactive Modules to Improve Students' Argumentation Skills on Salt Hydrolysis. *Jurnal Pendidikan Progresif*, *15*(3), 1864-1882. https://doi.org/10.23960/jpp.v15i3.pp1864-1882

Dianti, P., Sunandar, A., & Setiadi, A. E. (2023). Analisis Penguasaan Konsep dan Kemampuan Berargumentasi Siswa dengan Model Argument Driven Inquiry Berbasis Socio-Scientific Issue. *Qalam: Jurnal Ilmu Kependidikan*, *12*(2), 1–14. https://doi.org/10.33506/jq.v12i2.2706

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the Norms of Scientific Argumentation in Classrooms. *Science Education*, *84*, 287-312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Edwin, E., Widiana, I. W., Lasmawan, I. W., & Suharta, I. G. P. (2025). Curriculum Transformation Towards Future Education. *Prima Magistra: Jurnal Ilmiah Kependidikan*, *6*(2), 122-132. https://doi.org/10.37478/jpm.v6i2.4907

Epinur, E., Fuldiaratman, F., Miharti, I., & Minarni, M. (2024). Development of Scientific-Based Learning Devices Implemented in the Inquiry-Flipped Classroom Learning Model to Improve Science Literacy in Acid-Base Material. *Jurnal Penelitian Pendidikan IPA*, *10*(12), 10509–10517. https://doi.org/10.29303/jppipa.v10i12.9517

Facione, P. (2015). *Critical Thinking: What It Is and Why It Counts*. Insight Assessment.

Faize, F. A., Husain, W., & Nisar, F. (2018). A Critical Review of Scientific Argumentation in Science Education. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(1), 475-483. https://doi.org/10.12973/ejmste/80353

Fitria, A. R., Hasnunidah, N., Fadiawati, N., & Suyatna, A. (2025). Enhancing Scientific Argumentation Through the Integration of Argument-Driven Inquiry and STEM in E-Worksheets for Secondary Science Education. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 263–272. https://doi.org/10.29303/jppipa.v11i7.11603

Fransiska, N. (2023). *Efektivitas Penerapan Model Predict Observe Explain (POE) Terhadap Kemampuan Argumentasi Siswa pada Materi Asam Basa* (Doctoral Dissertation). Universitas Jambi.

Galimova, E. G., Sergeeva, O. V., Zheltukhina, M. R., Sokolova, N. L., Zakharova, V. L., & Drobysheva, N. N. (2025). Mobile Learning in Science Education to Improve Higher-Order Thinking Skills and Communication Skills: Scoping Review. *Frontiers in Communication*, *10*. https://doi.org/10.3389/fcomm.2025.1624012

Hasnunidah, N., Meriza, N., Fadhila, S., & Rosidin, U. (2025). Impact of STEM-Integrated Argument-Driven Inquiry on Developing Scientific Argumentation in Indonesian Middle Schools. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 986–997. https://doi.org/10.29303/jppipa.v11i10.12912

Haudek, K. C., & Zhai, X. (2024). Examining the Effect of Assessment Construct Characteristics on Machine Learning Scoring of Scientific Argumentation. *International Journal of Artificial Intelligence in Education*, *34*(4), 1482–1509. https://doi.org/10.1007/s40593-023-00385-8

Hofstein, A., & Lunetta, V. N. (2004). The Laboratory in Science Education: Foundations for the Twenty-First Century. *Science Education*, *88*(1), 28–54

Jiménez-Liso, M. R., López-Banet, L., & Dillon, J. (2020). Changing How We Teach Acid-Base Chemistry. *Science & Education*, *29*(5), 1291–1315. https://doi.org/10.1007/s11191-020-00142-6

Larasati, I., Pramasdyahsari, A. S., & Harun, L. (2025). Enhancing Elementary Student's Numeracy Skills Through Ethnomathematics-Based Learning: An Analysis of Minimum Competency Assessment Results. *Journal of Honai Math*, *8*(1), 71–88. https://doi.org/10.30862/jhm.v8i1.861

Lestari, S., Indrowati, M., & Sari, D. P. (2021). Pengaruh Model Pembelajaran PLGI Terhadap Kompetensi Literasi Sains Ditinjau dari Kemampuan Akademik. *Jurnal Inovasi Pendidikan IPA*, *7*(1), 61–73. https://doi.org/10.21831/jipi.v7i1.29845

Maisarah, A., Zulaiqah, N. A., Fitri, A., Hakiki, N., Mulyani, S., & Ritonga, S. (2025). Pengaruh Metode Diskusi Kelompok dan Debat Terhadap Kemampuan Berfikir Kritis Mahasiswa. *Edu Society: Jurnal Pendidikan, Ilmu Sosial dan Pengabdian kepada Masyarakat*, *5*(2), 334-346. https://doi.org/10.56832/edu.v5i2.1163

Martin, P. P., Kranz, D., Wulff, P., & Graulich, N. (2024). Exploring New Depths: Applying Machine Learning for the Analysis of Student Argumentation in Chemistry. *Journal of Research in Science Teaching*, *61*(8), 1757–1792. https://doi.org/10.1002/tea.21903

McNeill, K. L., & Krajcik, J. (2012). *Supporting Grades 5–8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing*. New York: Pearson

Mikeska, J. N. & Lottero-Perdue, P. S. (2022). How Preservice and In-Service Elementary Teachers Engage Student Avatars in Scientific Argumentation within a Simulated Classroom Environment. *Science Education*, *106*, 980–1009. https://doi.org/10.1002/sce.21726

Montero, J. A. (2026). A Structured Guide to Univariate Test Selection Based on Normality, Variance Homogeneity, and Graphical Data Exploration. *Journal of Surgical Research*, *318*, 230-240. https://doi.org/10.1016/j.jss.2025.10.053

Murni, H. P., Azhar, M., Ellizar, E., Nizar, U. K. & Guspatni, G. (2022). Three Levels of Chemical Representation-Integrated and Structured Inquiry-Based Reaction Rate Module: Its Effect on Students' Mental Models. *Journal of Turkish Science Education*, *19*(3), 758-772. https://doi.org/10.36681/tused.2022.148

Osborne, J. (2010). Arguing to Learn in Science: The Role of Collaborative, Critical Discourse. *Science*, *328*(5977), 463–466.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the Quality of Argumentation in School Science. *Journal of Research in Science Teaching*, *41*(10), 994–1020.

Putri, E. U., Li, M., Stianingsih, L., Kom, M., & Isfahani, R. (2025). *Asesmen Bahasa Inggris Berbasis Pembelajaran Mendalam (Deep Learning) di Sekolah Menengah Atas*. PT. Revormasi Jangkar Philosophia.

Rodríguez-Mora, F., Cebrián-Robles, D., & Blanco-López, Á. (2022). An Assessment Using Rubrics and the RASCH Model of 14/15-Year-Old Students' Difficulties in Arguing About Bottled Water Consumption. *Research in Science Education*, *52*(4), 1075–1091. https://doi.org/10.1007/s11165-020-09985-z

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of Informal Reasoning in the Context of Socioscientific Decision Making. *Journal of Research in Science Teaching*, *42*(1), 112–138.

Saido, G. A. M., Siraj, S., DeWitt, D., & Al-Amedy, O. S. (2018). Development of an Instructional Model for Higher Order Thinking in Science Among Secondary School Students: A Fuzzy Delphi Approach. *International Journal of Science Education*, *40*(8), 847–866. https://doi.org/10.1080/09500693.2018.1452307

Sampson, V., & Blanchard, M. R. (2012). Science Teachers and Scientific Argumentation: Trends in Views and Practice. *Journal of Research in Science Teaching*, *49*(9), 1122–1148.

Saputri, L. R., & Suprihatiningrum, J. (2023). Kajian Literatur Model Pembelajaran Problem Based Learning (PBL) Materi Asam Basa untuk Meningkatkan Critical Thinking dan Green Chemistry Skill. *UNESA Journal of Chemical Education*, *12*(3), 225-236. https://doi.org/10.26740/ujced.v12n3.p225-236

Satriya, M. A., & Atun, S. (2024). The Effect of Argument Driven Inquiry Learning Models on Scientific Argumentation Skills and Higher Order Students on The Topics of Acid Base. *Jurnal Penelitian Pendidikan IPA*, *10*(5), 2663–2673. https://doi.org/10.29303/jppipa.v10i5.6834

Simon, S., Erduran, S., & Osborne, J. (2006) Learning to Teach Argumentation: Research and Development in the Science Classroom. *International Journal of Science Education*, *28*, 235-260. https://doi.org/10.1080/09500690500336957

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing Student 21st Century Skills in Selected Exemplary Inclusive STEM High Schools. *International Journal of STEM Education*, *6*, Article 39. https://doi.org/10.1186/s40594-019-0192-1

Sugiyono, S. (2014). *Mixed Methods Research Methods*. Bandung: Alfabeta.

Susanto, A., Azhar, M., Yerimadesi, Y., Nizar, U. K., & Serli, S. P. (2026). Validity and Practicality of AI-Integrated Interactive Chemical Equilibrium E-

Module Based on Structured Inquiry to Improve Students' Critical Thinking Ability. *Jurnal Penelitian Pendidikan IPA*, *12*(4), 913–921. https://doi.org/10.29303/jppipa.v12i4.14507

Toulmin, S. E. (2003). *The Uses of Argument (Updated Edition)*. Cambridge: Cambridge University Press.

Triana, D., Yusup, M., & Sriyanti, I. (2026). Socioscientific Issues Integration in Science Education for Developing Scientific Argumentation Skills and Supporting Sustainable Development Goals: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, *12*(4), 113–125. https://doi.org/10.29303/jppipa.v12i4.14813

Utami, S. S., Aisyah, R. S. S., & Affifah, I. (2022). Application of the Argument-Driven Inquiry Learning Model in Stimulating Students' Scientific Argumentation Skills on Acid-Base Material. *Jurnal Pendidikan Kimia Indonesia*, *6*(1), 38–45. https://doi.org/10.23887/jpk.v6i1.39162

Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press.

Zohar, A., & Nemet, F. (2002), Fostering Students' Knowledge and Argumentation Skills Through Dilemmas in Human Genetics. *J. Res. Sci. Teach.*, *39*, 35-62. https://doi.org/10.1002/tea.10008