The Eurasia Proceedings of
Educational & Social Sciences (EPESS)
ISSN: 2587-1730

The Eurasia Proceedings of Educational and Social Sciences (EPESS), 2025

Volume 47, Pages 215-223

IConSE 2025: International Conference on Science and Education

Analysis of Students' Scientific Arguments in Physical Chemistry Laboratory Course

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Abstract: Building scientific arguments based on conducted laboratory experiments is a crucial aspect of chemistry education. Scientific arguments involve systematic collection, analysis, and interpretation of data to support or refute specific hypotheses. This process not only enriches students' understanding of scientific concepts but also enhances their ability to communicate ideas and findings in a logical and structured manner. This study aims to analyze the quality of arguments constructed by students in a physical chemistry laboratory course on the ternary liquid equilibrium topic. The research methodology employs a qualitative approach with a case study design. A sample consisting of 42 fourth-semester students from chemistry education programs was divided into 9 lab groups. Data collection was carried out through observation and document analysis, which were then analyzed qualitatively. The results indicate that the scientific arguments in lab reports constructed by students generally fall at level 1 (claim) and level 2 (claim + data or claim + warrant), with a greater emphasis on mathematical aspects than on chemistry aspects. Additionally, the use of "cookbook" lab procedures leads students to analyze the phenomena observed during the learning process adequately. Therefore, the researchers suggest developing inquiry-oriented lab procedures to address these issues.

Keywords: Scientific argument, Argumentation, Laboratory reports, Ternary system

Introduction

Ternary system, which is one of the materials in chemistry and physics, aims to learn the stability phase from system in terms of thermodynamics at a way thermodynamics at temperature and pressure. (Binous et al., 2021; Levine, 2016; Zhang et al., 2020) . Draft about equilibrium from the third component the represented in known diagram forms with a ternary system. The principle of the ternary phase diagram is identify and determine the equilibrium phase to obtain the right composition between compound solid-solid-solid (Koyama et al., 2021) , liquid-liquid-liquid (Shevchenko & Jak, 2019) , as well as a combination of both of them (Klamt & Loschen, 2018; Meng et al., 2019) Which aims to optimize reaction chemistry on an industrial scale.

At the university level, the Ternary system is preceded by class theory. In class This student will teach the rule Gibbs phase, determines limit phase and triple point, and visually represent temperature and pressure where two or more is at in equilibrium (Atkins et al., 2023; Levine, 2016) . After that, students will practice programming lectures and practice/experiment. Activities experiment. This becomes important because help student deepen concepts based on observed phenomena during activity and practical work, as well as develop skills (Shinod, 2021; Sweeder et al., 2019) .

Laboratory practice is an integral part of the field of Ternary Systems, as it allows for the simultaneous achievement of practical scientific experience and conceptual understanding (Hu-Au & Okita, 2021 ; Stieff, 2019). However, laboratory activities intended to make students' concepts more complete are often not fully realized because the aspects observed are mostly visual (Sweeder et al., 2019; Asprion et al., 2022) . Moreover, laboratory activities are not only about testing theories but are also used to build hypotheses and empirically resolve differing views (Shinod, 2021) .

Scientific arguments are necessary to construct quality experimental reports (Chen et al., 2020; Najami et al., 2020a) . According to Toulmin (2003) , Scientific arguments consist of a *claim*, *data*, *warrant*, *backing*, *qualifier*, and *rebuttal components*, which reflect the way scientists think in explaining and justifying a phenomenon. Through this framework, scientific arguments can be assessed not only based on the content of their statements, but also on the completeness of the underlying logic (Katchevich et al., 2013) . Research conducted by Kapici et al. (2022) revealed that students still have difficulty using evidence to support claims, presenting logical reasons to explain experimental data. In addition, Anisa et al. (2023) also revealed students' difficulties in using rebuttal in constructing claims.

Therefore, the focus of this study is to describe the argumentation patterns developed by students based on experimental reports. In the context of physical chemistry labs, which are rich in abstract concepts such as thermodynamics, kinetics, and phase equilibrium, students' ability to construct logical, evidence-based arguments is crucial. Analyzing students' argumentation patterns can provide insight into the extent to which they understand the relationship between theory and experimental results.

Literature Review

Argumentation in Chemistry Laboratory

Argumentation is a statement that contains a claim supported by data and is intended to influence someone. An argument is based on data or facts and is accompanied by reasoning to reinforce the opinion. An argument is the product of an argumentation process (Aleixandre & Erduran, 2008) . This perspective indicates that the process of producing arguments involves knowledge, beliefs, and values held and believed by an individual, as well as efforts to persuade others to accept and adhere to these beliefs or values (Hofstein et al., 2019) . Inch et al. (2006) describe three characteristics of arguments: First, a claim is a conclusion that one aims to be accepted by others. Second, a claim is supported by facts and reasoning or conclusions that connect facts and claims. Third, an argument seeks to influence someone who is in disagreement.

Toulmin (1958) introduced an argumentation model. The Toulmin argumentation framework (TAP) is based on legal procedures and argumentation discussions depicted in a systematic diagram (Figure 2) that applies to all fields of science (Katchevich et al., 2013). Based on Figure 1, there are four elements in an argument: data (D), claim (C), *warrant* (W), and support or *backing* (B). A claim is a conclusion, hypothesis, or opinion. Data are facts that support the claim. A warrant *is* the link between the data and the claim. Support is an assumption that justifies *the warrant* (Kaya, 2013).

Sampson and Clark (2008) explain that constructing a scientific argument is a process of using data, warrant, and backing *to* convince others of the validity of a particular proposition. Based on this view, the strength of an argument is based on the presence or absence of a specific combination of structural components. This is because argumentation is a crucial component of scientific literacy. Argumentation used in science learning not only improves students' critical thinking skills and scientific investigations but also provides practical significance for student development (Erduran & Yan, 2008).

If students recognize the benefits of argumentation, quality discussions will occur. Argumentation involves personal and social interactions, so students will strive to develop their knowledge and values. The scope of argumentation can ensure that students' collective, conceptual, and epistemic understanding can develop in this way (Duschl & Osborne, 2002). In addition, understanding the relationship between data and claims through justification and support in an argument can ensure the development of students' critical thinking (Kapici et al., 2022; Celik & Yifci, 2016) .

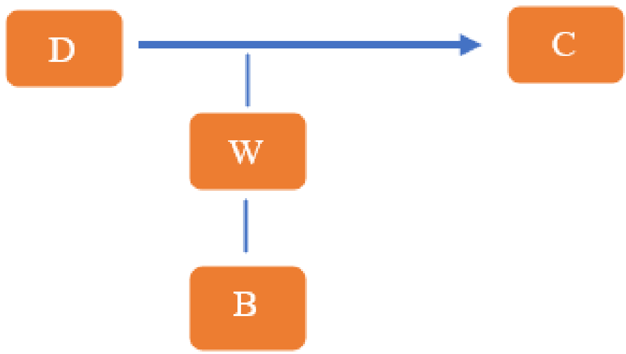


Figure 1. Toulmin argument pattern (TAP)

Phase Diagram of a Ternary System

There are two approaches used in studying phase equilibria, both of which are important for systematizing the large amount of data that has accumulated and in simplifying the collection of new data. These two approaches are the phase rule and the distribution law (Treybal, 1951) .

Phase Rule

When discussing phase rules, one must first understand the terms used in this regard. These terms are phase, component, and degrees of freedom. A phase is a homogeneous part of a system, which can be separated mechanically, homogeneous in terms of chemical composition and physical properties. Next, the number of components in a system is the minimum number of chemically independent species required to express the composition of each phase in the system. If a system contains one or more components in one or more phases at equilibrium, there is an important general relationship that must be satisfied between the number of phases (p), components (c), and degrees of freedom (f), namely:

$$\mathbf{f = c - p + 2} \tag{1.1}$$

where f = the number of degrees of freedom, or the number of independent variables that must be clearly defined in the system at equilibrium;
c = number of components, or the lowest number of independent constituent variables required to express the composition of each phase;
p = number of phases (Atkins et al.,2023; Levine, 2016; Treybal, 1951; Zhang et al., 2020).

Ternary System (Liquid-Liquid-Liquid)

The Ternary system is widely used in metallurgy, materials science, and pharmaceuticals (Atkins et al., 2023; Pye et al., 2018). For a three-component system, if we assume $p = 1$, then the value of the degrees of freedom is 4. It is impossible to express such a system in a complete graph in three dimensions, let alone in two dimensions. Therefore, generally, the system is expressed at constant temperature and pressure, and the degrees of freedom become $f = 3 - p$, so that the system can be expressed in two dimensions with an equilateral triangle graph (Levine, 2016). Then, Treybal (1951) classified them into several types, namely: a) A pair component, Partially soluble (Type 1); b) two pairs of components, Partially soluble (Type 2); and c) three pairs of components, Partially soluble (Type 3).

Method

Objectives and Questions Study

This study aims to analyze the components of scientific arguments constructed by students in their laboratory reports after completing a practical activity on ternary phase equilibrium involving the water-chloroform-acetic acid system. The analysis focuses exclusively on arguments explicitly presented in students' post-experiment laboratory reports. Purpose: This Produce question study follows:

1. What are the components of an argument? only those contained in the report experiment, student post-implementation activity experiment?
2. How category of argument levels construct students in the report experiment?

Research Model

Methods used in this research were qualitative, with a case study as one of the purposeful designs to explore a phenomenon deeply (Creswell & Guetterman, 2019), events, or a case, a certain in-context life, real (real-life context).

Participants

Participants in this study consisted of 42 undergraduate students (30 female and 12 male) majoring in Chemistry Education. All participants were in their fourth semester and were enrolled in a Physical Chemistry Laboratory Course at a university in Bandung, Indonesia. The students were divided into nine Laboratory groups and conducted a practical activity on three-phase equilibrium, specifically the water-chloroform-acetic acid system.

Data Collection and Data Analysis

Data collected is to report practical work for students on the topic of the ternary phase equilibrium. Report compiled by representatives of each group and collected within 7 days after the session practical (before the next session of the topic's practical work). The report section, which describes relevant hypotheses, discussions, and conclusions, analyzed structure of arguments. Illustration of Toulmin's argument framework about the Ternary system can be seen in Figure 2 below.

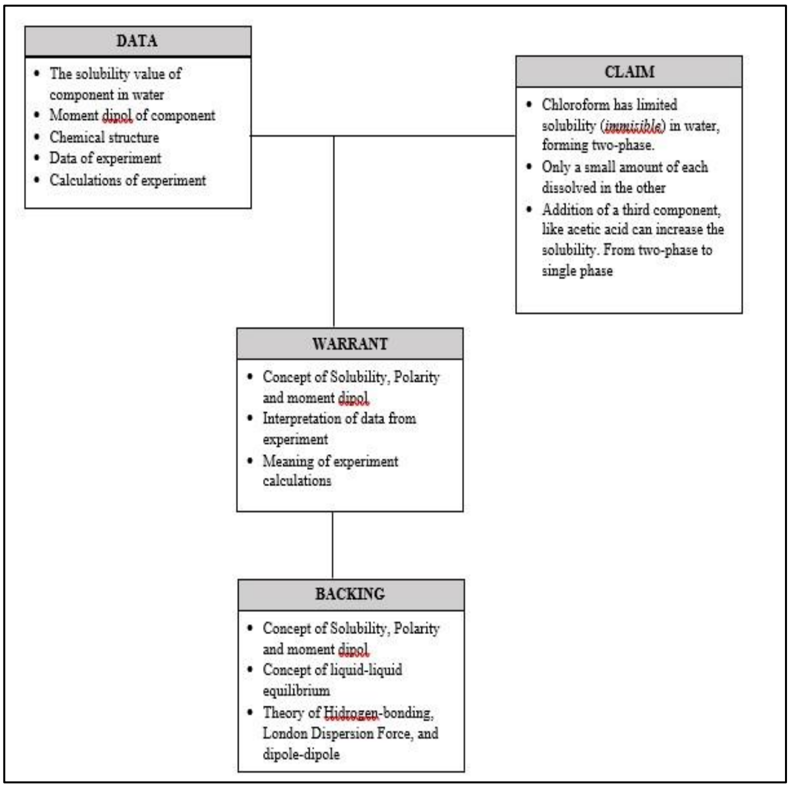


Figure 2. Argument structure of Toulmin in the ternary system

Next, the structure of the scientific argument that was built by the student was tabulated based on the concept of levels of argument developed by Erduran et al. (2004) and Osborne et al. (2004). The purpose of categorization is to see the depth of the scientific argument constructed post-implementation practicum. Table 1. below serve criteria and structure.

Table 1. Level of argument in the chemistry laboratory

The level of the argument	Symbol	The components of the argument
1	C	Claim
2	CD/CW	Claim + Data or Claim + Scientific Basis Warrant
3	CDW/CDR/CWR	Claim + Data + Warrant or Claim + Data + R ebuttal or Claim + W arrant + R ebuttal
4	CDWB	Claim + Data + Warrant + Backing
5	CDWR	Rebuttal that includes Claim + Data + Warrant

Results and Discussion

Research Question 1: What are the components of an argument? Only those contained in the report experiment, student post-implementation activity experiment?

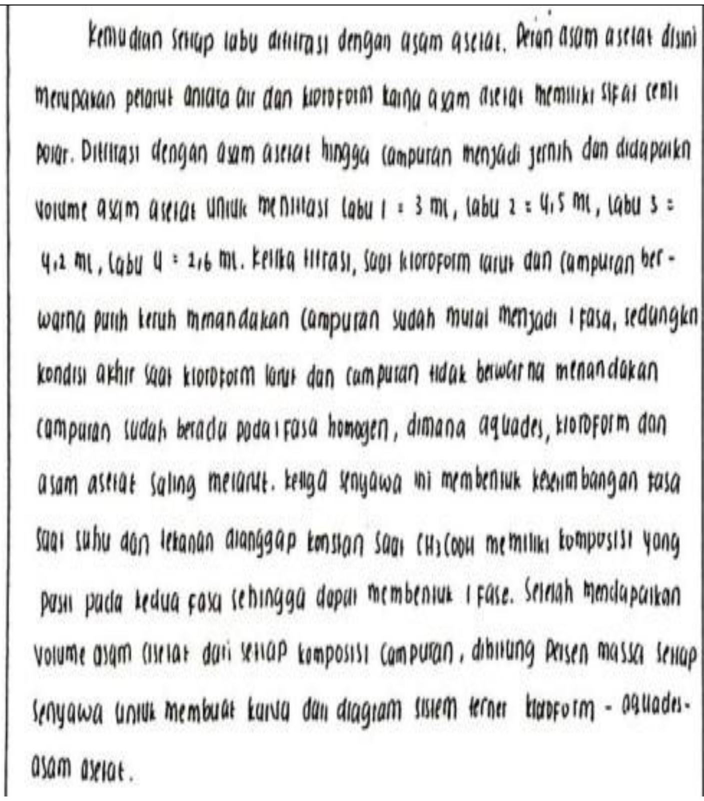
Profile of Structure Argument in Experiment Report

Analysis to report of the experiment from 9 groups show all over students have compiled an explanation resulting in a narrative containing TAP elements, however, with varying quality and completeness. In general, most of the time the group is capable serve claims and data with enough clarity, but the warrant and backing components are still a little identified within the report. Distribution: The emergence of TAP is presented in Table 2 below.

Table 2. Distribution TAP appearance in the report of the experiment student

Components of Toulmin Argument Pattern (TAP)	Group 1	2	3	4	5	6	7	8	9	Explanation: In a way, General
Claim	✓	✓	✓	✓	✓	✓	✓	✓	✓	All groups write claims, whether contained in the discussion or in the conclusion
Data	✓	✓	✓	✓	✓	✓	✓	✓	✓	Experimental data presented in the form of calculation, results observation, a table, and a Ternary diagram graph
Warrant	–	✓	–	✓	–	–	–	–	–	Several students explained the connection between data and the principles of the equilibrium phase
Backing	–	–	–	–	–	–	–	–	–	Support emerging theories in the report, no correlation to claims built

Furthermore, TAP analysis, as seen in Figure 2, identified that group students claim that sour acetate hold role important between water and chloroform. However, its role (in aspect chemistry) is not explained in more detail by students. Then, each group obtains data on the acid volume of acetate required. To remove turbidity, but why is there a volume difference in each pumpkin, and his role is not explained in more detail and in-depth. Therefore, accuracy make claim based on the question study as well as understanding the connection between claims and data obtained during the experiment become factor important For produce quality arguments. (Aguirre-Mendez et al., 2020; Bretz, 2019; Songsil et al., 2019)


Kemudian setiap labu dititrasi dengan asam asetat. Peran asam asetat disini merupakan pelarut antara air dan kloroform karena asam asetat memiliki sifat semi polar. Dititrasi dengan asam asetat hingga campuran menjadi jernih dan didapatkan volume asam asetat untuk menitrasi labu 1 = 3 ml, labu 2 = 4,5 ml, labu 3 = 4,2 ml, labu 4 = 2,6 ml. Ketika titrasi, saat kloroform larut dan campuran berwarna putih keruh menandakan campuran sudah mulai menjadi 1 fasa, sedangkan kondisi akhir saat kloroform larut dan campuran tidak berwarna menandakan campuran sudah berada pada 1 fasa homogen, dimana aquades, kloroform dan asam asetat saling melarut. Ketiga senyawa ini membentuk kesetimbangan fasa saat suhu dan tekanan dianggap konstan saat CH_3COOH memiliki komposisi yang pasti pada kedua fasa sehingga dapat membentuk 1 fase. Setelah mendapatkan volume asam asetat dari setiap komposisi campuran, dihitung persen massa setiap senyawa untuk membuat kurva dan diagram sistem terner kloroform - aquades-asam asetat.

In English :

then each flask is titrated with acetic acid. The role of acetic acid here is a solvent between water and chloroform because acetic acid has semi-polar properties. Titrated with acetic acid until the mixture becomes clear and the volume of acetic acid is obtained to titrate flask 1 = 3ml, flask 2 = 4.5 ml, flask 3 = 4.2 ml, flask 4, 2.6 ml. during titration, when chloroform dissolves and the mixture is cloudy white indicates that the mixture has begun to become 1 phase, while the final condition when chloroform dissolves and the mixture is colorless indicates that the mixture is in 1 homogeneous phase, where distilled water, chloroform, and acetic acid dissolve in each other. These three compounds form a phase equilibrium when the temperature and pressure are considered constant, and CH_3COOH has a definite composition in both phases, so that it forms 1 phase. In addition to obtaining the volume of acetic acid from each mixture composition, the mass percentage of each compound is calculated to create a curve and diagram of the ternary system of chloroform –water – acetic acid.

Description: Red font = Claim; Blue font = Data

Figure 2. Example explanation by students in the report experiment

Research Question 2: How category of argument levels constructs students in the report experiment

Based on the analysis of laboratory report documents, student arguments are found in 3 levels: a) *level 1*: At this level, the arguments constructed by students are basic and limited to statements that directly link experimental results with theoretical concepts without much critical analysis. These arguments often lack adequate data support or rely solely on visual interpretation without strong references to literature or more complex chemical concepts. Level *2*: Students at this level demonstrate a better ability to connect experimental results with relevant theory, accompanied by more in-depth data analysis. Arguments at this level begin to include discussions on data validity and the identification of possible sources of error in the experiment. However, these arguments are still somewhat limited in complexity and often do not consider all relevant variables or alternative explanations.

Based on Fig.3, it is clear that students still struggle with constructing arguments during laboratory activities. In addition to focusing primarily on mathematical aspects or calculations, students have difficulty connecting theoretical concepts learned in class with their practical application. Moreover, the use of "cookbook" style guides adversely affects the students' ability to develop scientific arguments (Najami et al., 2020a). These challenges highlight the need for a more integrated approach in laboratory instruction, where theoretical knowledge and practical skills are seamlessly connected. To address these issues, educators might consider redesigning laboratory activities to emphasize critical thinking and argumentation. This could involve providing students with opportunities to formulate and test their own hypotheses, rather than merely following predetermined procedures.

Additionally, moving away from "cookbook" style guides towards more inquiry-based and open-ended experiments could better support students in linking theory with practice and developing stronger scientific arguments (Aguirre-Mendez et al., 2020; Petritis et al., 2021; Toulmin, 2003) . Encouraging reflective practices and peer discussions during and after laboratory sessions may further enhance students' ability to construct well-reasoned arguments based on empirical evidence

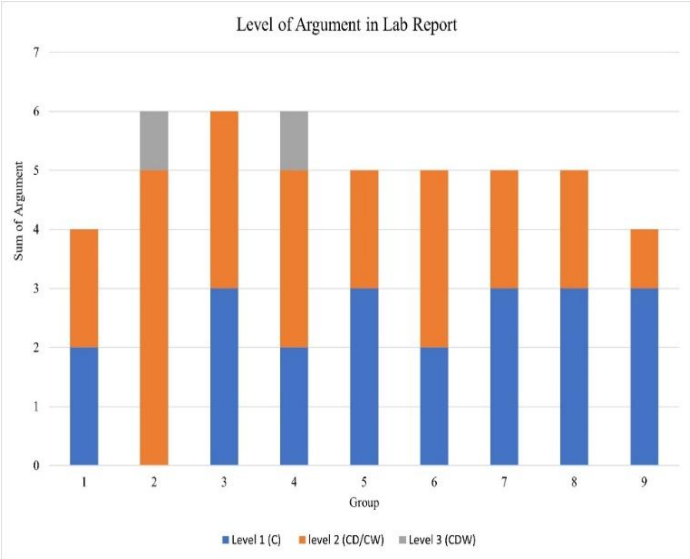


Figure 3. Level of argument in lab report

Conclusion

Research results show that able students can build scientific arguments in practical work, chemistry, physics, and phase diagram topics, Ternary Still be at the level. Most of the arguments found are at levels 1 and 2. Student arguments tend to focus on aspects of mathematics and description without justification or strong scientific evidence. The majority of data is limited to mentioning numbers only, without describing the meaning behind numbers that are intended for support claims, and warrant and backing components are rare appear. Students still have difficulty connecting experimental results with the underlying theory. They do not yet fully understand how to construct a logical connection between empirical data and claims scientific based on principles of thermodynamics and concepts of equilibrium phase (Williamson, 2021) . Besides that, the use of procedure " *cook-book* " type practicums has limited room for students, because they are more focused on following the technical steps than reasoning about observed phenomena. In a way, overall research confirms that ability constructing student arguments is still at the descriptive, not yet reach stage analytical and reflective stage, as learning based inquiry (Kapici et al., 2022; Najami et al., 2020)

Recommendations

To produce quality scientific arguments and be at level 5, the following recommendations are given:

1. Re- design learning Laboratory with an inquiry or argumentation. Lecturers and assistants need to change the experimental model from the "cook-book" approach to open-ended or argument-driven inquiry (ADI). This model allows students to build hypotheses, test, and defending claim based on empirical evidence.
2. Explicit integration of TAP in learning. Use of TAP is necessarily made into an explicit part from guidance writing report. Students must be trained to recognize and write down component claims, data, warrants, and backing in the analysis results experiment.
3. Strengthening integration theory and practice. Lectures on theory and practice need to be connected in a way systematic and studied repeat with more coherence. These aims for students can see a direct connection between theory or principles on the topic of phase diagrams, Ternary, with phenomena observed empirically during experiment.

By implementing these strategies, it is hoped that students' scientific argumentation skills in the context of a physical chemistry laboratory will improve from a descriptive level to a higher analytical argumentative level. This improvement not only supports the achievement of academic competency but also develops essential scientific thinking skills for future educators.

Scientific Ethics Declaration

* The authors declare that the scientific, ethical, and legal responsibility of this article, published in the EPESS journal, belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflict of interest

Funding

* This work was supported and funded by the Indonesian Education Scholarship (BPI), Center for Higher Education Funding and Assessment (PPATK), and Indonesian Endowment Fund for Education (LPDP), whose assistance and funding are gratefully acknowledged by the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Science and Education (www.iconse.net) held in Antalya/ Türkiye on November 12-15, 2025.

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To cite this article:

Siahaan, A.T., Rohman, I., Liliasari, L., & Khoerunnisa , F. (2025). Analysis of students' scientific arguments in physical chemistry laboratory course. *The Eurasia Proceedings of Educational and Social Sciences (EPESS), 47,* 215-223.