Pictorial-Based Learning (PcBL): Fostering Students' Argumentation Skills and Understanding of Chemistry

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Abstract. This study highlights the implementation of Pictorial-Based Learning (PcBL) in basic chemistry classes and assesses its contribution to students' argumentation skills and understanding of chemistry. Thirty-five students aged 19-21 years enrolled in general chemistry, covering solubility & intermolecular forces, gas laws, kinetic molecular theory, and thermochemistry, at Universitas Negeri Malang, East Java, Indonesia, participated in this study. The intervention was conducted over one term/semester. Students' argumentation skills were assessed at the end of each topic and classified using Toulmin's Argument Pattern (TAP), which comprises claims, data, warrants, backing, and rebuttals. This study uncovered the following outcomes. The implementation of PcBL contributed to improving students' argumentation skills. However, no students demonstrated the highest level (5). Most students' argumentation skills ranged from Level 3 to Level 4, with Level 3 being the most common. Therefore, it implies an adequate contribution of the approach in improving students' argumentation skills. However, the correlation between students' argumentation skills and their understanding of chemistry was not substantial. This study

amplifies the need for the PcBL in broader chemistry teaching across cohorts and topics. Its contribution to forming other students' soft skills is also a worthwhile future exercise.

Keywords: Model and modelling in chemistry, visualisation, scientific argument, deep understanding

1. INTRODUCTION

School systems around the world are being urged to create frameworks that emphasise acquiring skills, knowledge, and attitudes required for success in the twenty-first century [1]. A more complex society and a quickly changing technology-based economy have presented new and challenging problems to schools and communities alike [1] required for personal, occupational, and social inclusion [2]. Therefore, chemistry instruction should be delivered from a perspective that fosters students' robust understanding of chemistry and develops their 21st-century skills, including scientific argumentation. Using scientific argumentation in education is crucial, as it enhances students' engagement in the teaching and learning process and enables them to develop their ideas by exploring their own thoughts rather than presenting them in pre-existing templates [3].

Building scientific arguments is critical for all scientists, regardless of their field [4]. Students' involvement in an argumentative environment can lead to a better understanding of a relevant concept [5]. Students' argumentation skills and critical thinking positively contributed to their understanding of fundamental biology concepts. [6]. Science for citizenship must stress how science works, and students should be given opportunities to study science-in-the-making, assess evidence, and examine arguments that entail uncertainty [7].

Students' argumentation skills have been a concern in education worldwide for the last decade.[8] Empirical data, rather than just theoretical discourse, highlight the beneficial impact of argumentation on student learning within science education [9]. Unfortunately, many teenagers and even adults do not exhibit promising argumentation skills [10]. The findings suggest that students require additional assistance in using evidence and reasoning effectively and applying conceptual understanding to construct well-grounded arguments [4].

As a developing country, Indonesia is keen to promote students' soft skills, including argumentation, to prepare the younger generation for competitiveness. However, at this stage, Indonesian students' performance in this area remains insufficient. Some studies have found that Indonesian students' argumentation skills are unimpressive, with predominantly low levels (ranging from level 0 to 3) [11], [12]. Our previous research [13] also discovered that Indonesian students are unsatisfied with their ability to solve unfamiliar types of questions. This challenge reflects students' lack of argumentative skills, as evidenced by their apprehensive performances in international surveys such as PISA, TIMSS, and the Global Creativity Index (GCI). Therefore, promoting students' argumentation skills is a primary goal of the Indonesian government. For this reason, chemistry instruction should be designed to strengthen students' argumentation skills and deepen their mastery of chemistry concepts. Chemistry educators at the secondary and university levels are at the forefront of efforts to teach Indonesian students, aiming to develop their high-level thinking and skills in a holistic manner.

Pictorial-Based Learning (PcBL) & The role of visualisation in chemistry teaching

In recent decades, substantial studies have emerged, focusing on the advantages of utilizing visualizations encompassing graphics, drawings, animations, and simulations as a means to support the process of learning chemistry [14]. It fulfils instructional roles by capturing students' attention to particular content areas [15], illustrating both concrete and abstract details or processes [16], and demonstrating the operation of dynamic systems or the temporal evolution of scientific phenomena [17]. Visualisation plays a crucial role in educating students in the sciences [18]. Science, knowledge, and communication have all benefited greatly from the use of visualisation [18]. Therefore, it is inevitable that having knowledge of visualisation is the key to learning and understanding chemistry accordingly [19]. Many other types of media can be used to illustrate and convey scientific and chemical ideas, including but not limited to pictures, graphs, photographs, diagrams, and tables. Numerous studies provide credence to the claim that visuals are more memorable and effective for teaching scientific concepts and fostering the underlying cognitive processes of concept management, acquisition, and integration [20]. Students' cognitive growth and information-processing skills can be boosted by providing them with visually accurate representations of chemical concepts [21].

The ability of students to develop and use a model is an essential skill, as stated in the Next Generation Science Standards (NGSS) framework. The need to present models in chemistry and science teaching is primarily fulfilled through various media (physical or digital) to convey chemical concepts more easily. It describes, explores, and explains the abstract ideas of chemical behaviours [22]. However, utilising a model as an instructional approach is rare. Gaytan et al. have discussed the consent to consider the model as a supplement to content for students or as an instructional approach [23]. They presented works in biology and history that utilise models as scientific practice and suggested that the distinction between the two aspects could lead to significant consequences; therefore, they stressed that future research to explore this issue is required.

Chemistry teaching aims to promote students' understanding of chemistry and encourage them to learn the necessary 21st-century skills, including argumentation skills. The term argumentation skills can be traced back to the work of Toulmin since 1958, covering the ability to provide strong evidence to support the claim. It covers several key indicators: claim, data, warrant, backing, rebuttal, and qualifier [9].

In accordance with this study, some research employed graph-oriented methods with the assistance of computer tools to improve students' understanding and argumentation skills [24]. Another study utilised computer assistance to examine students' knowledge of socio-scientific issues [25]. In a more intense intervention, Crowell & Kuhn [10] worked for 3 years to improve students' argumentation skills. However, most of these studies were conducted on secondary and primary school students. Therefore, in this study, we followed up on these positive results at the university student level. Reflecting on the findings of their study, Evagorou & Osborne [8] suggested a further study to map students' argumentation skills from different backgrounds and perspectives. They also stressed using visualisation to promote students' understanding of science and how it works [26], which is compatible with argumentation skills.

When learning and teaching chemistry, visual representations like simulations and graphics are commonly used as mental scaffolding [17]. Langbeheim et al [27] utilised a pictorial representation to observe students' learning progress on the topic of matter and its properties. Some pictorial questions were also employed to reveal to students a scientific explanation of acid-base [28]. In this study, we applied Pictorial-based Learning (PcBL) in a general chemistry class and measured the profile of students' argumentation skills in each meeting. Students' deep understanding of chemistry was reflected in their responses to the integrative question type.

Our previous work [29] explored the potency of this approach for promoting students' conceptual change in chemical kinetics. Although we found that the advantage of PcBL students over Direct Instructional Teaching Method (DITM) students was only a small gap, the quality of PcBL students' answers was slightly higher than that of their counterparts. In addition, the pictorial approach has also been applied to uncover students' higher-order thinking skill levels [30] and their understanding of chemical kinetics [31]. Our previous review uncovered a significant contribution of visualisation in science teaching, including chemistry, but the number of studies focusing on this aspect is limited [32]. This approach also demonstrates long-term benefits in improving students' soft skills, including critical thinking, problem-solving, and argumentation [33].

Theoretical framework

Chemistry is the science that explains macroscopic phenomena (the real, tangible world) through microscopic reasoning (unobservable, abstract, and intangible) based on molecular chemical behaviour. For example, visually, students can observe that when water is placed in a freezer, freezing (ice) occurs, and the ice will float in water. This phenomenon is observable to the naked eye. What cannot be observed is the molecular behaviour that causes freezing: placing it in the freezer lowers the system's temperature, thereby reducing the kinetic energy of the water molecules. This situation slows the motion of water molecules, making their interactions more orderly, forming hydrogen bonds in a tetrahedral pattern, and creating a three-dimensional hexagonal network that leaves gaps between molecules, resulting in a lower density than water and causing it to float.

Johnstone's Triangle, or the triplet of chemical representation [34], highlights why science, including chemistry, is complicated for students. The root of the difficulty lies in the characteristics of science and the methods of teaching, which do not adequately take into account the nature of science itself. Johnstone introduced the concept of triplet representation [35]. Chemical concepts are communicated through three levels: (1) macroscopic or physically observable/tangible phenomena; (2) symbolic, involving symbols and reaction equations; and (3) sub-microscopic or particulate, which encompasses structural representations at the atomic and molecular levels.

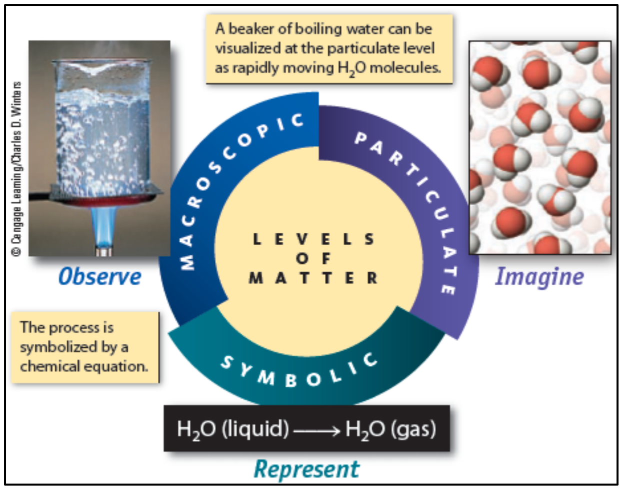

Figure 1. Representation of water (H_2O) at the three levels [36].

The chemical triple representation is exemplified by water (H_2O), as illustrated in Figure 1. At the macroscopic level, students perceive water in a glass, which can be ingested to alleviate thirst. At the microscopic level, they can only conceive of the innumerable water molecules (6.02 x 10^{23} H_2O molecules), each including two hydrogen atoms and one oxygen atom, with oxygen as the central atom and the two hydrogen atoms positioned as terminal atoms in a three-dimensional V configuration. Simultaneously, the symbolism of H_2O, encompassing phase state symbols (liquid/l, gas/g), enhances communication, particularly in textual contexts.

Representations in chemistry serve as instruments by which students, educators, and chemists engage with abstract chemical topics [37]. The ability to connect information, ideas, and transformations in each representation of a concept is a more meaningful indicator of understanding than manipulating symbolic notation [38], [39]. For example, many students, even those majoring in chemistry, can balance chemical equations by placing the correct coefficients and indices. However, understanding molecular behaviour or macro-scale phenomena represented by the equilibrium equation is a unique challenge for most chemistry students or undergraduates. To address this phenomenon, we utilise visualisation to help chemistry students learn more actively and meaningfully, and to serve as an assessment tool that reveals their deep understanding, based on Pictorial-Based Learning (PcBL).

The PcBL is expected to impact students' logical reasoning about the abstract nature of chemistry concepts for several reasons. Firstly, a visual model's demonstration of chemical behaviour will help students logically infer how and why chemical behaviours or reactions occur. Secondly, the dynamic representation will enhance the understanding of causal mechanisms in chemical processes by linking the three levels of chemical representations. Thirdly, reducing the cognitive burden by simplifying models leads to a focus on targeted concepts. At this stage, university students should already possess the ability to understand abstract concept entities [40]. Unfortunately, Bird [41] uncovered that most university-level chemistry students did not arrive at the formal operational stage. This lack of ability is rooted in the insufficient logical reasoning, which is also a robust predictor of students' performance in several chemistry courses [41].

The PcBL strategy in this study can be classified as a Brain-Based Educational Practice. Schunk [42] categorises Brain-based Educational Practice into several teaching strategies, including problem-based learning, simulations and role-playing, active discussions, graphics, and a favourable learning environment. According to multimedia learning theory, combining pictorial representation with verbal explanation contributes to a better learning outcome than verbal instruction alone [43]. Because of how our brains and eyes are wired, we absorb more information visually than in any other way [44]. The research indicates that linking the observable (macroscopic) realm of chemical phenomena to the imperceptible (particulate) domain of atoms and molecules improves student comprehension in chemistry [45].

The nature of chemical behaviour, explained by its sub-microscopic and particulate nature, requires modelling assistance to portray it in a concrete form. For this reason, students must be able to extract relevant information from visual representations in figures, graphs, and other forms. Chemistry teaching should be delivered optimally by considering the nature of chemical behaviour itself. In their work, Westbroek et al [46] described three prospective techniques to enhance substantive chemistry education: using pertinent situations, providing information on a necessary basis, and ensuring students perceive the significance of their contributions. Visual representations reduce the students' cognitive capacity, which is limited according to the cognitive load theory [47], [48]. Taking this into account, utilising visualisation is a form of teaching chemistry on a student-necessity basis.

Students' activity in PcBL is expected to train their argumentation skills. Science, including chemistry concepts, is constructed from a scientific process involving observation, data collection, and conclusion. These constructions are justified by theories explaining why the observable facts occur. For example, a series of observations led to a relationship between temperature and gas volume at constant pressure (Charles's Law). The phenomenon and other gas laws are theoretically explained by the kinetic molecular theory. In building theories to explain observable facts, events, and other phenomena, agreement and disagreement often exist [49]. The incidents of disagreement, conflicting opinions, and challenges to ideas mostly occur more often than general agreement [50], [51]. Therefore, chemistry students should exhibit strong argumentation skills.

Scientific argumentation is a skill demanding sufficient reasoning in conjunction with other inquiry-thinking processes [52]. Studies in this area involving chemistry students as prospective chemistry teachers are limited [53]. Scientific reasoning involves cognitive processes that facilitate creating and testing hypotheses, which are crucial components of scientific undertakings [54]. These cognitive processes encompass formal logic, such as probabilistic logic, as well as non-formal processes, including model-based reasoning[55] and analogical reasoning [56]. Scientific argumentation has been essential to mastering scientific concepts [57] due to its significant support for cognitive skills and undeniable function in 21st-century skills [58]. Students will automatically process and delve into their more profound understanding by presenting the key indicators of argumentation skills [59].

Although the vital pivotal role of argumentation skills has been acknowledged worldwide, limited effort has been made to employ an instructional approach specifically to train them intentionally [60]. This approach is derived from characteristic chemistry concepts that embrace the role of models and modelling, particularly visualisation. Therefore, in this study, we utilised a specific chemistry teaching approach, PcBL, to build students' skills and understanding of chemistry. The term 'understanding' has several definitions in the education community. In Bloom's cognitive taxonomy, understanding is a second level of taxonomy, representing a low mastery level. In this paper, we refer to the meaning of 'understanding' in line with several key aspects of conceptual understanding, including fundamental/basic understanding, applying knowledge, answering questions, and explaining concepts [61].

Research aims

The objectives of this research are to measure and describe: (1) the profile of chemistry students' argumentation skills levels after experiencing PcBL in the topic of Solubility & Intermolecular Forces (SIF), Gas Laws (GL), Kinetic Molecular Theory (KMT), and Thermochemistry (Thc), (2) the progress of students' argumentation skills levels during 1 teaching term using PcBL across the four topics, (3) students' understanding across the four topics after experiencing PcBL, and (4) the correlation between students' understanding and their argumentation skills levels.

2. METHOD

This study employed a single-group experimental design and involved 35 first-year students of chemistry education at Universitas Negeri Malang, aged 19 to 21 years old. The study was conducted over one semester in the 2022/2023 academic year, focusing on Basic Chemistry 2, which covered three topics: Solubility & Intermolecular Forces, gas laws, and thermochemistry. The group of students participating in this study was a bilingual class. In our department, among the eight classes in the total student intake each year, several eligible students are assigned to a single class as bilingual students. The teaching process in this class occurs in both Indonesian and English. Therefore, having two equal experimental and comparison groups is not feasible due to the department's lack of two comparable classes. The primary requirement for this class is English proficiency, which is assessed on the first day at the university. The students completed the Basic Chemistry 1 course before embarking on this study. In Basic Chemistry 1, students learned about matter and measurement, stoichiometry, atomic structure, and chemical bonding.

PcBL syntax

The PcBL strategy is implemented in the general chemistry class through the following steps: opening, pictorial trigger, concept exploration and sharing, verification and closure. Let's explain these steps in the teaching of Gas Laws. At the *opening* stage, the lecturer provides a brief explanation of the learning aims and a brief overview of the Gas Laws, without delving into the concepts. Next (*pictorial trigger*), the image depicting gas behaviour is presented (Figure 2). These pictures served as a cognitive trigger for students to understand the relationship between volume (V) and pressure (P) as explained by

Boyle's Law. How does the volume of the balloon increase with the higher altitude in the atmosphere? Students should also determine whether atmospheric pressure increases or decreases with increasing altitude. At this stage, students should individually extract information from the Figure and relate it to gas behaviour. In the next step (*concept exploration and sharing*), students work in pairs to discuss and share their interpretations of the figure and its relationship to the concept. The discussion is followed by the lecturer leading it classically. The students talked about what they learnt from the picture interactively. The lecture concludes the class after all the concepts have been discussed in accordance with the scientific understanding (*verification and closure*).

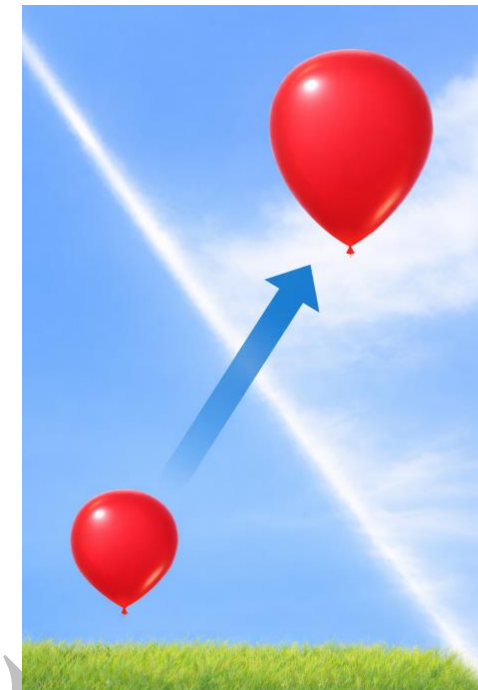

Figure 2. Pictorial trigger for Boyle's Law

Instrument & Data Collection

Students' argumentation skills were measured at the end of each topic using 3 instruments, including the Argumentation Test of Solubility & Intermolecular Forces (SIF), Gas Laws (GL), Kinetic Molecular Theory (KMT), and Thermochemistry (Thc). Each instrument was administered at the end of the teaching for each topic. Each topic was carried out for 3-4 meetings. Toulmin's Argument Pattern (TAP), comprising claims, data, warrants, backing, qualifiers, and rebuttals, is employed in this study [62] to assess students' argumentation skills. A claim is a public statement for general acceptance, such as *it is correct, I have no idea, or it is incorrect*. Data are evidence that supports a claim, for example, *it is correct* (**claim**) because *the frequency of collision increases the reaction rate* (**data**). A warrant describes the correlation between the claim and the data. For example, *the reaction will be faster in a smaller area (volume)*. Backing is a generalisation that clarifies the body of experience utilised to validate the believability of the argumentative approach employed in a specific instance. For instance, *according to collision theory,* *increasing collision frequency increases the amount of energy produced to reach the activation energy*. A rebuttal is an exceptional situation that may undermine the strength of a supporting argument. Meanwhile, a qualifier refers to a statement that denotes the confidence level that may be attributed to a conclusion based on the supporting arguments provided.

The authors developed all the argumentation skill questions. Subsequently, colleagues, organic and physical chemists responsible for teaching final-year students in the chemistry department, reviewed the prototype questions, resulting in minor adjustments to several questions. Meanwhile, students' understanding was evaluated at the end of the semester using a multiple-choice instrument type (instrument available on request). The instrument is named Test of Chemistry Students' Understanding (TCSU) for simplification. The test was constructed collectively by the Basic Chemistry Team Teaching and utilised to evaluate all students taking Basic Chemistry (8 classes in total) within the Chemistry department.

Data Analysis

The detailed frameworks for categorising the level of students' argumentation skills are employed in the procedure from Cetin [62], as provided in Table 1. Content analysis procedures, adopted from Lundman et al and Kleinheksel et al [63], [64] were employed to assign the level of students' argumentation skills: organisation, coding, interpretation (initial categorisation), peer debriefing, and final categorisation. At the organisation stage, students' answers to the argumentation test were grouped into two groups (correct and incorrect answers). The incorrect answers or those left empty on the answer sheet are categorised as Level 0 of argumentation skills (L0AS). The correct answers are further sent to the coding stage. During the coding stage, students' answers are stored based on the similarity of their conceptual points of view. For example, in the GL question, those related to the change in temperature with the volume change are grouped in the same compartment. In the interpretation stage, all the answers were assigned to the relevant argumentation level (Levels 1 – 5). The next stage, peer debriefing, is a recheck and discussion with all the team members to ensure that the assigned level is acceptable. At the final categorisation, strong agreement was obtained, and the final categories of students' argumentation levels were reformed.

Table 1. Framework for assessing students' argumentation skills [62].

Level	Description
Level 1 (L1AS)	Claim only
Level 2 (L2AS)	Claim, data (evidence supporting the claim) and/or warrant (relationship between claim and data)
Level 3 (L3AS)	Claim, data/warrant, backing or qualifier
Level 4 (L4AS)	Claim, data/warrant, backing and qualifier

Students' understanding is classified based on the percentage of obtained scores, as displayed in Table 2. The categorisation of students' understanding, as displayed in Table 2, is built upon the procedure for determining the course final grade in some Indonesian universities. The correlation between students' knowledge of chemistry and the level of their argumentation skills was measured using *the product-moment correlation*. As aforementioned, students' understanding of chemistry is obtained from their scores at TCSU.

Table 2. The classification of students' understanding

Score	Category
85 - 100	High
70-84	Moderate
55-69	Weak
< 54	Poor

3. RESULTS AND DISCUSSION

Profile of Students' Argumentation Skills: Solubility & Intermolecular Forces (SIF)

Solubility & intermolecular forces have been taught at secondary and university levels in many countries. Knowledge regarding intermolecular forces is essential for students to predict material properties correctly [65], including chemical & physical properties and bioactivity [66], [67]. This topic is challenging for students due to the confusion of terminology between intramolecular and intermolecular forces [68]. Robust understanding in this area is essential because it can be utilised to explain molecular interaction mechanisms (how and why) [66]. However, based on our searching so far, the number of studies concerning solubility & intermolecular forces mainly how the teaching of the topic influences students' argumentation skills, is unfound.

In this study, students' argumentation skills related to solubility & intermolecular forces were assessed using the following question. Here is the question: "*At 25◦C, the solubility of benzoic acid ($HC_7H_5O_2$) in water is lower than its solubility in benzene. Assess whether the statement is correct or incorrect.* (*Hint: Benzoic acid produces a dimer with benzene*).

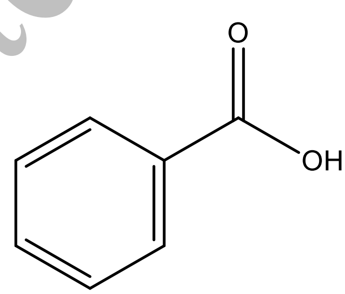

Figure 3. Structure of Benzoic Acid

This question is designed to assess students' scientific understanding of solubility principles, specifically the scientific argumentation they will provide to support their answers. Whether students can correctly mention the solubility values of benzoic acid in water (0.34 g/100 mL) and in Benzene (C_6H_6), 10.0 g/100 mL, is not the primary concern; how do students provide a scientific argument instead? The hint regarding dimer formation is offered to stimulate students' ideas about the dimer structure and its relationship to the molecule's polarity. Students with low scientific reasoning may simply apply the rule of like dissolves like by considering that the polarity of water is greater than that of benzene. By acknowledging that benzoic acid is also polar, they may assume that its solubility in water will be higher. They could ignore the monomeric structure of the acid.

The monomeric structure of benzoic acid (Figure 3) will form a dimer of benzoic acid with equivalent H-bonds [69]. Dimeric structures endure in low-polarity solutions. However, their stability is primarily contingent upon the solvent [70]. Therefore, this dimerisation should be a clue for students to predict the solubility of the compound in water and benzene by considering the polarity of the formed dimer. This scientific reasoning is seemingly in consideration of some students with scientific argumentation, as presented in Table 3.

Table 3. Examples of Argumentation Skills Levels for SIF

Level 2				
Claim	**Data**	**Warrant**		
The statement is correct.	• The solubility of benzoic acid is distributed between two phases according to an equilibrium equation. • Benzoic acid is hardly soluble in water but in ethanol, chloroform, and ether. • Benzoic acid is a weak acid. • Because at the same temperature, the solubility of benzoic acid in organic solvents (11 g/100 mL) is higher than its solubility in water (0,34 g/100 mL) • The solubility of benzoic acid in water is 0.34 g/100 mL • The solubility of benzoic acid in benzene is higher with 10.0 g/100 mL • Benzoic acid will form dimer in benzene			
	Benzoic acid is soluble in benzene, forming hydrogen bonds between molecules.	It leads to the formation of dimer.		
	Benzoic acid is soluble in benzene, forming a dimer.	The solubility of benzoic acid in benzene is higher than in water.		
	• The solubility of benzoic acid in water is lower than 1 • The solubility of benzoic acid in benzene ranges from 1 – 10	• Benzoic acid is easily soluble in water • Benzoic acid can also be soluble in other organic solvents		
	Benzoic acid will form dimer in benzene due to the hydrogen bonding	• Benzoic acid is easily soluble in benzene • Benzoic acid is hardly soluble in water		
Level 3				
Claim	**Data**	**Warrant**	**Qualifier**	
The statement is correct.	Benzoic acid has a non-polar outer site	It forms a dimer that is insoluble in water	The dimer could lead to the insolubility of benzoic acid in water	
	• Benzoic acid is hardly soluble in water but is greatly soluble in chloroform, ether, and ethanol. • Benzoic acid is a weak carboxylate aromatic acid.		Benzoic acid is soluble in benzene because both are non-polar.	
	• The solubility of benzoic acid will be distributed between two phases, which refers to the equilibrium equation. • Benzoic acid is soluble in benzene and forms hydrogen bonding	The hydrogen bonding leads to the formation of dimer	Therefore, benzoic acid is more soluble in benzene than in water or other non-organic solvents	
	Both benzoic acid and benzene are non-polar	Benzoic acid is soluble in benzene and forms hydrogen bonding	The hydrogen bonding could lead to the formation of a dimer	
	• The solubility of benzoic acid in water is 0,34 g/100 mL • The solubility of benzoic acid in benzene is 10,0 g/100 mL (higher)		• Benzoic acid is hardly soluble in water • Benzoic acid forms a dimer with benzene • Hydrocarbon compounds are mostly non-polar	
	Benzoic acid is soluble in benzene and forms hydrogen bonding, leading to a dimer formation.		The dimer is the unification of two identical molecules.	
	Benzoic acid is more soluble in benzene due to the hydrogen bonding	The hydrogen bonding leads to the formation of dimer	Benzoic acid is insoluble in water because the carboxylic group is polar, but most parts of the benzoic acid molecule are non-polar	
Level 4				
Claim	**Data**	**Warrant**	**Backing**	**Qualifier**

The statement is correct.	Benzoic acid will form dimer due to the intermolecular bonding	The solubility of benzoic acid in benzene is higher than its solubility in water	Solubility will be higher if the polarity between the two molecules is similar	The dimers of Benzoic acid and benzene are both non-polar, while water is polar

Students mostly recognised that the solubility of benzoic acid in benzene is higher than its solubility in water. This phenomenon is confirmed by the majority of students who mostly provided the claim 'the statement is correct'. However, the number of students who follow the claim and data with relevant warrants is equal to those without warrants. Many students with Level 2 Argumentation Skill (L2AS) provided claims and data without warrants, backing, and qualifiers. However, some followed this with a warrant that the structure of benzoic acid facilitates dimer formation, leading to a decrease in polarity. Therefore, its solubility in a non-polar solvent (benzene) is higher than that of water, which is more polar.

Students with Level 3 Argumentation Skill (L3AS) demonstrated concept mastery comparable to that of L2AS students, except that they classified their answers as claim, data, warrant, and qualifier in a proper manner. Only a single student demonstrated an outstanding Level 4 Argumentation Skill (L4AS). The student provided a robust scientific understanding and argument with a good logical order. The student began with the formation of a dimer due to the intermolecular bonding of the benzoic acid molecules (claim). The warrant that the solubility of benzoic acid in benzene is higher than in water was followed by the backing that solubility will be higher if the polarity between the two molecules is similar. The qualifier that "the dimer of Benzoic acid and Benzene is both non-polar, while water is polar" is assertive for the L4AS quality.

All in all, those students always provide at least follow-up data to support their claim that the solubility of benzoic acid in water is lower than its solubility in benzene. This study provided supportive evidence that the use of PcBL positively contributed to the formation of students' scientific argumentation in Solubility and Intermolecular Forces. The previous study [71] found that students' understanding of intermolecular forces could be fostered with problem-based learning and reduced the topic's unscientific understanding of incidents.

Profile of Student's Argumentation Skills: Gas Laws

In Indonesian universities, Gas Laws are covered in introductory chemistry and physical chemistry courses. The works of Robert Boyle, Jacque Charles, and Amedeo Avogadro are recognised as the 3 historical milestones of gas laws introduced in both courses. In this study, students' argumentation skills related to gas laws were assessed using the following question focusing on the relationship of volume, temperature and moles of gases. As per the previous topic, using gas laws to assess students' argumentation skills has not been found. The following statement is the question *in italics*. *After the appropriate adjustments have been made to the initial gas sample maintained at a pressure of 1.0 atm, demonstrate the approximate level of the movable piston in Figures 3 (a) and (b).* This question aims to measure students' understanding of applying the Gas Laws from a picture of a movable piston.

This typical question is uncommon in the assessment procedures for basic chemistry class assessment in many Indonesian universities. The questions are mostly presented on an algorithmic basis, in which students are required to calculate one of the variables (pressure/P, volume/V, or temperature/T) with two other known variables. Students can simply substitute all the numerical values into the gas laws formulas and do mathematical operations. Therefore, it is often the case that in some chemistry topics, including chemical kinetics [30], [31], limiting reactants [72], stoichiometry [73], basic quantum [74] students can provide a correct mathematical calculation without fully understanding the conceptual meaning of the formula.

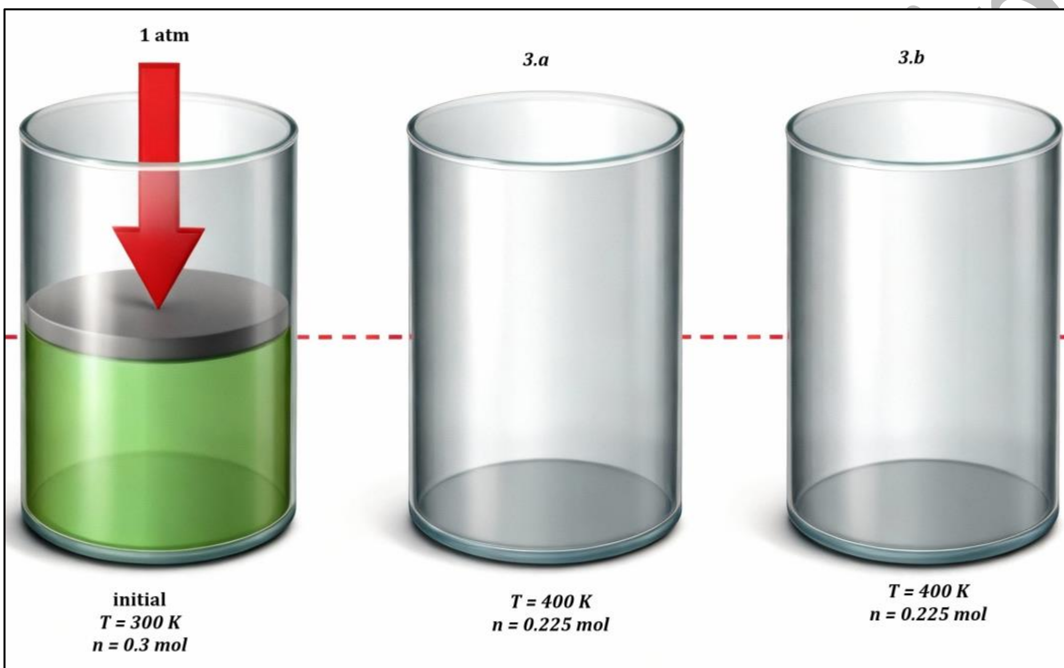

Figure 4. A movable piston

Students with robust scientific understanding firmly recognise the relationship between the temperature of the gas system and the mole. They addressed that the temperature increases 1.3 times while the mole decreases with the same value, leading to a constant volume of V1 to VA. Meanwhile, for the V1 to VB, both variables decrease by 1.5 times for temperature and 1.3 times for the mole. Therefore, they correctly predicted that the VB < V1. In this circumstance, the question was not intended to ask students to provide an exact numerical value of the change in volume due to the changes in the two variables. For this reason, the numerical values provided by students to support their answers are not taken into account for grading procedures. However, the ultimate measures are the scientific logic regarding the change in volume, whether an increase, a decrease or a constant and the argument for backing those. The previous study on Gas laws found that students' success in answering Gas laws questions depends on 3 factors, including number format, volume unit, and temperature unit [75].

As in the previous topic, most students correctly identified the claim and the data. They all understood the relationship between pressure, volume, and moles in gas behaviour. In this topic, all L2AS students supported their claim with a warrant, including that the volume of gases increases with temperature, decreases with temperature, and decreases with the number of moles. The most intriguing backing from L3AS is that Avogadro's Law is inapplicable, implying a cautious assessment of the effect of the two variables (temperature and moles). The students considered that (Figure 4.a) the increase in temperature (300 – 400 K) increases the volume, while the decrease in mole (0.3 – 0.225 mol) decreases the volume. The contradictory effect leads students to conclude that the initial volume (VI) tends not to change significantly (VA). As with the previous topic, L4AS students demonstrated a better order of logical reasoning, from the possible change of the volume in two conditions to its relation to the gas laws' behaviours.

Table 4. Examples of Argumentation Skills Levels for GL

Level 2				
Claim	**Data**		**Warrant**	
• VA = VI • VB = ½ VI • VB decreases • The figure describes the temperature and the number of moles of the gases	• VI = 90 R; VA = 90 R; VB = 45 R • VA = VI; VB = ½ VI • VA = 8.96 L; VB = 4.48 L • VA = 90 R; VB = 45 R		• Due to the difference in temperature and mole with the constant pressure of 1 atm • The volume of gases increases with the increase in temperature • The volume of gases decreases with the decrease in temperature • The volume of gases decreases with the decrease in moles	
Level 3				
Claim	**Data**	**Warrant**	**Backing**	
• VB decreases • VB decreases as predicted by Charles's and Avogadro's Laws • The volume of gases increases with the increase in temperature	• VI = 90 R • VA = 90 R • VB = 45 R	• The volume of gases increases with the increase in temperature • The volume of gases decreases with the decrease in temperature • The volume of gases decreases with the decrease in moles	• Applying Charles's Law due to the constant piston pressure • Avogadro's Law is not applicable • Charles's, Gay-Lussac's and Avogadro's laws • Applying Charles's Law due to the constant piston pressure	
Level 4				
Claim	**Data**	**Warrant**	**Backing**	**Qualifier**
• VB decreases • VA = VI • VB ≠ VA • VA > VB	• VA = VI; VB = ½ VI • VI = 90 R; VA = 90 R; VB = 45 R • TA is higher • VI = 7.38; VA = 7.38; VB = 3.69	• No change in the VA, while the VB decreases by half of the VI • The volume of gases increases with the increase in temperature • The volume of gases decreases with the decrease in temperature • In this case, the temperature affects the volume	• Following Avogadro's, Charles's, and Gay-Lussac's laws • Following Charles's and Avogadro's laws	• In many circumstances, the volume of gases increases with the increase in temperature, and vice versa. • The volume of gases mostly decreases with a decrease in moles. • According to Charles's Law, at a constant pressure, the volume of gas is directly proportional to its temperature. • According to Avogadro's Law, at constant pressure and temperature, the volume of gas is directly proportional to its moles.

		• The volume of gases mainly decreases with a decrease in temperature • According to Charles's and Gay-Lussac's Laws, at constant pressure, the volume of gas is directly proportional to its temperature

Profile of Students' Argumentation Skills: Kinetic Molecular Theory (KMT)

In this study, the question for the Kinetic Molecular Theory (KMT) of gases is represented by the root mean square velocity. It represents the measure of gas-particle average speed. In most Indonesian universities, this topic is hardly covered in basic chemistry courses but in physical chemistry. However, this concept is provided in many general chemistry textbooks, which are the most common references for basic chemistry courses.

Table 5. Examples of Argumentation Skills Levels for KMT

Level 2		
Claim	**Data**	**Warrant**
Correct statement	• U_{ark} O_2 16 m/s; U_{ark} UF_6 4.89 m/s • U_{ark} O_2 1.62 x 10^3 m/s; U_{ark} UF_6 1.52 x 10^5 m/s • U_{ark} O_2 2.6 x 10^3 m/s; U_{ark} UF_6 0.23 x 10^5 m/s • U_{ark} O_2 263.44 m/s; U_{ark} UF_6 23.9 m/s • U_{ark} O_2 1.16 m/s; U_{ark} UF_6 0.468 m/s	• The molar mass of O_2 is lower than that of UF_6 molecules; therefore, the former one is 3,3 times faster • The higher the temperature, the faster the gas molecules • The higher the molar mass of gas molecules, the slower its movement

Level 3				
Claim	**Data**	**Warrant**	**Backing**	**Qualifier**
Correct statement	• U_{ark} O_2 1.16 m/s; U_{ark} UF_6 0.49 m/s • U_{ark} O_2 : U_{ark} UF_6 = 3.3 : 1 • U_{ark} O_2 3.3 m/s; U_{ark} UF_6 0.23 m/s • U_{ark} O_2 513 m/s; U_{ark} UF_6 154 m/s • U_{ark} O_2 16.2 m/s; U_{ark} UF_6 4.9 m/s • The molar mass of O_2 is 36 g/mole, and UF_6 is 352 g/mole	• The molecule of gas O_2 moves 3.3 times faster than the molecule of gas UF_6 • The calculation using the RMS speed equation confirms the ratio • The higher the molecular mass, the lower the U_{ark} value	• The velocity of gas molecules is determined by the gas constant, temperature, and molar mass • According to the kinetic molecular theory of gases, the molecular speed of gases is affected by the temperature, in which the higher the temperature, the higher the kinetic energy, leading to a higher molecular speed	
Correct statement	• U_{ark} O_2 1.16 m/s; U_{ark} UF_6 0.49 m/s • U_{ark} O_2 : U_{ark} UF_6 = 3.3 : 1 • U_{ark} O_2 3.3 m/s; U_{ark} UF_6 0.23 m/s • U_{ark} O_2 513 m/s; U_{ark} UF_6 154 m/s • U_{ark} O_2 16.2 m/s; U_{ark} UF_6 4.9 m/s • The molar mass of O_2 is 36 g/mole, and UF_6 is 352 g/mole	• The molecule of gas O_2 moves 3.3 times faster than the molecule of gas UF_6 • The calculation using the RMS speed equation confirms the ratio • The higher the molecular mass, the lower the Uark value		• At the same temperature, a gas with a lower molar mass will have a higher molecular speed. • The molecular speed of gases is inversely proportional to their molar mass.

Level 4				
Claim	Data	Warrant	Backing	Qualifier
Correct statement	• U_{ark} O_2 1.6 m/s; U_{ark} UF_6 0.479 m/s • The kinetic energy produced in the O_2 molecules is higher than that of the UF_6 • U_{ark} O_2 : U_{ark} ; UF_6 = 3.3 : 1 • The molecular speed of gas molecules is inversely proportional to the molar mass.	• The molecular speed of O_2 molecules is higher due to its lower molar mass compared to the molar mass of UF_6 • At the same temperature (65°C), The molecular speed of O_2 is 3.3 times higher than the speed of UF_6 molecules. • At the same temperature, the higher the molar mass, the lower the molecular speed	• The calculation using the RMS speed equation confirms the ratio of molecular speed between O_2 and UF_6 molecules. • The difference in molar mass • The phenomenon is relevant to the kinetic molecular theory of gases • Graham's Law of Effusion	• The equation shows that the molar mass (M) is inversely proportional to the Uark • At the same temperature, the higher the molar mass, the molecular speed tends to be lower. • At the same temperature and pressure, the diffusion and effusion of gases are inversely proportional to the molar mass.

Students' argumentation skills related to the Kinetic Molecular Theory of gases were assessed using the question below. *At 65°C, the O_2 molecule moves 3.3 times faster than the UF_6 molecule. Identify whether the statement is correct or incorrect. Provide your scientific arguments.*

$$U_{ark} = \sqrt{\frac{3RT}{M}}$$ *With M is molar mass.*

In this question, students are required to figure out that the Root-mean-square velocity of a gas is directly proportional to the square root of its temperature, measured in kelvins. Since the variable M is present in the denominator, it may be inferred that the greater the weight of the gas, the slower the movement of its molecules. Acknowledging the O_2 and UF_6 molar mass ratio, they should understand that the statement is correct.

All the students with L2AS in this topic provided a warrant regarding the effect of molar mass on the molecular speed of those gases. Meanwhile, those with L3AS incorporated their warrant with the backing related to the relationship between temperature and molar mass and the gases' molecular speed. Students with L4AS even completed their qualifier regarding gas diffusion and effusion behaviours.

Profile of Students' Argumentation Skills: Thermochemistry (Thc)

Thermochemistry is a quite familiar topic for chemistry students in Indonesia. Their exposure to the topic has been experienced since secondary school, first-year university and the following years in some advanced chemistry courses such as thermodynamics, physical chemistry and others. Considering that the topic is a basis for understanding other concepts, such as thermodynamics, is understandable. Studies on the topic of thermochemistry related to students' understanding and unscientific understanding have been carried out in previous research [76].

Students' argumentation skills related to thermochemistry were assessed using the following questions, particularly in the concept of Hess law.

Calculate the ΔH◦ for the following reaction (use data from a table of thermodynamic data)

$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

$2Na(s) + CO_2(g) \rightarrow Na_2O(s) + CO(g)$

Please state whether the following statement *is correct or incorrect: "An excellent way to put out a sodium fire is with a water or carbon dioxide fire extinguisher." Identify whether the statement is correct or incorrect. Explain your answer.*

Table 6 demonstrates students' strong knowledge of calculating the enthalpy change for the chemical reaction presented in the question. Solving questions related to Hess Laws requires mathematical operation ability, which Indonesian students are primarily good at [31]. For this reason, the question was not emphasised in the calculation of the Hess Law. Students with L2AS focused on the classification of fire extinguishers to support their belief that, as class D fire, water or carbon dioxide are unsuitable for sodium fire. Meanwhile, those with L3AS followed up their warrant with a qualifier regarding the reactivity of sodium to water, leading to an explosion in contact. Meanwhile, L4AS students incorporated their argument, supported by evidence that the energy released by the reaction between sodium and water.

Table 6. Examples of Argumentation Skills Levels for Thc

Level 2				
Claim	**Data**	**Warrant**		
Incorrect statement	• ΔH1= -832 kJ/mol • ΔH2= -368 kJ/mol • ΔH3= -133 kJ/mol • For solid metals such as magnesium, aluminium, sodium, potassium, and others, dry powder and sand are recommended	• Sodium fire is classified as Class D fire in which water and regular fire extinguishers involving combustible reactive metals should not be applied; instead, dry powder is recommended. • Water is used as an extinguisher for non-metals such as wood, paper, and plastic. Meanwhile, CO_2 is used for flammable liquids and high-voltage electricity. • Sodium forms flammable hydrogen and NaOH when in contact with water, so it is not suggested that the fire be extinguished with sodium.		
Level 3				
Claim	**Data**	**Warrant**	**Qualifier**	
Incorrect statement	• ΔH1 = -831.8 kJ/mol • ΔH2 = -368.4 kJ/mol • ΔH3 = -132.9 kJ/mol • The chemical equations tell us that the reaction between sodium and water or CO_2 produces gases.	• Sodium fire is classified as Class D fire in which water and regular fire extinguishers involving combustible reactive metals should not be applied; instead, dry powder is recommended. • When sodium is in contact with water or carbon dioxide, an exothermic reaction with enough energy/heat to spontaneously burn H2 gas and ignite an explosion.	• Sodium is reactive to water and explosive; meanwhile, CO_2 will spread the fire quickly. • The contact between sodium and water will enhance the burning instead of extinguishing it. • Water is used as an extinguisher for non-metals such as wood, paper, and plastic. Meanwhile, CO_2 is used for flammable liquid and high-voltage electricity. • Carbon dioxide extinguishers are suitable for use on Class B and Class C fires.	
Level 4				
Claim	**Data**	**Warrant**	**Backing**	**Qualifier**

Incorrect statement	• $\Delta H1$ = -831.78 kJ/mol • $\Delta H2$ = -367.6 kJ/mol • $\Delta H3$ = -132.89 kJ/mol	Water extinguishers (Class A) are used for non-metal solid fires such as paper, cloth, wood, and rubber. Meanwhile, Carbon Dioxide ($CO2$) is used for flammable liquids (class B) and electrical equipment (Class C).	• Most alkali metals, such as sodium, react with water exothermically. So, a small piece of it can explode. • The reaction between sodium metal and water generates a lot of heat (exothermic) because the hydrogen gas formed during the reaction will ignite and cause a small explosion. Regarding the energy released, the reaction between sodium and water is also quite high.	The reaction produces caustic soda (sodium hydroxide) and flammable hydrogen gas in this case. Therefore, if a metal fire is extinguished with water or carbon dioxide, it can cause a steam explosion that can spread over a wider area.

Progress of Students' Argumentation Skills

The level of students' argumentation skills was evaluated on every topic. With this procedure, the growth of students' argumentation skills was monitored. The descriptions of. Figure 4 shows that in the first topic, Solubility & Intermolecular Forces, although no L1AS was observed, students' argumentation skills generally fall in the weak category. This phenomenon is derived from the fact that most students demonstrated L0AS with 13 students (highest), followed by the L2AS and L3AS in order. Meanwhile, only 1 student demonstrated level 4 (L4AS) in this topic. This ensures that most students' argumentation skills in the SIF topic are mainly at the lower level, with a significant drop at L4AS.

A different trend emerges for the Gas Laws (GL), recording the highest number of students with L4AS over the topics, reaching 10. The number of students with L0AS also dropped significantly, with only 5 students. This trend indicates a shift in students' argumentation skills to higher levels, with L3AS leading the count.

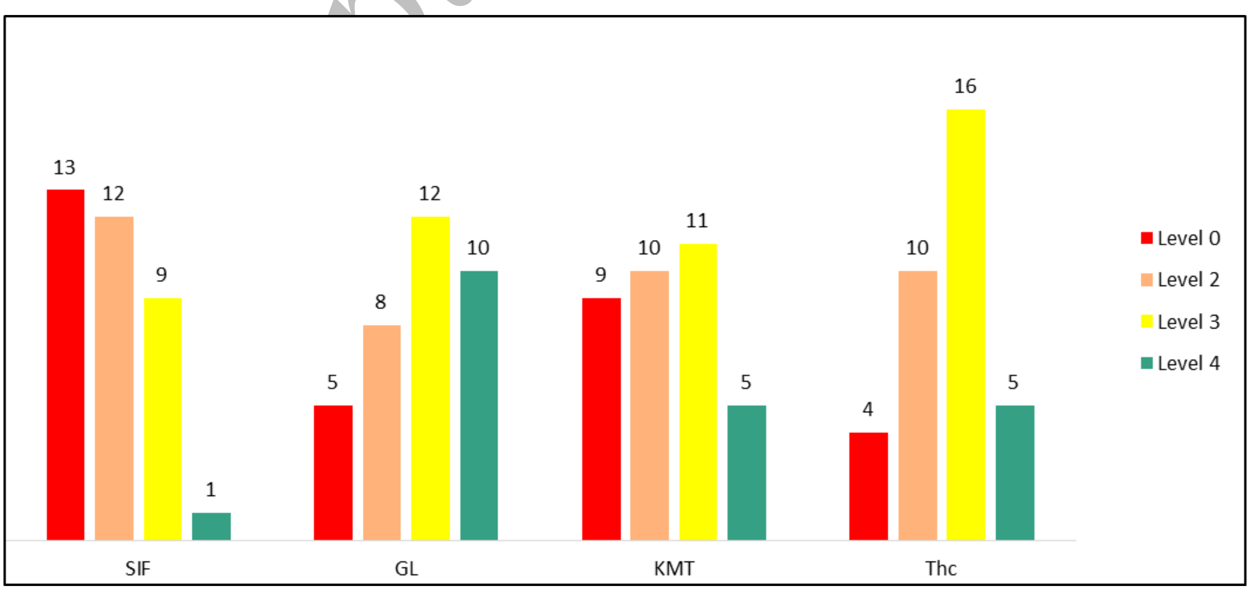

Figure 5. The progress of students' argumentation skills level each topic (SIF: Solubility & Intermolecular Forces, GL: Gas Laws, KMT: Kinetic molecular Theory, Thc: Thermochemistry)

A more variative distribution of students' argumentation skills is demonstrated for KMT. The highest argumentation level is found at L3AS with 11 students, while L2AS is slightly behind with 10 students. L0AS also obtains a relatively high number of 9 students. Meanwhile, the number of L4AS students was slightly higher for the second topic but still higher than the first.

The level of argumentation skills in thermochemistry (Thc) exhibits a unique trend, peaking at the L3AS with 16 students. As the first three topics, L3AS also dominated the incident of argumentation level in thermochemistry. With the majority of students' argumentation level concentrated in Level 3, a sharp decline at the lower and higher levels (L2AS and L4AS) is observed. All in all, Figure 5 reveals that L3AS consistently holds the highest number across the four topics. Meanwhile, the SIF showed the highest L0AS, indicating that many students were unable to provide the expected answer on this topic.

Figure 5 also describes the progress of students' argumentation levels on each topic. The figure shows that L2AS slightly dropped over topics, while L3AS substantially improved. This implies that students' argumentation levels increase over time. An interesting phenomenon is observed for the L4AS. The number of students showing for this level was initially very low, with only 1 student (SIF). However, the number of students showing this level gradually increased over the meetings and topics. However, the highest number was shown on the Gas Laws, the second topic among the four. Based on this data, it is more likely that students' argumentation skills will reach a peak in this area.

The outcomes of this study demonstrate a significantly higher argumentation level than the previous findings in Indonesian universities [77], [78] that mostly concentrated on Level 2. However, comparing the findings of this study with those of the two studies should be approached cautiously due to the differing research designs between them. Additionally, the nature of each topic can also impact students' argumentation skills. A topic that is considered challenging may lead to suboptimal argumentative skills among students, and vice versa. Despite these limitations, this study positively enhanced students' argumentation skills by providing them with a challenging exercise. Cox & Gulacar [79] offered regular and irregular tasks for two different groups in the Gas Laws teaching and found better performances for those with irregular tasks. To sum up, this study demonstrates similar results to the previous findings, accomplishing positive evidence in improving students' argumentation skills using an integrated instructional approach [80], Argument-Driven Inquiry (ADI)[81], laboratory-based course [82] and others.

Student's Understanding of Basic Chemistry

Students' understanding of chemistry after experiencing PcBL is retrieved by the score of their answer to the TCSU. The test consisted of 30 multiple-choice questions covering all four topics, as well as additional topics not included in the argumentative questions, such as matter and measurement, stoichiometry. Students' scores were converted to a maximum of 100 if they answered all the questions correctly. The TCSU was used as the basis for grading students' achievements in the basic chemistry class with the following criteria: >85 for A, 80–84 for A^-, 75–79 for B^+, 70-74 for B, 65-69 for C^+, 60-64 for C, 55-59 for D, and <55 for E. A grade of C is the minimum requirement for passing the course. The question was in the Indonesian language because the TCSU was also applied to other non-bilingual classes. An example of a translated question is provided in Figure 6. The question is designed to assess students' mastery of applying gas laws.

A container has a volume of 2.10 L, containing a gas with a mass of 4.65 g at a pressure of 1.00 atm and a temperature of 27.0 °C. What is the molar mass of the gas?
A. 55.14 g/mol B. 54.6 g/mol C. 49.60 g/mol D. 48.9 g/mol E. 11.10 g/mol

Figure 6. Example of a question in the TCSU instrument

Table 7 shows the distribution of students' numbers based on the score in answering the TCSU and corresponding performance categories. Notably, none of the students recorded the most expected performance (85-100). However, the number of students in the moderate and weak categories is equal. On average, the students' scores were 63.4, falling into the *weak* category. Although none of the students reached the *robust* category, a substantial portion (40%) demonstrated a quite moderate understanding, with scores over 70. As additional information, compared with the other 7 classes of first-year chemistry students who took the same test at the university, taught using a non-PcBL approach, this class performed better. With only 7 PcBL students scoring in the poor category, this is a worthwhile exercise in chemistry instruction.

Table 7. Examples of Argumentation Skills Levels for Thc

Score	Number of students	Category
85 - 100	0	High
70-84	14	Moderate
55-69	14	Weak
< 54	7	Poor

This finding is positive evidence that the PcBL is a potential teaching approach for improving students' understanding. In our previous research employing this approach [29], students performed better in answering chemical kinetics questions than non-PcBL students. In another study, using the eChem tool to link chemical concepts and representations can promote chemistry students' understanding [83]. Visual model mastery is even considered a predictive tool of students' general chemistry examination grades [19]. To sum up, several studies have confirmed the positive impact of visualisation in fostering students' understanding of many chemistry topics, including stereochemistry [84], electrochemistry [14], [85], chemical reaction [86], organic chemistry [87] and many others.

A similar study that employed three different visual representations confirmed the positive impact of the model in improving students' understanding of electrochemistry as well as their motivation to learn chemistry [14]. Students were also involved in generating drawing activities in this teaching intervention. Furthermore, Stammes et al [88] emphasised that involving students in drawing chemical behaviours can benefit chemistry educators by mirroring and reflecting students' deep and actual thinking. By generating their drawing, chemistry educators have plenty of insight into students' conceptual understanding [89]. This approach could be considered for the next implementation of PcBL to emphasise that students should generate a drawing regarding chemical behaviours rather than provide a pictorial representation to be analysed.

Correlation Between Students' Understanding and Their Argumentation Skills

When the correlation between students' understanding of chemistry and the level of their argumentation skills is examined using product-moment correlation (Table 7) with a Pearson correlation coefficient = 0.062, statistically, there is a positive but very weak correlation between these two variables. This result implies that there is ***almost no linear relationship*** between students' understanding and their argumentation skills. The significance or p-value (0.723), which is much higher than 0.005, confirms that the correlation is not statistically proven. The correlation value suggests that students with a good understanding of chemistry will not necessarily have better argumentation skills, and vice versa.

The result of this study is in line with the other previous findings in an Indonesian university employing an integrated chemical literacy and socio-scientific issue (SSI) approach. Although the approach effectively improved students' argumentation skills, there was no observable correlation between students' argumentation skills and their content-related SSI mastery [90]. They found that even higher achievement students required a proper guide in order to produce a suitable claim, data, warrant, backing, and rebuttal. Considering that both studies were carried out in Indonesian universities, the similarity is understandable due to the same academic culture and experiences. The work of Ramadhani [91] in Indonesia reported the relationship between students' argumentation skills and the nature of chemical representations, but not their understanding of chemistry.

Table 8. Product-moment correlation test between students' understanding of chemistry and their argumentation skills

		Argumentation Skills	TCSU
Argumentation Skills	Pearson Correlation	1	.062
	Sig. (2-tailed)		.723
	N	35	35
TSCU	Pearson Correlation	.062	1
	Sig. (2-tailed)	.723	
	N	35	35

However, relevant research in this area revealed the opposite outcomes in this study. The different outcomes reported the positive impact of graph-oriented tasks in improving students' mastery and argumentation skills [24]. In a laboratory-based activity, students with good argumentation skills are more likely to be successful in explaining the sub-microscopic representation of chemistry concepts, leading to a better understanding [82]. Argumentation-based teaching even contributed to the improvement of students' understanding and their attitude towards chemistry [92]. All of the aforementioned studies were conducted in countries other than Indonesia, such as Taiwan and Turkey, which have cultural and societal characteristics different from those of Indonesia. Therefore, this opposite outcome is plausible. Further studies involving larger cohorts and communities are required to yield more definitive conclusions regarding this counterintuitive result.

Previous studies in the area of science and chemistry education uncovered the robust correlation between students' argumentation skills and other skills, including their understanding of the Nature of Sciences, NOS [93], and critical thinking [94]. Other relevant studies also reported the positive impact of the context-based approach in thermochemistry and thermodynamics teachings on the students' chemical literacy [95]. In teaching socio-scientific issues, students with a better understanding gave better arguments [96]. The findings emphasise the need to explore this research area in greater depth.

4. CONCLUSION

Our findings mark the positive contribution of Pictorial-based Learning (PcBL) in enhancing students' argumentation skills. In addition, students' scientific characters tend to be more scientifically sound on topics. Although none of the students demonstrated Level 5 argumentation skills, the positive progress in students' argumentation levels suggests consistent support for the PcBL in developing students' argumentation skills. The missing Level 5 may also critique how to effectively implement this approach in subsequent chemistry teachings. While this study revealed a positive effect on chemistry concepts acquisition, the correlation between students' understanding of chemistry and their argumentation skills level is delicately weak. This study provides a strong foundation for exploring the use of PcBL to enhance the quality of chemistry teaching. Reflecting on the previous works [14], [88], developing this PcBL for students to generate a pictorial representation may be reasonable.

Implications for the study

Utilising visual aids to promote students' argumentation skills [97], which incorporate a strong understanding of chemistry, is relevant to the Multimedia Learning theory and cognitive load theory [43], [47], [48]. The pictorial representations elicit students' higher-order thinking, including argumentation skills, while the amount of information stored in students' short- and long-term memories is reasonable. Although the impact of the PcBL on students' argumentation skills and their understanding of chemistry over the four topics (SIF, GL, KMT, and Thc) is noticeable, a cautious approach to applying this method in future chemistry teaching and research is recommended. While the pictorial trigger stimulated students' cognitive processing, resulting in deeper engagement with chemistry learning, other variables—including the nature of the chemistry concepts, students' spatial ability, prior knowledge, and other potential factors that could influence the intervention outcome—should also be taken into account. The subsequent study should explore the most effective strategy to enhance the effectiveness of pictorial triggers by utilising advanced technologies, including Virtual Reality (VR), Artificial Intelligence (AI) features, and other 3D technologies, to assist students in extracting necessary information and transforming it into effective chemical behaviours.

Limitations of the study

The single-group design, regarded as a weak experimental design, may limit the transferability of this study's findings. Therefore, future research involving a larger population and utilizing a stronger experimental design, such as a two-factorial or Solomon four-group design, is recommended. Moreover, the diverse nature of the topics and various types of questions may have also influenced the outcomes. In addition, due to the limited time, students' argumentative answers on each topic were not returned. Therefore, it may be beneficial to mark, return students' answers, and discuss them to provide feedback, thereby optimally building their argumentation skills.

AI-assisted technology statement

In the preparation of this work, the writers utilised Grammarly to improve linguistic clarity and to detect and rectify certain misspellings. Following the use of this tool, the authors meticulously evaluated and revised the information as necessary, assuming full responsibility for the publication's content.

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