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Implementation of Evidence-Based Research Project-Based Learning in Chemistry Practicum to Improve Students' Conceptual and Argumentation Skills

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ABSTRACT

This study is motivated by the importance of improving students' conceptual understanding and scientific argumentation skills in chemistry practicum, particularly on the topic of acids and bases. It aims to evaluate the effectiveness of the Project-Based Learning (PjBL) model combined with the Evidence-Based Research (EBR) approach in supporting both aspects. This study employs a descriptive quantitative approach using a pre-experimental one-group pretest–posttest design The research subjects were 26 Chemistry Education students who participated in two cycles of practicum. Data were collected through a conceptual understanding test and report analysis using the Toulmin Argumentation Pattern (TAP) rubric, then analyzed descriptively. The results showed an increase in the average conceptual understanding score from 11.81 to 13.15, and the TAP score from 10.46 to 14.15. Most students demonstrated positive development in both aspects. These findings indicate that the PjBL–EBR model is effective in fostering scientific thinking, constructing data-based arguments, and engaging actively during the practicum. The implementation of this model is relevant for exploration-based practicums and is recommended for other chemistry topics. These findings indicate that the PjBL–EBR model is effective in encouraging students to think scientifically, construct evidence-based arguments, and actively engage during practicum activities. This model is considered relevant for exploratory-based practicums and has the potential to be applied to other chemistry topics.

INTRODUCTION

Chemistry learning, as an integral part of science education, plays an important role in developing students' conceptual understanding, scientific process skills, and critical thinking abilities. In this case, practical activities play a very important role and cannot be separated from the learning process. Through practical activities, students not only learn concepts theoretically but also gain direct experience by observing and exploring chemical phenomena in the laboratory. This activity provides opportunities for students to actively engage in the scientific process, such as designing experiments, collecting and analyzing data, and drawing conclusions based on the results obtained (Hamid et al., 2024). Thus, practical work becomes a tangible means of bridging theory and practice, while training students in constructing rational and evidence-based scientific arguments.

However, the implementation of practical work in higher education still faces various obstacles. Generally, practicum activities are carried out with a mechanistic approach, where students are only asked to follow instructions sequentially without any room for critical thinking, independent exploration, or active problem solving. This condition hinders the development of higher-order thinking skills, such as the ability to analyze, evaluate, construct logical arguments, and understand concepts in depth. In addition, students often focus more on achieving experimental results without fully understanding the scientific process they are undergoing. Aisyah et al. (2024) states that these limitations can be overcome through a project-based approach that not only increases active engagement but also trains students' critical thinking and scientific argumentation skills. A similar point is emphasized by (Purwanti et al., 2022), which shows that the effective implementation of Blended Project-Based Learning can improve students' conceptual understanding and develop higher-order thinking skills that are integrated with practical activities.To address this, a learning approach is needed that is not only results-oriented but also emphasizes the learning process, thereby encouraging students to actively engage in laboratory activities. Scientific argumentation is essential in chemistry laboratory practice because it enables students to justify their claims using evidence and scientific reasoning. It represents a central component of scientific investigation, as it allows learners to articulate their reasoning, connect observational data with chemical concepts, and understand how scientific knowledge is constructed and validated. Recent research has also shown that many students still struggle to provide valid evidence and coherent explanations during laboratory tasks, indicating that their argumentation skills are not yet well developed (Zaroh et al., 2022)**.** Therefore, explicit instruction and assessment of scientific argumentation are needed to strengthen students’ reasoning processes and enhance the overall quality of chemistry laboratory learning. To reinforce this point, recent research on local-wisdom-based worksheets with a STEAM approach in acid–base topics demonstrates that practicum activities designed to promote active discussion, problem solving, and reflection can significantly improve students’ conceptual understanding, affective engagement, and psychomotor performance (Salamiyah et al., 2023). Such findings support the view that chemistry laboratory learning should integrate structured opportunities for students to construct and justify claims using experimental evidence, so that practical work functions not only as a procedural activity but also as a context for developing scientific argumentation skills.

Chemistry education students who are preparing to become teachers must have a thorough understanding of concepts and theories through practical activities. Practical work allows students to link directly observed phenomena with abstract scientific ideas, thereby building connections between the domains of observation and ideas (Spaan et al., 2025). In this process, students need to be trained to develop critical thinking skills, explore problems independently, and develop solutions based on experimental data. Practical work designed with a scientific approach is also an effective means of building pedagogical skills, as students learn not only to understand concepts but also how to explain them scientifically to learners (Oliveira & Bonito 2023; Shana & Abulibdeh 2020). Thus, practicums are not only a means of obtaining experimental data, but also a space for professional training for prospective teachers. For this reason, a learning approach is needed that is not only results-oriented, but also emphasizes the thinking process and active learning experiences of students in laboratory activities. However, despite the importance of conceptual and argumentation competencies, previous studies have emphasized that the assessment of students’ conceptual understanding in chemistry especially on acid–base topics remains limited. Many learners still experience substantial conceptual difficulties, such as misunderstanding acid–base strength, pH calculation, and indicator interpretation, which indicates that assessment practices have not yet supported deeper diagnostic feedback. Similar findings were reported by Zaroh et al. (2022), who noted that the evaluation of scientific argumentation skills among pre-service chemistry teachers is often not conducted systematically. This gap suggests that many prospective teachers enter laboratory courses without receiving adequate feedback on their reasoning and evidence-based explanations, potentially hindering their ability to link experimental data with scientific concepts. In line with this, (Salamiyah et al., 2023) highlight that even when practicum worksheets are implemented, students still require structured guidance to interpret data correctly and justify claims using appropriate evidence. Strengthening assessment related to conceptual understanding and scientific argumentation is therefore essential to improving the quality of chemistry laboratory learning.

To overcome the limitations of conventional practical training, the Project-Based Learning (PjBL) model is an innovative approach that provides contextual and meaningful learning experiences. PjBL encourages students to work in teams, complete real projects, and reflect on their learning outcomes through an authentic scientific process (Purwanti et al., 2022). When integrated with *Evidence-Based Research* (EBR), PjBL is able to instill a culture of scientific thinking, where students not only carry out experiments but also perform critical analysis based on valid data. Research by Wahyudiati et al. (2022) found that the application of Project-Based Learning significantly improved the critical thinking skills and *problem-solving skills* of prospective chemistry teachers in the General Chemistry course. Thus, the combination of *Project-Based Learning* (PjBL) and *Evidence-Based Research* (EBR) is believed to enrich the quality of chemistry laboratory learning through an authentic scientific process approach based on experimental data.

In the context of acids and bases, a structured Project-Based Learning (PjBL) approach with evidence-based analysis provides students with a great opportunity to understand chemistry concepts in a more in-depth and contextual manner. Practicals designed in the form of projects encourage students to actively and collaboratively explore the relationship between pH, changes in natural indicators, and observation data. This approach allows students to be directly involved in the actual scientific process, from designing experiments, collecting and analyzing data, to constructing scientific arguments based on the evidence found. Several studies state that PjBL not only encourages conceptual understanding but also develops critical thinking skills and builds scientific arguments. Pratiwi & Ikhsan (2024) show that the application of PjBL in chemistry learning contributes greatly to improving students' mastery of concepts and higher-order thinking skills. Meanwhile, Istiqomah et al. (2022) emphasize that conducting project-based practicums that integrate critical thinking skills can increase students' active involvement in the scientific process and encourage them to express ideas logically, systematically, and based on experimental data. These research results are in line with the findings of Pratiwi & Ikhsan (2024), who stated that the application of Project-Based Learning (PjBL) significantly improves the mastery of chemistry concepts through meaningful experimental activities. In the context of science learning, conceptual understanding is a basic skill that enables students to not only memorize scientific facts, but also understand the relationships between concepts, principles, and phenomena observed in the field (Wahyudiati et al., 2022). Therefore, this study aims to implement and examine the effectiveness of PjBL combined with the Evidence-Based Research (EBR) approach in improving students' conceptual understanding and scientific argumentation skills through acid-base practicums. Recent research emphasizes the need for innovative chemistry learning models that enhance students' engagement and understanding. (Paristiowati et al., 2024) found that integrating new instructional models with digital tools significantly improves student activity and learning outcomes. In line with this, the present study offers a contribution to the development of practicum learning models by implementing a PjBL–EBR approach that promotes evidence-based scientific practice and supports the competencies required for pre-service chemistry teachers.

METHODS

Research Design

This study employs a descriptive quantitative approach using a pre-experimental one-group pretest–posttest design. This design measures students' conceptual understanding and scientific argumentation skills before and after the PjBL–EBR intervention. A pretest was conducted to assess students' initial knowledge, followed by the instructional treatment, and a posttest was administered to determine learning gains. Similar one-group pretest–posttest procedures have been used in recent chemistry education studies to analyze learning outcomes, such as measuring conceptual changes (Mayasri et al., 2023) and evaluating the effectiveness of instructional materials. In addition, studies on acid–base learning have shown that pretest–posttest analysis is effective for identifying students' conceptual gains using statistical indicators such as N-Gain, as demonstrated in research on the REACT model for acid–base topics (Lestari et al., 2021). Therefore, this design is appropriate for determining the effectiveness of the PjBL–EBR approach in this study.

Research Target

The research subjects were 26 students from the Chemistry Education Study Program at Mulawarman University who participated in acid–base practicum activities in the even semester of the 2024/2025 academic year. The participants were selected using purposive sampling, considering their active involvement in practicum sessions. Purposive sampling is commonly used in educational research when participants are chosen based on specific characteristics relevant to the study objectives, ensuring the credibility and suitability of the sample (Cahyani & Gusman et al., 2023) (Mayasri et al., 2023). In this study, students' consistent engagement and prior experience in laboratory activities were essential criteria to obtain meaningful data regarding conceptual understanding and scientific argumentation performance.

Research Data

The research data consisted of assessments of students' conceptual understanding and scientific argumentation performance obtained through conceptual tests and student laboratory reports.

Research Instruments

Data collection was carried out using two main types of instruments, namely conceptual understanding tests and scientific argumentation ability analysis. These two instruments were analyzed based on the practical reports compiled by students after conducting the experiments. The conceptual test evaluated students' mastery of pH concepts, acid-base properties, and changes in natural indicator colors. Meanwhile, scientific argumentation skills were analyzed using a rubric based on the Toulmin Argumentation Pattern (TAP), which includes four main elements: claim, data, justification (warrant), and argument coherence. Details of the indicators for each instrument are shown in Table 1 and Table 2.

Table 1. Assessment Grid for Students' Conceptual Understanding in the Acid-Base Laboratory

No	Conceptual Understanding Indicators	Description	Score
1	Understanding of acid-base concepts	Students did not provide any answers	0
		Students only mention the terms acid or base without explaining pH	1
		Students mentioned the pH and properties of the solution, but it did not match the theory.	2
		Students explain pH and acid-base properties using general theory, but their explanation is incomplete.	3

No	Conceptual Understanding Indicators	Description	Score
		Students explain pH, acid-base properties, and the relationship between theory and practice completely and coherently	4
2	Understanding of synthetic and natural indicators	Students did not provide any answers at all.	0
		Mentioned that both synthetic and natural indicators change color without explaining the cause	1
		Explaining the color change, but not relating it to the compound structure or pH	2
		Explains the color change and structure of synthetic and natural indicators in general	3
		Explains changes in indicator structure (e.g., anthocyanin/flavylium ion) due to pH accurately	4
3	Connection between data and concepts	Students did not provide any answers at all.	0
		Mentioned the practical data (color, pH) without connecting it to the acid-base concept	1
		Connecting data to concepts, but inaccurately or illogically	2
		Connecting data and concepts with some scientific explanations	3
		Linking data and concepts with accurate and logical theoretical explanations	4
4	Use of scientific terms	Students did not provide any answers at all	0
		Students use general terms without scientific context	1
		Using some scientific terms but not correctly	2
		Using most scientific terms correctly	3
		Consistently uses scientific terms correctly and in accordance with the context of chemistry	4

(Latumapina et al., 2024)

Table 2. Assessment Grid for Student Scientific Argumentation Using the Toulmin Pattern (TAP)

Score	Definition (TAP Components)	Example (in the context of synthetic indicators/natural indicators)
0–1 points	**No argumentation or misconception.** The answer only mentions color or conclusions without scientific basis. Does not include data or is incorrect in interpretation.	"The solution turns red, so it's a base." *(misconception – 0 points)*"The pH is acidic because the color is red" *(claim without clear data – 1 point)*
2 points	**Claim + data** The answer includes a claim and observational data (color or pH), but does not include a scientific explanation (warrant).	"The indicator color changes to red at pH 3, so the solution is acidic." (*claim + data*)
3 points	**Claim + data + warrant (macroscopic explanation)** The answer explains the relationship between the data and the claim based on general theory, but does not involve the particle/submicroscopic level.	"The solution is acidic because its color is red at pH 3. This is consistent with the properties of synthetic and natural indicators that change color at certain pH levels."
4 points	**Claim + data + warrant + backing (complete explanation)** The answer includes: - Accurate claim - Data (color and pH) - Warrant (basic chemical explanation) - Backing (mechanism of anthocyanin structure change in acidic and basic conditions) - Coherent and logical	"The solution is red at pH 3, indicating acidic properties. Both synthetic and natural indicators such as anthocyanin change color depending on pH. Under acidic conditions, the anthocyanin structure is predominantly in the form of a flavylium cation (backing), which produces a red color.

(Uzuntiryaki-Kondakci et al., 2021)

Data Analysis

The data obtained were analyzed quantitatively using a descriptive approach. The analysis was conducted on students' conceptual understanding and scientific argumentation scores, both individually and in groups, using laboratory reports from experiment 9 as pretest data and experiment 10 as posttest data. Student scores were classified into several categories to identify achievement patterns, namely 8–9, 10–11, 12–13, 14–15, and the maximum score (16). In addition, score changes from experiment 9 (pretest) to experiment 10 (posttest) were examined to identify patterns of improvement, decline, or stability for each student. To strengthen the interpretation of high performance, two additional indicators were used: scores above 13 (indicating strong mastery) and a score of 16 (indicating full mastery of all assessment indicators), applied to both conceptual understanding and scientific argumentation.

To provide a broader methodological basis, this study also refers to simple statistical techniques commonly used in single-group pretest–posttest designs in chemistry education research, namely the gain score method (posttest – pretest). Gain scores are often used to evaluate the magnitude of improvement and learning effectiveness, as reported by Mayasri et al. (2023). The determination of score ranges and performance categories refers to Brookhart's (2013) numerical rubric principle, where the highest score indicates the most complete achievement of learning objectives. Overall, this analysis strategy provides a strong quantitative basis for evaluating the effectiveness of the PjBL–EBR model in practical learning.

RESULTS AND DISCUSSION

Students' Conceptual Understanding

Conceptual understanding was assessed based on four indicators, namely: understanding of acid-base concepts, understanding of natural indicators, the relationship between data and concepts, and the use of scientific terms. Both experiments conducted, namely the pretest and posttest, were assessed using these conceptual aspects. Figure 1 shows the distribution of students based on their conceptual understanding scores on the pretest and posttest. There was a shift in the number of students to the higher score category on the posttest. In the pretest, most students were in the 8–13 score range, with 6 students in the 8–9 category, 6 students in the 10–11 category, and 5 students in the 12–13 category. Meanwhile, in the posttest, the number of students in these categories decreased to 2, 1, and 13 students, respectively. Conversely, a significant increase in the number of students was seen in the high score categories. The number of students who scored 14–15 increased from 1 to 2, and in the maximum score category (16), it increased from 7 to 8. This distribution pattern shows that most students experienced an increase in their mastery of acid-base concepts after participating in experiment 10 (posttest). This indicates that the application of the Evidence-Based Research (EBR)-based Project-Based Learning (PjBL) model has a positive impact on students' conceptual understanding.

These findings are in line with the results of the study (Yulizah et al., 2025) which emphasizes the importance of developing project-based acid-base chemistry teaching materials to improve conceptual understanding and critical thinking skills. Furthermore, these results are supported by a systematic review by Yanti and Novaliyosi (2023) which concluded that the PjBL model is effective in developing various academic skills at different levels of education, including conceptual, collaborative, and problem-solving skills. This model encourages students to construct conceptual meaning through active engagement in evidence-based experiments and discussions

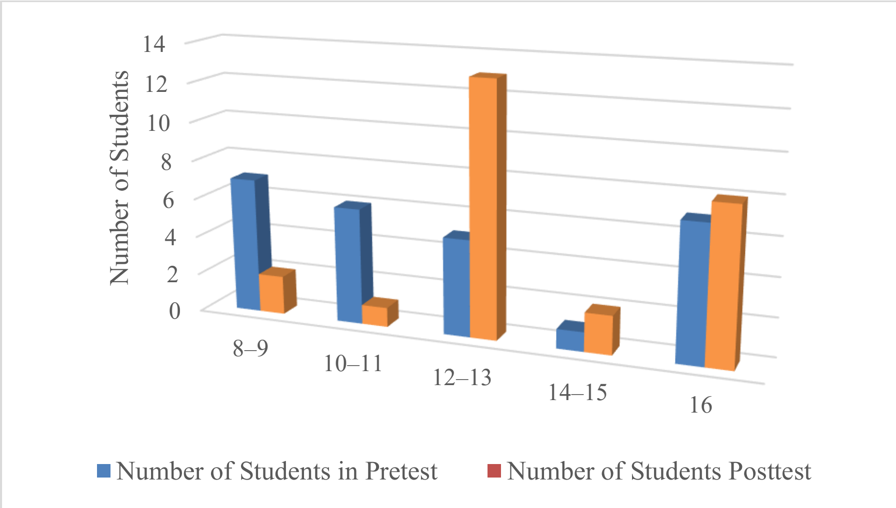

Figure 1. Conceptual Understanding Score Categories

The number of students with scores >13 and a maximum score of 16 is presented in Figure 2, showing the number of students who obtained conceptual understanding scores above 13 and the maximum score (16) on the pretest and posttest. On the pretest, only 1 student obtained a score above 13, and 7 students achieved the maximum score. Meanwhile, in the posttest, the number of students with scores above 13 increased to 2, and the number who achieved the maximum score rose to 8. Although the increase appears limited, this pattern shows that some students managed to achieve a more complete mastery of the concepts after taking the posttest. The increase in the number of students with the highest scores reflects the successful implementation of the Project-Based Learning (PjBL) model integrated with Evidence-Based Research (EBR) in encouraging optimal learning outcomes.

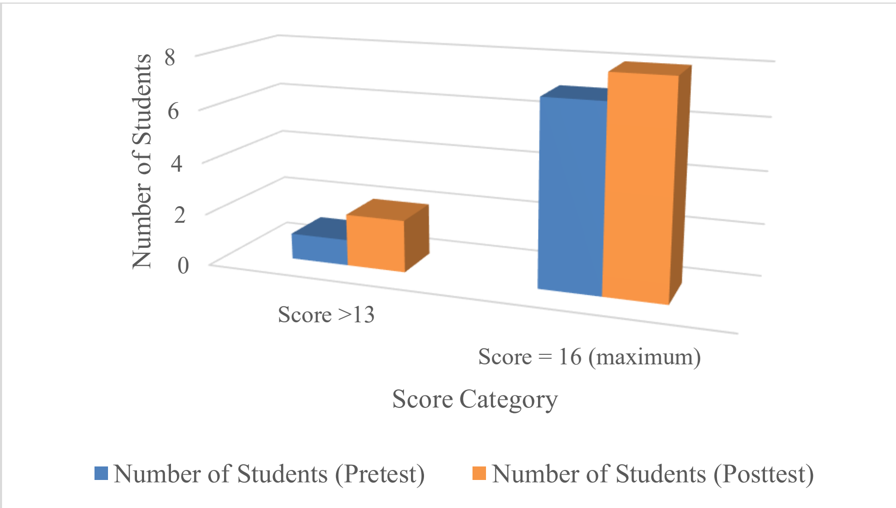

Figure 2. Number of Students with Scores >13 and Maximum Scores of 16

The visualization of the trend in student score changes is presented in Figure 3, which shows an upward pattern from the pretest to the posttest. Based on a comparison of scores between experiments, it shows the number of students based on changes in conceptual understanding scores from the pretest to the posttest. A total of 15 students experienced an increase in scores, 8 students had the same scores, and only 3 students experienced a decrease. The dominance of the "increase" category indicates that most students experienced an increase in conceptual understanding after taking the posttest. Meanwhile, the number of students who remained the same or decreased was very small, indicating that most participants benefited from the practicum experience. This indicates that the project-based learning (PjBL) model combined with the Evidence-Based Research (EBR) approach contributes positively to student learning achievement.

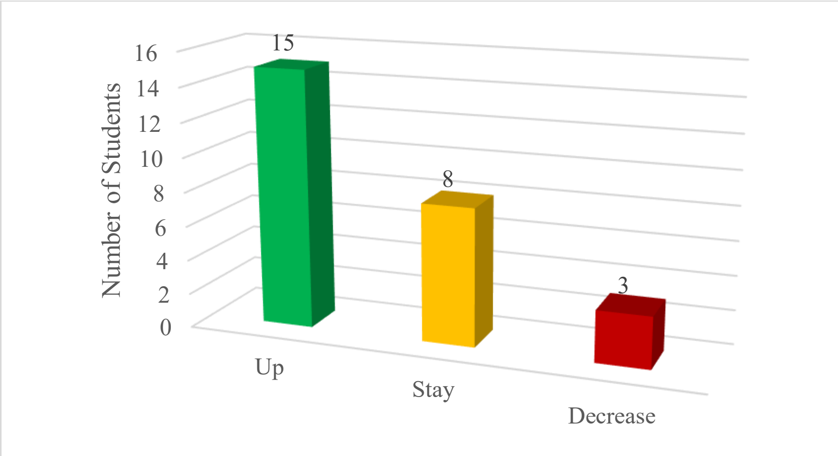

Figure 3. Number of students based on changes in conceptual understanding scores between the pretest and posttest

Students with consistently high scores used scientific terms appropriately, were able to relate experimental data to acid-base theory, and explained changes in natural indicator colors scientifically. Some students even maintained perfect scores in both experiments, demonstrating comprehensive and stable mastery of the concepts. In addition, there were students who experienced a 100% increase in their scores, indicating that this learning approach is adaptive to various levels of initial ability. This distribution reinforces the finding that the project- -based learning model is able to encourage most students to achieve a deeper level of understanding of acid-base material.

However, there were still a small number of students who showed minimal improvement or stagnant scores. This shows that although the project-based approach is generally effective, additional mentoring strategies are needed to reach all students optimally. Research by Pratiwi & Ikhsan (2024), states that the PjBL model significantly improves mastery of chemistry concepts through meaningful experimental activities. This is reinforced by Wahyudiati et al. (2022), which explains that conceptual improvement is closely related to investigative learning and the use of evidence-based data. The findings of Kumar (2024) also support that the use of natural indicators in practical work can strengthen concept representation and significantly improve students' conceptual understanding.

Student Scientific Argumentation (TAP)

The assessment of students' scientific argumentation skills was based on the Toulmin model, which includes four main components: claim, data, warrant, and coherence, in accordance with the analytical rubric that had been developed. Figure 4 shows the distribution of students based on their scientific argumentation scores on the pretest and posttest. There was a significant shift in the distribution toward higher scores after the posttest. In the pretest, most students were in the low score category, namely 11 students with scores of 8–9 and 7 students with scores of 10–11. This number decreased dramatically in the posttest, to 0 and 1 student, respectively.

Conversely, the improvement was clearly seen in the medium and high score categories. The number of students with scores of 12–13 increased from 4 to 12, those with scores of 14–15 increased from 1 to 2, and those with the maximum score (16) increased from 3 to 11. This pattern shows that the majority of students experienced an increase in their ability to construct scientific arguments, particularly in terms of a more complete and logical structure of claims, data, and scientific justification (warrant). This improvement shows that the Project-Based Learning (PjBL) approach applied during the practicum played a major role in building students' critical and argumentative thinking skills. This is in line with the results of Setiono et al. (2021) research, which shows that the application of the PjBL model can improve students' scientific argumentation skills, especially in including data, constructing claims, and providing systematic justifications for their answers. Students who are actively involved in investigation and discussion are proven to be more capable of constructing strong evidence-based arguments.

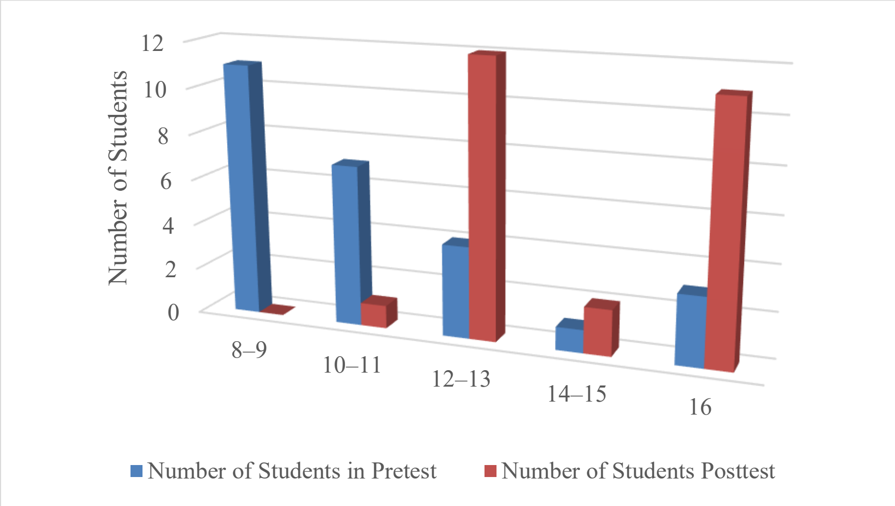

Figure 4. Scientific Argumentation Score Categories (TAP)

The analysis in Figure 5 shows the number of students who obtained scientific argumentation scores above 13 and the maximum score (16) on the pretest and posttest. On the pretest, only 1 student obtained a score above 13 and 3 students achieved the maximum score. Meanwhile, on the posttest, the number of students who obtained scores above 13 increased to 2, and those who achieved the maximum score increased significantly to 11. This pattern shows an increase in the quality of students' scientific argumentation, especially in the highest score category. The surge in the number of students who achieved the maximum score indicates that most of the practicum participants were able to meet all the scientific argumentation assessment indicators very well on the posttest. This reflects significant progress in the skills of constructing claims, data, and scientific justifications logically and coherently.

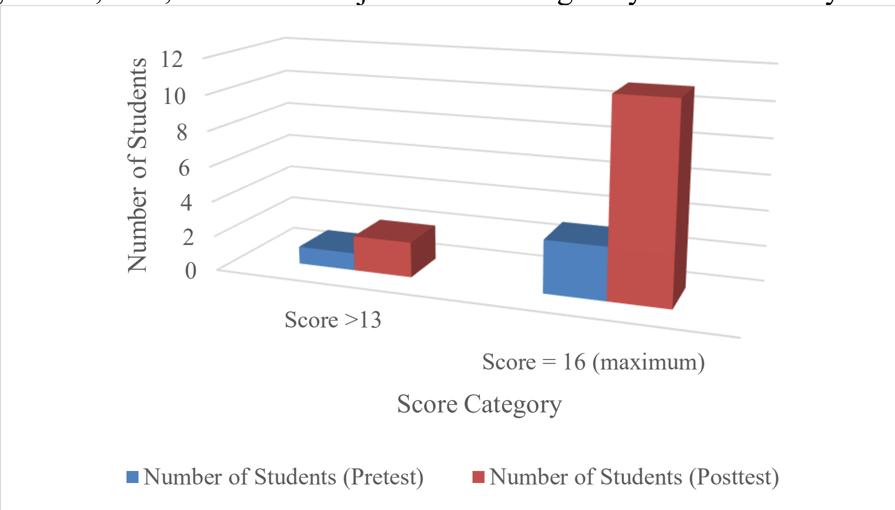

Figure 5. Number of Students with Scores >13 and Maximum Scores of 16

The visualization of the trend in student score changes presented in Figure 6 shows the development of students' scientific argumentation scores (TAP) from the pretest to the posttest. A total of 22 students experienced an increase in scores, 3 students remained the same, and only 1 student experienced a decrease. The dominance of the "increase" category indicates that most students experienced substantial improvement in constructing scientific arguments, especially in the aspects of claims, data, and justifications (warrants) that were more complete and logical. This improvement is closely related to the series of learning activities implemented during the practicum. Data recording activities trained students to collect accurate observational evidence, which served as the foundation for formulating claims. Group discussions encouraged them to compare findings, evaluate the relevance of evidence, and refine their warrants. Meanwhile, the interpretation of experimental results guided students to connect data with chemical concepts, enabling them to construct stronger backing for their arguments. These processes collectively contributed to their ability to think scientifically and communicate reasoning more systematically. The few students who experienced a decline did not significantly influence the overall trend.

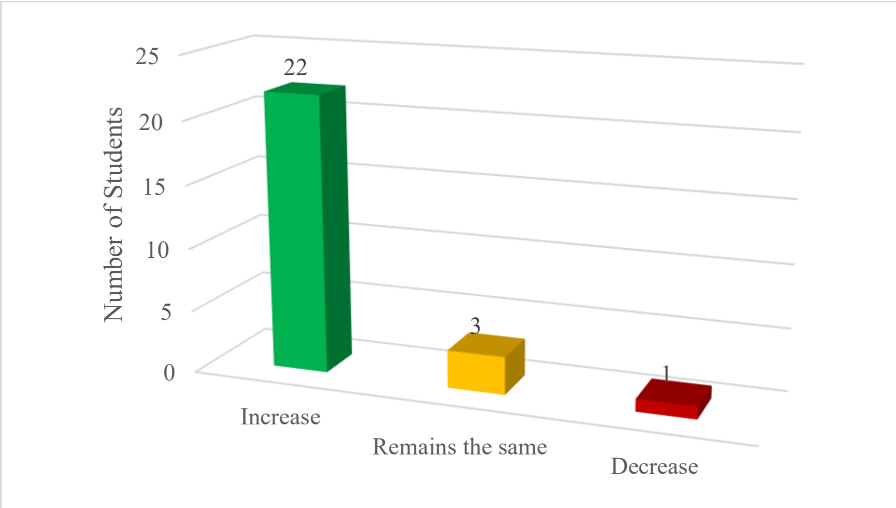

Figure 6. Number of Students Based on Changes in Scientific Argumentation Scores Between Pretest and Posttest

This improvement is in line with the findings of Uzuntiryaki-Kondakci et al. (2021), which show that argumentation-based laboratories enable prospective chemistry teachers to develop deeper scientific arguments by integrating experimental data, submicroscopic concepts, and scientific reasoning. Students in the study experienced improvements in constructing claims supported by strong evidence and reasons based on relevant chemistry concepts. Similar findings were reported by Zhang & Browne (2023), who examined students' scientific arguments based on three competency components: identification, evaluation, and production of arguments. Their study confirms that the ability to construct complete and relevant scientific arguments can be improved through structured laboratory experiences designed to stimulate evidence-based scientific reasoning. Some students demonstrated full mastery of the structure of scientific argumentation. This can be seen from the maximum TAP scores achieved by several students, including one student whose report is shown in Figure 7. This evidence demonstrates an understanding of the elements of claim (color and pH), data (experimental observations), warrant (basic concepts of acids and bases), and backing (the mechanism of anthocyanin structure), which form a complete and coherent scientific argument.

Dengan melakukan pengamatan perubahan warna, dapat ditentukan kisaran pH yang dapat dideteksi secara efektif oleh indikator alami ini. Indikator alami dapat dibuat dengan memanfaatkan zat warna alam, yaitu zat warna antosianin. Antosianin dapat diperoleh pada hampir semua jaringan tumbuhan tingkat tinggi termasuk bunga, daun, batang, buah, dan akar. Zat antosianin yang berupa senyawa organik berwarna memiliki kemampuan untuk bereaksi dengan asam ataupun basa seperti halnya dengan indikator sintetis [7].

Indikator adalah suatu zat yang dapat mengalami perubahan warna jika berada pada pH tertentu. Sedangkan indikator alami adalah zat-zat yang terkandung di dalam tumbuhan yang dapat mengalami perubahan warna. Beberapa senyawa organik yang berperan dalam zat warna pada seperti antosianin, flavonoid, imine, karoten dan anthraquinoid memiliki kemampuan berubah warna pada rentang pH tertentu. Sifat inilah yang dapat dimanfatkan sebagai indikator asam basa alam [8].

Figure 7. Example of a Student's argument in the Posttest that Contains Complete Elements of Claim, Data, Warrant, and Backing.

Combined Analysis and Improvement in Student Ability

After conducting an analysis per aspect, the data processing results also showed an overall improvement in student abilities, both in terms of conceptual understanding and scientific argumentation. To reinforce these findings, an analysis of the average score and changes in each student's score in both aspects was conducted. A combined analysis of the two assessment aspects, namely conceptual understanding and scientific argumentation, revealed that most students experienced positive development during the practicum process.

Table 3. Average Scores for Students' Conceptual Understanding and Scientific Argumentation in the Pretest and Posttest in the PjBL–EBR-Based Acid-Base Practicum

Ability	Average Pre-test Score	Posttest Average Score	Improvement
Conceptual Understanding	11,81	13,15	+1,34
Scientific Argumentation (TAP)	10,46	14,15	+3,69

Figure 8 shows a comparison of the average student scores in the aspects of conceptual understanding and scientific argumentation (TAP) between *the pretest* and *posttest*. In the aspect of conceptual understanding, the average student score increased from 11.81 to 13.15. Meanwhile, in the TAP aspect, the increase was more significant, from an average of 10.46 to 14.15. This increase shows that both aspects of student abilities experienced positive development after the implementation of Project-Based Learning (PjBL) supported by the Evidence-Based Research (EBR) approach. The practicum activities designed not only encouraged students to understand concepts in depth but also shaped stronger scientific and argumentative mindsets. The higher increase in TAP scores compared to the conceptual aspect indicates that this approach is highly effective in developing critical thinking skills and the formulation of data-based scientific arguments.

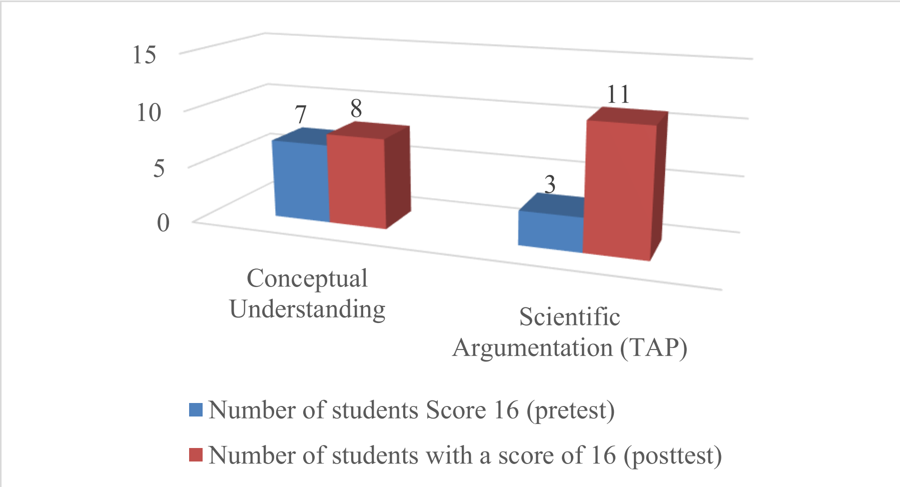

Figure 8. Comparison of Average Student Scores Based on Changes in Combined Scores (Conceptual and TAP)

This increase indicates that the learning model applied not only promotes strong conceptual understanding but also encourages students to achieve the highest level of scientific argumentation. The maximum scores in both aspects indicate that some students were able to perfectly meet all the established indicators after the intervention. This supports the findings of Paramita et al. (2021), who stated that the use of learning models can significantly improve students' argumentation and conceptual understanding, especially when they are encouraged to use experimental data in constructing scientific claims and explanations.

Similarly, Ni'mah et al. (2024) in their analysis of student lab reports found that the strength of the argumentation structure in lab reports is closely related to good conceptual understanding. They emphasize the importance of explicit guidance on the use of experimental data to support claims and construct evidence-based explanations, which are the main foundations of scientific argumentation. Thus, the results of this study support the importance of integrating project-based and evidence-based learning approaches in designing laboratory experiences that are not only informative but also transformative for students.

Student Activities and Engagement in Improving Conceptual Understanding and Scientific Argumentation

Student activity and active participation during chemistry practicums were systematically observed through daily logbooks that recorded their behavior, contributions, and interactions in the laboratory. The results of the observations showed that most students demonstrated good engagement, such as actively recording experimental data, discussing in groups, asking questions to assistants, and expressing their opinions when writing reports. This was also reflected in their practicum performance scores and affective attitudes. Most students obtained maximum scores (100) in psychomotor and affective aspects, as seen in the practical assessments for meetings 9 and 10. These activities were not only reflected in more meaningful practical work but also in their achievements in conceptual and argumentative aspects (Asli et al., 2023). Students who consistently showed enthusiasm during the experiment tended to obtain higher combined scores, both in conceptual understanding and in constructing data-based scientific arguments. Conversely, students who tended to be passive or only performed the minimum tasks showed stagnant results, and some even experienced a decline in scores. This indicates a positive correlation between psychomotor and affective involvement during practical work and conceptual mastery and scientific argumentation skills (Kapici et al., 2022).

These findings support the view that active participation in scientific practice encourages students to think more critically, reflect on the experimental process, and meaningfully relate data to theory. In the context of Project-Based Learning (PjBL) and Evidence-Based Research

(EBR) approaches. In this study, the integration of Project-Based Learning (PjBL) with the Evidence-Based Research (EBR) approach was implemented through a series of structured laboratory activities that emphasized both project completion and evidence-based reasoning. Students worked collaboratively in small groups to design and carry out acid–base practicum projects, including planning experimental procedures, conducting observations, and collecting empirical data. Throughout the practicum, students were encouraged to base every claim and conclusion on the experimental evidence obtained, rather than solely following procedural instructions. The EBR component was reflected in the requirement that students analyze their experimental data critically, interpret the results using relevant acid–base theories, and justify their conclusions with valid evidence. Group discussions were conducted to evaluate the accuracy of the data, refine scientific reasoning, and connect experimental findings with theoretical concepts. By combining project-based tasks with systematic data analysis and justification, the PjBL–EBR approach provided students with authentic opportunities to practice scientific inquiry, develop logical argumentation, and strengthen their conceptual understanding through evidence-based conclusions. Student engagement not only contributes to the technical success of the practicum but also strengthens their cognitive and epistemic development (Asli et al., 2023). Students who actively recorded data, collaborated in analyzing results, and discussed findings with their teams found it easier to connect experimental evidence with acid–base theory and construct logical, data-driven arguments. The greater improvement in scientific argumentation compared to conceptual understanding can be explained by the nature of TAP tasks, which require deeper reasoning and justification through claims, data, and warrants, whereas conceptual understanding often involves recalling or recognizing content knowledge. Project-Based Learning and EBR also shape students' scientific work ethic, discipline, and collaboration skills during the learning process (Kapici et al., 2022) providing repeated opportunities to formulate claims, interpret data, and defend arguments. Therefore, student performance and active participation during practical work serve as important supports for the successful development of both conceptual understanding and scientific argumentation skills.

CONCLUSION AND RECOMMENDATIONS

This study shows that the application of the Project-Based Learning (PjBL) model combined with the Evidence Based Research (EBR) approach in acid-base identification practicums has been proven effective in improving students' conceptual understanding and scientific argumentation skills. The average conceptual score increased from 11.81 to 13.15, and the TAP score from 10.46 to 14.15, with 85% of students showing an improvement in both aspects. This model not only provides a contextual and meaningful learning experience but also fosters scientific thinking skills and active participation during practical work. Students who actively recorded data, discussed, and engaged in projects tended to have higher learning outcomes. Therefore, the PjBL–EBR model is recommended for application to other exploratory chemistry topics using experimental research designs to obtain stronger variable control so that the research results more validly explain cause and effect as research outcomes. Educators are advised to provide explicit guidance on the structure of arguments and the use of experimental data in student reports, as well as to make performance and attitude assessments part of project-based assessments.

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