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Enhancing Argumentation Skills of Prospective Chemistry Teachers through the 5E Learning Cycle Model

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Abstract:
This study aims to examine the development of pre-service chemistry teachers' argumentation skills during the completion of structured tasks embedded in the 5E Learning Cycle, as well as their responses to this training. Argumentation is a key component of effective chemistry learning; however, many pre-service teachers still lack confidence and the capacity to construct coherent, well-supported arguments. This research investigated the effectiveness of the 5E Learning Cycle model in strengthening argumentation skills using a quasi-experimental time-series design involving 71 students distributed across three classes in a chemistry review course. Data were collected through collaborative worksheets and individual pretest–posttest instruments and were analyzed using Toulmin's argumentation model. The findings indicate a progressive enhancement in students' argumentation performance, particularly in the formulation of claims, the use of data, and the articulation of warrants, backing, and rebuttals across topics such as chemical bonding, chemical equilibrium, acid–base chemistry, and organic chemistry. Nevertheless, a decrease in the quality of claims, warrants, and qualifiers was observed on the acid–base posttest, suggesting that certain content areas may require more targeted support. Overall, the results demonstrate that structured task-based

activities within the 5E Learning Cycle can effectively foster argumentation skills in pre-service chemistry teachers, while also highlighting the need for refinement in topic-specific implementation. This study contributes new insights into the design of argumentation-focused training in teacher education programs aimed at strengthening the professional competence of future chemistry teachers.

Keywords: argumentation skills; Learning Cycle 5E; worksheet; Toulmin argumentation model.

未来化学教师在5E学习循环培训中论证能力的发展

摘要：化学科学学习中的论证能力对准化学教师而言是一大挑战，尤其是那些缺乏自信、无法以结构化且高质量方式表达科学论点的准教师。对于准化学教师而言，掌握科学论证能力至关重要，因为这直接影响其思维能力和问题解决能力。然而现实是，他们目前并不具备这一能力。本研究旨在通过采用5E学习循环模型，结合时间序列设计，对71名参加学校化学复习讲座的三个班级进行培训，以提升准化学教师的论证能力。研究通过八次面对面授课，教授多个讲座主题，以追踪论证能力随时间的发展。通过工作表测量协作论证能力，而个体论证能力则通过前测和后测工具进行评估。评估采用图尔敏（Toulmin）论证模型。数据分析结果显示，通过培训，学生的论证能力随时间推移有所提升。在学习化学键、化学平衡、酸碱化学和有机化学等主题时，提出主张、数据、理由、支持、反驳和限定词等技能方面均有所提升。然而，在酸碱化学主题的后测中，提出主张、理由和限定词的技能有所下降。

关键词：论证技巧，5E学习循环，练习册，图尔敏论证模型

1. Introduction

The rapid advancement of science, technology, and information in the 21st century demands that learners develop a broad set of higher-order competencies, including science process skills, scientific literacy, argumentation, creative and critical thinking, and problem-solving abilities [1]. Within this landscape, the integration of scientific inquiry and argumentation into chemistry education is essential. Their combined use enables students to engage in epistemic practices that support the construction of authentic scientific knowledge and a deeper understanding of the nature of science.

Argumentation skills are particularly critical in chemistry learning because they underpin the meaningful acquisition of chemical concepts and the improvement of learning outcomes. Well-structured and increasingly complex argumentation allows students to deepen their understanding of scientific phenomena by formulating claims, justifying these claims, and providing appropriate evidence to support them. Previous studies have shown, for example, that students' argumentation in topics such as buffer solutions often remains at the level of simple claims or claims supported only by data, without the inclusion of rebuttals or critical evaluation of alternative explanations [2]. This indicates the need to systematically enhance the quality of instruction so that students are explicitly trained to advance their argumentation beyond basic claim–evidence structures.

Empirical research further suggests that several dimensions of critical thinking such as the use of strategies and tactics, the ability to provide simple and extended explanations, and the capacity to evaluate information are effectively fostered in STEM-based project learning [3]. Learners who possess well-developed critical thinking skills are better able to analyze problems, assess the credibility of arguments, and draw reasoned conclusions when solving problems and making decisions. The development of these skills requires deliberate and sustained practice, including exposure to multiple cases and to both logically sound and unsound arguments, so that students learn to discriminate between them [4].

In the context of chemistry education, critical thinking should be cultivated through active learning approaches that situate students in real-world problem contexts, foster interaction and dialogue among learners, and encourage the expression and negotiation of diverse perspectives. Students need time and structured opportunities to grapple with problems, generate

questions, and formulate well-founded arguments. The construction of such arguments can be organized around the essential components of scientific inquiry: (1) claims, (2) data, (3) warrants that connect data to claims, (4) backing to support the warrants, (5) rebuttals that challenge data, assumptions, or logic, and (6) qualifiers that indicate the strength and scope of the conclusions [2–4]. The evidence outlined above suggests that systematic practice in argumentation simultaneously promotes students' critical thinking skills.

To effectively train students in argumentation, an appropriate instructional model is required. Prior studies indicate that science process skills, levels of argumentation, and prospective science teachers' conceptual understanding can be enhanced through carefully designed argumentation-oriented learning environments [2–4]. Game-based argumentation learning, for example, has been reported to yield high levels of student engagement and advanced argumentation performance [5]. Among the available instructional frameworks, the Learning Cycle 5E model—comprising Engagement, Exploration, Explanation, Elaboration, and Evaluation has been shown to support meaningful learning and the development of argumentation skills. Within this model, argumentation training can be grounded in students' authentic experiences, thereby increasing their engagement and fostering both critical and creative thinking. Each phase of the 5E cycle provides opportunities for students to participate actively, construct and refine their own concepts, and iteratively improve the quality of their scientific arguments. Importantly, such training can be embedded in structured assignment activities, minimizing disruption to regular lecture schedules.

During the argumentation process, ideas are progressively elaborated as students reflect on their own reasoning and on the perspectives of their peers. The pedagogical objectives of incorporating argumentation into learning include: (1) equipping students with the skills to critically evaluate everyday claims and to accept or reject these claims based on available evidence; (2) using argumentation as a method of learning through group interaction and discussion, thereby facilitating knowledge construction and the integration of new evidence into existing cognitive frameworks; (3) emphasizing the dynamic and revisable nature of scientific knowledge, which can be updated when controversial issues are revisited in light of new evidence; and (4) training students to use forms of scientific discourse that are characteristic of specific disciplinary domains. Engaging students in argumentation thus not only strengthens their understanding of scientific concepts, but also nurtures critical thinking, scientific communication, and collaboration competencies that are indispensable in contemporary educational contexts.

For novice learners who still require substantial guidance in managing complex cognitive processes, the development of argumentation and problem-solving skills should be supported through adequate and gradually reduced scaffolding [1]. In this regard, the present study is designed to progressively cultivate students' argumentation and problem-solving abilities through structured training activities, thereby responding to the documented need for systematic, pedagogically sound interventions in chemistry education.

2. Method

This study employed a quantitative quasi-experimental approach using an equivalent time-series design implemented within an authentic higher education context. The target population comprised all pre-service chemistry teachers enrolled in the School Chemistry Review course in the Faculty of Teacher Training and Education (FKIP) at Tadulako University (Untad). A census sampling technique was adopted: all 71 students were included as participants and were distributed across three intact classes. These students, as pre-service chemistry teachers, were deemed suitable for the research aims, which focused on developing scientific and argumentative thinking skills in relation to school chemistry learning materials.

All participants received an identical instructional intervention consisting of exposure to course content, explanation of the learning procedures, provision of explicit argumentation skill guidelines, and administration of structured assignments using argumentation skill worksheets. Core learning activities were conducted face-to-face using a case study method, while structured assignments were completed outside regular class hours in separate training sessions. Within the case-based learning component, written examinations were administered after every two face-to-face meetings (including training activities), with each session lasting 50 minutes per credit unit. These examinations were intended to monitor the progression of students' problem-solving and argumentation performance. Training for completing the structured argumentation worksheets was implemented using the Learning Cycle 5E model. The primary focus of the present study is on students' performance in the structured assignments; outcomes from the case study examinations in lectures are considered a secondary, spillover ("herding") effect.

The research design followed an equivalent time-series structure, represented as:

O_1	X_1	O_2	X_2	O_3	X_3	O_4	X_4	O_5	X_5

where O_1, O_2, O_3, O_4, and O_5 denote repeated measurements of students' argumentation skills before and after successive cycles of structured-task training, and X_1–X_5 represent the corresponding instructional

interventions. The argumentation skill worksheets and test instruments were constructed around contextualized cases to capture the development of students' argumentation abilities over time. Both instruments underwent content and construct validation by experts in Chemistry Education. Revisions were made iteratively based on expert feedback until a valid set of instruments was obtained, as summarized in the research flow presented in Figure 1.

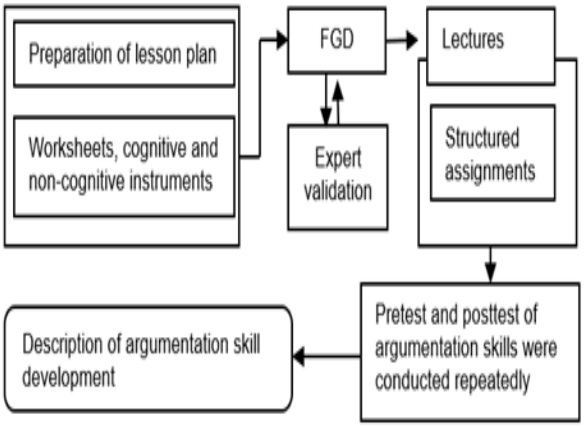


Figure 1. Research Flow

The training was operationalized through the Learning Cycle 5E model, encompassing the phases of engagement, exploration, explanation, elaboration, and evaluation; the detailed implementation of each phase is depicted in Figure 2. Data on argumentation skills were collected through: (1) a pre-test administered to each student prior to participation in the argumentation skills training associated with the structured assignments and post-tests administered after every two face-to-face sessions. In total, eight face-to-face sessions (corresponding to four action cycles) were conducted using student worksheets. Worksheet 1 addressed food-related contexts linked to chemical bonding; Worksheet 2 focused on body health in relation to chemical equilibrium; Worksheets 3 and 4 examined human health issues connected to acid–base chemistry and organic chemistry. (2) A response questionnaire was administered to gather students' perceptions of the implementation of the argumentation skills training in solving the structured problems.

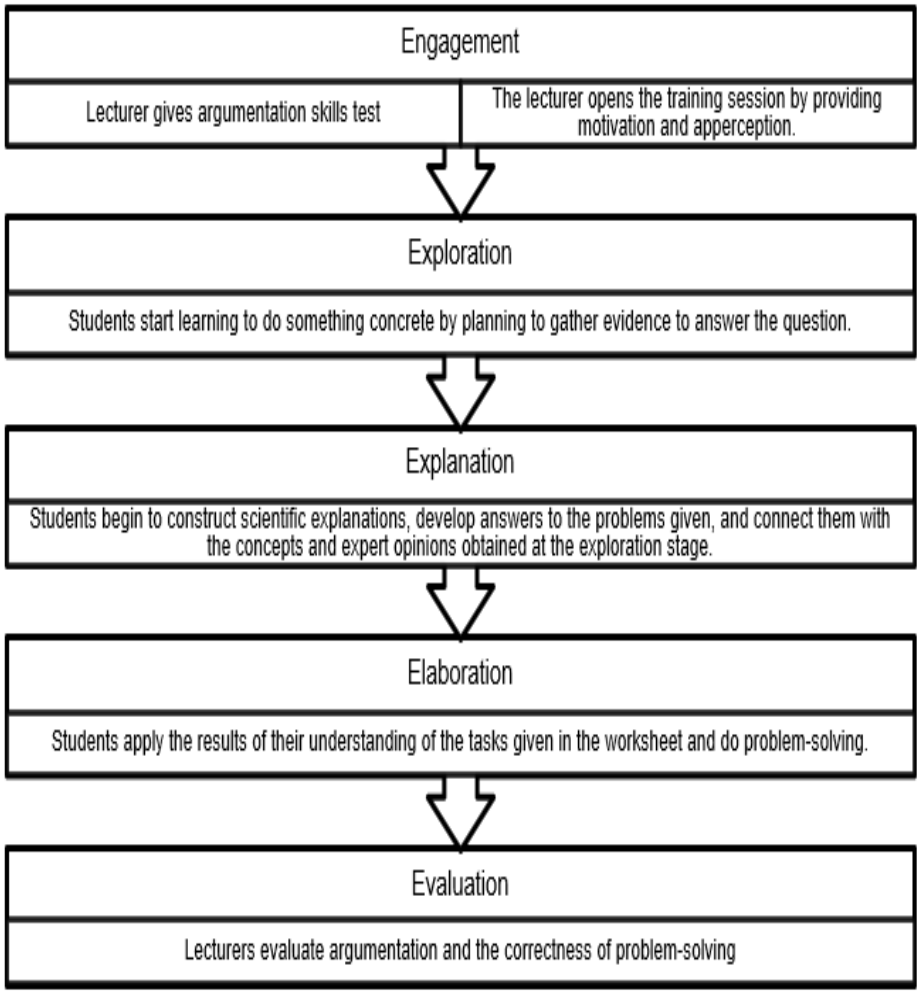


Figure 2. Stages and Activities of Training Argumentation Skill with Learning Cycle 5E (developed by the authors)

Data analysis techniques were carried out by: 1) assessment of argumentation skills with Toulmin model. 2) Determination of the results of student response questionnaire analysis. 3) The development of argumentation skills is said to be achieved if there is an increase in achievement based on point 1 above.

3. Result

The research results obtained were the argumentation skills of pre-service chemistry teachers and data on their responses to the argumentation skills training activities they got. The instrument used to train argumentation skills is the Worksheet. The instrument was used to explore the individual argumentation skills of chemistry teacher candidates using the argumentation skills test instrument. Both instruments were validated by chemical education experts, and the results obtained are described as follows :

3.1. Instrument validation result

The results of the validity assessment of the argumentation skills test instruments were obtained at 0.7 which indicated that the instrument was declared valid so that it could be used to collect data correctly. The assessment results were strengthened by the recommendations of the validators and the results are shown in Table 1.

The data in Table 1 shows that the argumentation skills test and worksheets made to train argumentation skills can be used to reveal the argumentation skills of pre-service chemistry teachers through training using Learning Cycle 5E after minor improvement.

Table 1. Validators assessment result (compiled by the authors)

No	Instrument	Recommendation	Follow up
1	Argumentation skills test	Validator 1: Can be used Validator 2: Can be used with minor improvements	Has been improved according to the validator's suggestions
2	Argumentation skills worksheet	Validator 1: Can be used with minor improvements Validator 2: Can be used with minor improvements	

3.2. Result of argumentation skills training

Data on students' argumentation skills development was measured using a validated argumentation skills test. The test was conducted before and after the argumentation skills training. The pretest and posttest were in the form of environmental and human health problems for all teaching topics/materials on which argumentation skills were trained. The argumentation skills training consisted of four actions, and each action was conducted twice face-to-face. During the argumentation skills training, students used worksheets that were done collaboratively. Data on argumentation skills during the training is shown in Figure 3.

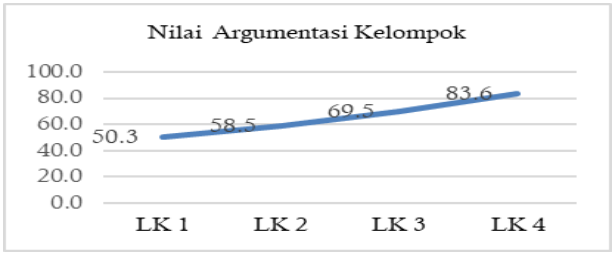


Figure 3. Argumentation skill trend with Learning Cycle 5E (developed by the authors)

Figure 3 shows a steady improvement in students' argumentation skills across the four worksheets (LK). The average score increased from 50.3 in LK 1 to 83.6 in LK 4. Furthermore, data on students' argumentation skills measured individually from pretest and posttest result can be seen in Figure 4.

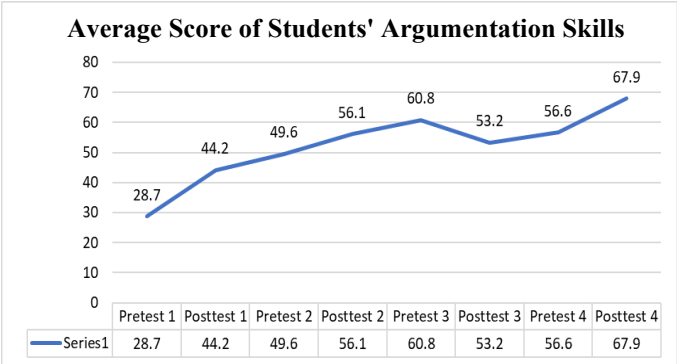
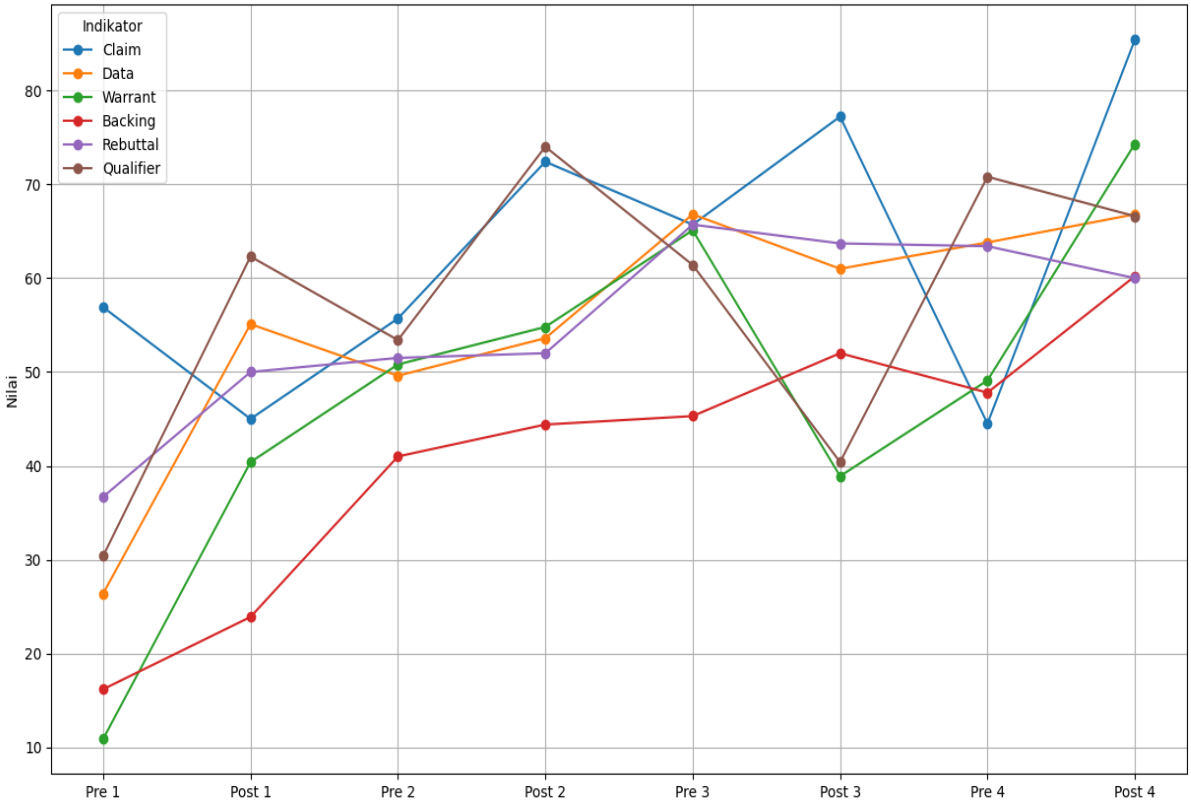


Figure 4. Individual argumentation skills trend (developed by the authors)

Figure 4 shows a gradual increase in students' individual argumentation skills over the four training sessions. The average score rose from 28.7 in Pretest 1 to 67.9 in Posttest 4.

3.3. Argumentation skills for each argumentation aspect

Trend on the development of students argumentation skills score for aspect measured, namely: claim, data, warrant, backing, rebuttal, and qualifier presented in Figure 5



Indikator	Pre 1	Post 1	Pre 2	Post 2	Pre 3	Post 3	Pre 4	Post 4
Claim	56.9	45.0	55.7	72.4	65.7	77.21	44.5	85.4
Data	26.4	55.1	49.6	53.6	66.8	61.0	63.8	66.8
Warrant	10.9	40.4	50.8	54.8	65.1	38.9	49.1	74.3
Backing	16.2	23.9	41.0	44.4	45.3	52.0	47.8	60.2
Rebuttal	36.7	50.0	51.5	52.0	65.7	63.7	63.4	60.0
Qualifier	30.4	62.3	53.4	74.0	61.4	40.4	70.8	66.6

Figure 5. Trend of Argumentation Skill Per Aspect (developed by the authors)

Figure 5 shows the trend in argumentation skill scores across six aspects. Overall, claims, warrants, data, and backing improved during the training. Meanwhile, rebuttals and qualifiers experienced lower increases, with a fluctuating pattern. This indicates that students' claim-building and logical reasoning skills developed significantly, while rebuttals and qualifiers required more reinforcement in the learning process.

3.4. Response of chemistry teacher candidate students to the implementation of argumentation skills training

The training activities to improve students' argumentation skills ended with the collection of student responses to the implementation of actions in the form of training. Data on student responses obtained after participating in a series of learning activities using the Learning Cycle 5E to train the argumentation skills of prospective chemistry teachers are given in Table 2. Student responses are said to be very good if the number of students who respond to certain aspects is in the range of 85%-100%, good if it is in the range of 70%-84.9%, less good in the range of 55%-69.9%, and not good if less than 55%.

Table 2. Response of pre-service chemistry teachers to the implementation of argumentation skills training (compiled by the authors)

No	Aspect	Percentage	
1	Aspect of feeling	Pleased (%)	Not pleased (%)
	a. The way lecturers teach	100	0
	b. Worksheets used	70	30
	c. Learning media used	96	4
	d. classroom learning atmosphere	96	4

	e. how the lecturer responds	100	0
	Average aspect of feeling	93	7
2	Aspect of novelty	New (%)	Not new (%)
	a. Worksheets used	56	44
	b. classroom learning atmosphere	52	48
	c. Learning media used	59	41
	d. The way lecturers teach	70	30
	Average aspect of novelty	59	41
3	Aspect of interest	Interested (%)	Not Interested (%)
	Interest in participating in learning activities like this again	67	33
4	Aspect of impact	Impact (%)	No impact (%)
	Impact on the ability to solve problems, critical thinking and argumentation	85	15
5	Aspect of understanding worksheets and training strategies	Yes (%)	No (%)
	a. Understanding of the language used in the worksheets	78	22
	b. Interest in the problem-solving methods used in the worksheets	70	30
	Average aspect of understanding worksheets and training strategies	74	26
	Average of all aspects	77	23

The data in Table 3 shows that in general, chemistry teacher candidates responded well to the implementation of argumentation skills training. This is evidenced by the results of student responses with an average of 77% in all aspects, namely: aspects of feelings, novelty, interest, impact, and aspects of understanding of the worksheets and the training strategy used (Learning Cycle 5E).

4. Discussion

Students' argumentation skills during training from meeting one to four show continuous improvement when using the Learning Cycle 5E model (Figure 3).

There were four topics covered during the argumentation skills training actions, namely: 1) chemical bonding; 2) chemical equilibrium; 3) acid-base; and 4) organic chemistry in daily life. There is a significant development of argumentation skills over a while when learning about chemical bonds and chemical equilibrium, up to the acid-base pretest, but argumentation skills decreased during the acid-base topic posttest, and then there was a significant increase again on the topic of organic chemistry (Figure 4).

The problem given on the pretest of acid-base topic (pretest 3) was about neutralization reactions in the environment familiar to students' lives, and the problem on the posttest (posttest 4) was about hydrolysis related to food preservation. The high average argumentation skills of students on the pretest occurred in almost all aspects of argumentation skills, five out of six aspects of argumentation skills, namely claims, data, warrant, rebuttal, and qualifier, but when students were tested for their ability to argue in the posttest, they were only able to have three of the six expected argumentation skills, namely claims, data, and rebuttal while warrant, backing, and qualifier indicated low. This low ability is thought to be because when arguing to solve complex problems that are rarely found in their daily lives, students have not been able to provide logical explanations for the statements they claimed and do not understand the concept of hydrolysis well. Hydrolysis is the basic concept of preserving packaged food on the question given during the post-test (Click link). This also causes them to be unable to provide good conclusions (qualifier). It can be said that pre-service chemistry teachers have not been able to link abstract concepts with factual knowledge that is rarely found in everyday life, which impacts their argumentation skills. However, compared to the findings by Devi which examined students' argumentation skills on the topic of buffer solutions, they were only able to claim and claim with data.

When viewed from the aspects of students' argumentation skills on each topic specifically (Figure 5): a) students' skills in making claims on chemical bonding, equilibrium, and acid-base increased but fell on organic chemistry. b) Students' ability to provide data in sequence that supports claims on chemical bonds, chemical equilibrium, acid-base, and organic chemistry has increased in the pretest and posttest, indicating that their ability to provide facts based on data to convince claims has developed. c) Students' skills in warrant improved over time with diverse themes, but they dropped in the acid-base topic posttest. Claims also have this condition. d) The backing shows that students can connect theory, claims, and data. This skill is well-developed on all topics. e) Students' capacity to do rebuttal on the claim statements showed good improvement on all areas, as did data and warrant. f) Students' ability to draw conclusions (qualifiers) has improved across topics, although it has declined on acid-base.

Based on these findings, it can be concluded that the trajectory of students' argumentation skills over the course of the training improved significantly across all components. However, a decline was observed in the claim, warrant, and qualifier components in posttest 3. Nisa [2] grouped students into levels of argumentation that they developed and then provided targeted training; their results showed that, overall, students were able to construct arguments at all levels, yet one aspect

remained particularly challenging, namely the warrant. In line with their findings, the present study suggests that the warrant component should be a consistent focus whenever argumentation-based instruction is implemented.

Students' errors in formulating appropriate claims are likely attributable to their limited familiarity with, and insufficient information about, the mechanisms of action of chemical preservatives in packaged foods [3]. These inaccuracies negatively affect the warrant component, as students are unable to provide logical justifications for their claims, which in turn undermines the quality of their conclusions. Overall, the results indicate that students' argumentation skills improved after training with the 5E Learning Cycle, both in group work and in individual tasks.

Students' responses presented in Table 2 can be summarized as follows: (1) almost all students (93%) reported that they were satisfied with the way the class was managed, as well as with the media and worksheets used by the lecturer; (2) more than half of the participating students indicated that the activity was new to them particularly the lecturer's instructional approach and expressed an interest in taking part in similar activities in the future. It appears that during this training students were motivated to formulate claims in response to the given problems and even to challenge claims they perceived as inappropriate. (3) Eighty-five percent of students stated that the argumentation-skills training enhanced their ability to argue, think critically, and solve problems. This self-report is supported by the pretest and posttest data, which show a significant improvement over time in almost all components of argumentation skills (Figure 5). Students' positive affect toward the training is further reinforced by their statements regarding their level of understanding of the worksheet content and their interest in the 5E Learning Cycle–based training model.

These results support an inquiry-based constructivist perspective, according to which students should be actively involved in constructing knowledge through meaningful learning experiences [5]. When students are given structured tasks within the 5E Learning Cycle framework, they explore, articulate, and reflect on their scientific ideas, thereby developing critical and argumentative thinking skills. The observed development of argumentation skills such as the ability to formulate claims, provide data, construct warrants, and supply backing indicates that the instructional process effectively fostered students' argumentation competencies in accordance with Toulmin's model of scientific argumentation.

This study also offers practical evidence that integrating the 5E Learning Cycle with structured argumentation tasks can constitute an effective instructional approach in the preparation of prospective chemistry teachers. Designing assignments that systematically require students to produce claims, data, warrants, backing, rebuttals, and qualifiers can enhance their readiness to implement argumentation-based instruction in their future classrooms. These findings are consistent with previous research that has highlighted the importance of formative assessment, feedback, and active student engagement in improving the quality of teacher education.

5. Conclusion

The findings of this study demonstrate a consistent enhancement in the argumentation skills of pre-service chemistry teachers following training with structured tasks implemented within the 5E Learning Cycle model. Improvements were observed across all components of argumentation claims, data, warrants, backing, rebuttals, and qualifiers. The most substantial gains occurred in the domains of claims and warrants, indicating that students became more capable of formulating clear, defensible statements and articulating coherent lines of reasoning. Enhanced performance in the data and backing components further suggests that, with sustained practice, students' ability to connect empirical evidence to relevant scientific theories also strengthens over time. Analysis of student responses revealed a positive disposition toward this learning approach: 77% of participants reported satisfaction with the training and perceived a meaningful impact on their critical thinking and problem-solving abilities.

From a theoretical standpoint, the results support the view that systematic practice of argumentation through structured tasks in the 5E Learning Cycle promotes the development of scientific reasoning and argumentation, largely due to its emphasis on inquiry-oriented cognitive processes. Practically, the model provides a structured and reflective framework that enables pre-service chemistry teachers to embed argumentation training into existing course structures without disrupting the flow of regular instruction. Future research should examine how integrating the 5E Learning Cycle and structured tasks with digital tools or collaborative online platforms might further strengthen students' use of evidence and reasoning. In addition, extending this line of inquiry to other scientific disciplines and employing qualitative discourse analysis could yield deeper insights into how argumentation evolves throughout the problem-solving process.

Declarations

Author Contributions

Conceptualization, Ijirana; methodology, Ijirana; validation, Ijirana, Tri Santoso and Magfirah; formal analysis, Ijirana; investigation, Magfirah, Yuli Nurmayanti, Irwan; resources, Ijirana, Tri Santoso and

Magfirah; data curation, Magfirah; writing—original draft preparation, Ijirana; writing—review and editing, Magfirah; visualization, Magfirah; supervision, Ijirana, Tri Santoso; project administration Ijirana; funding acquisition, Ijirana. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

This study is based entirely on secondary data. All datasets analyzed in this article were obtained from previously published sources and institutional records that are properly cited in the manuscript. No new primary data were generated.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

Use of Artificial Intelligence Tools

The authors used an artificial intelligence–assisted language model (ChatGPT, OpenAI, San Francisco, CA, USA) solely to support the improvement of academic English writing. Specifically, the tool was employed to (i) refine grammar, syntax, and clarity of sentences, (ii) suggest alternative academic phrasing, and (iii) help restructure some paragraphs for better coherence and readability. All scientific ideas, research design, data analysis, interpretations, and conclusions originated from the authors. The AI tool was not used to generate research data, perform statistical analyses, create or select references, or make substantive intellectual contributions to the study. Every AI-assisted text suggestion was critically reviewed, edited, and approved by the authors, who take full responsibility for the content of the manuscript.

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