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Enhancing Scientific Argumentation Skills in Chemistry on the Topic of Chemical Bonding through Argument-Driven Inquiry of Grade-10 Students

Potjana Ponil[1*], Panwilai Dokmai[2]
[1]*Master Science Education Program, Rajabhat Maha Sarakham University, Thailand*
[2]*Master Science Education Program, Rajabhat Maha Sarakham University, Thailand*
*Email: 668010300105@rmu.ac.th

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Abstract. This research aimed to develop the scientific argumentation skills of Grade-10 students on the topic of chemical bonding through argument-driven inquiry. The action research study was conducted with the target group of 10 grade-10 students from Mueang Mahawichanukool School, Maha Sarakham Province. The participants were enrolled in the first semester of the 2024 academic year. These research tools were: 1) Argument-driven inquiry lesson plans on the topic of chemical bonding, consisting of 11 plans with duration time of 22 hours, 2) Scientific argumentation skills test included three questions from three scenarios for measuring student's argumentation skills after each operational cycle. The test has IOC validity ranging from 0.89 to 1.00 and reliability coefficient of 0.8 and 3) Observation form for scientific argumentation behavior observation. Quantitative data were analyzed by mean ($\bar{x}$), standard deviation (S.D.), and percentage (%). Qualitative data was analyzed through content analysis. The research results found that the first operational cycle, two students (20%) had scientific argumentation skills at a good level, five students (50%) at a moderate level, and three students (30%) at a low level. In the second operational cycle, two students (20%) had scientific argumentation skills at a very good level, two students (20%) at a good level, four students (40%) at a moderate level, one student (10%) at a low level, and one student (10%) at a very low level. In the third operational cycle, three students (30%) had scientific argumentation skills at a very good level, one student (10%) at a good level, and six students (60%) at a moderate level. Students exhibited an increased level of scientific argumentation skills, with the observed progression across all components of argumentation.

Keywords: Argument-Driven Inquiry; Action Research; Scientific Argumentation Skills; Chemical Bonding

INTRODUCTION

In the 21st century, rapid advancements in science and technology have significantly influenced society, making education essential for developing high-quality individuals with the skills and competencies needed for this era. The Basic Education Development Plan (2023–2027) identifies critical 21st century skills, focusing on the 3Rs and the 8Cs (Office of the Basic Education Commission, 2022). These objectives align with the Basic Education Core Curriculum 2008, focus on developing students' competencies in communication, information literacy, analytical thinking, decision making, and problem solving, with a strong emphasis on the consideration of social impacts. Preparing learners with these essential skills is crucial in today's educational context. (Ministry of Education, 2008). In the digital age, where information disseminates rapidly, propaganda and persuasive advertisements have become an integral part of daily life. To make accurate and well-informed decisions, individuals must engage in logical reasoning supported by credible evidence. This process of thoughtful decision making, grounded in scientific reasoning and evidence, necessitates the use of scientific argumentation as a key tool for in the evaluation process (Jantarakantee, 2016).

Scientific argumentation refers to the process of validating claims in the field of science using evidence and reasoning. It involves constructing and presenting arguments based on scientific evidence to support or refute claims or hypotheses (Erduran, 2019). This process encompasses claims, supporting reasoning, the use of evidence, counter arguments, and rebuttals grounded in evidence (Lin & Mintzes, 2010). Scientific argumentation is a critical process for students as it helps them develop critical thinking skills, problem solving abilities, and teamwork capabilities. It enables students to gain a deeper understanding of scientific concepts and fosters the mindset of a scientist (Özelma & Seyhan, 2022). Moreover, scientific argumentation enhances social interactions and interpersonal communication skills. It provides students with opportunities not only to share their perspectives but also to understand diverse viewpoints through the argumentation process (Celep, 2015). The argumentation skills not only help students become scientifically literate but also enhance higher order thinking skills, scientific process skills, communication skills, and the ability to evaluate the credibility of information, which are the primary goals of science education (Jantarakantee, 2016). Furthermore, scientific argumentation serves as a foundational skill that facilitates the development of other competencies, including analytical thinking, distinguishing between facts and opinions, fostering participatory learning, improving communication skills, cultivating informed citizenship, and enhancing educational quality. This skill is indispensable for 21st century work environments, equipping students for success in life as informed citizens who can communicate effectively and contribute constructively to society (Pharanat & Nuarngchalerm, 2018).

According to a study by the Organization for Economic Co-operation and Development (OECD), data on the ability to combat fake news and misinformation among 15-year-olds across 77 countries revealed that Thai students ranked 76th out of 77 countries. This indicates that Thai students have a significantly low capacity for filtering fake news (OECD, 2021). The primary cause of this issue is the lack of critical thinking skills, which are essential for distinguishing accurate information from misinformation. Critical thinking acts as a compass, guiding individuals to focus on facts, credible opinions, and disregard unsupported or deliberately distorted information. This aligns with findings from Mueang Mahawichanukool School's self-assessment report, which identified that some students lack analytical thinking, systematic problem-solving, and critical thinking skills. Similarly, during observation and practicum, the researcher found that most students lacked the ability to construct arguments, provide logical reasoning, and present credible evidence of key components of critical thinking. These skills are fundamental for analyzing and evaluating problems using logic, reasoning, and systematic decision-making, which enables the creation of new, reliable knowledge (Mueang Mahawichanukool School, 2022). The assessment of the scientific argumentation skills of ten students revealed that only one student demonstrated a good level of scientific argumentation; four students were at a moderate level, another four were at a low level, and one student was at a very low level. This demonstrates a general lack of argumentation skills among students. Furthermore, an analysis of the components of argumentation indicated deficiencies in students' ability to provide reasoning, present evidence, and effectively counterargue. These shortcomings stem from an overall lack of analytical thinking skills. The issues outlined are critical components of critical thinking skills, which can be cultivated through the practice of argumentation (Rusmini, 2021). Enhancing these skills through targeted instruction and practice is essential for empowering students to think critically and respond effectively to challenges in the modern information age.

Approaches to designing activities that enhance students' scientific argumentation skills, enabling them to better understand, connect content, and apply knowledge in explaining or summarizing concepts using credible and accurate scientific evidence and reasoning, including various models. These models include open-ended learning (Maneetup & Harnsoongnoen, 2023), jigsaw learning, informal cooperative learning, and argument-driven inquiry (Amelia, Asrial, & Effendi-Hasibuan, 2020). Among these approaches, the researcher selected argument-driven inquiry to develop scientific argumentation skills. Argument-driven inquiry (ADI) is a science teaching method emphasizing the creation of arguments, examination of evidence, and data analysis through inquiry and evidence gathering to construct arguments and summarize information (Janhom & Jantrasee, 2019). This method is more suitable than open-ended learning, which lacks specific argumentation steps, does not fully engage students in argumentation practice, and does not require written argument evaluation reports. It is also more effective than jigsaw learning and informal cooperative learning. This conclusion is supported by the study of Amelia, Asrial, & Effendi-Hasibuan (2020), which compared the argumentation skills fostered by three learning approaches: jigsaw learning, informal cooperative learning, and argument-driven inquiry. The results showed that argument-driven inquiry was the most effective in promoting argumentation skills. Similarly, research by Amelia, Suciati, & Maridi (2018) compared students' argumentation skills argument-driven inquiry versus traditional teaching methods. The findings indicated that argument-driven inquiry significantly enhanced students' argumentation skills compared to conventional classroom instruction. As discussed above, general instructional methods that do not include explicit steps for argumentation often result in less effective development of students' argumentation skills. In contrast, argument-driven inquiry incorporates specific steps designed to foster argumentation, making it more effective than traditional teaching methods. This approach emphasizes the development of scientific argumentation skills through the construction of arguments, examination of evidence, and data analysis. It involves inquiry and evidence-based exploration to construct arguments and summarize information (Janhom & Jantrasee, 2019).

In chemistry education, the subject matter is highly specialized and often operates at the microscopic level, involving real but invisible phenomena. The content is complex and interdisciplinary, making it difficult for students to grasp. Traditional lecture-based teaching often limits students' opportunities for critical thinking and independent knowledge construction, which may hinder their ability to understand and integrate scientific concepts (Kamart & Wara-asawapati Srisa-ard, 2022). One such topic is chemical bonding fundamental concepts essential for understanding the structure of matter, chemical reactions, and properties of substances. Due to its abstract nature, many students struggle to comprehend bonding concepts effectively. Scientific argumentation helps deepen students' understanding by encouraging active engagement through making claims, using evidence, and logical reasoning. It fosters inquiry, clarifies misconceptions, and promotes explanation in students' own words, especially useful for abstract topics like chemical bonding. Argumentation also supports peer interaction, enabling students to evaluate ideas and build clearer conceptual understanding together. To address this challenge, the researcher adopted an argument-driven inquiry approach to improve students' scientific argumentation skills. These skills are critical for logical reasoning, evidence-based explanation, and the evaluation of multiple perspectives. They also support students in making informed decisions, distinguishing facts from opinions, and engaging in analytical, evidence-driven discussions. This approach is consistent with the findings of Walker & Sampson (2013), who demonstrated that argument-driven inquiry promotes deeper conceptual understanding and critical thinking by engaging students in scientific practices such as designing experiments, analyzing data, and constructing arguments based on evidence. The argument-driven inquiry model also aligns with constructivist learning theory, which emphasizes that students actively build knowledge through inquiry, discussion, and social interaction, making it particularly effective in abstract and complex subjects like chemistry.

RESEARCH OBJECTIVES

Enhancing the scientific argumentation skills of grade 10 students on the topic of chemical bonding through argument-driven inquiry.

METHODOLOGY

This study is action research aimed at developing students' scientific argumentation skills through argument-driven inquiry. The research process follows the four-step model proposed by Kemmis & McTaggart (1988), which includes: 1) Planning, 2) Action, 3) Observation, and 4) Reflection. The study consists of three operational cycles.

Target Group

The target group of this research was 10 tenth-grade students enrolled in a chemistry course during the first semester of the 2024 academic year at Mueang Mahawichanukool School, a small-sized secondary school in which the entire Grade 10 cohort comprises only ten students. Some students lacked analytical thinking, systematic problem-solving, and critical thinking skills and based on observation and practicum, the researcher found that most students still demonstrated limited abilities in constructing and engaging in scientific argumentation. Therefore, these ten students were selected as the target group for this study.

Research Tools

The research tools used in this study can be categorized into three types.

1. Learning management: Argument-driven inquiry plans on the topic of chemical bonding, consisting of 11 lesson plans over a total of 22 hours. The learning process consists of eight steps: 1) identifying the task, 2) gathering information, 3) constructing arguments, 4) argumentation activities, 5) writing an investigation report, 6) peer evaluation, 7) revising the report, and 8) reflective discussion. The learning management plans were evaluated for quality using a Likert scale, a 5-point rating scale. The results indicated that the plans were deemed highly appropriate, with mean scores ($\bar{x}$) ranging from 4.88 to 4.91.

2. Scientific argumentation skills test: This test was subjective and included three questions from three scenarios for measuring student's argumentation skills after each operational cycle. In the first operational cycle, the assessment was based on scenarios related to the ionic bond. The second operational cycle involved scenarios of the covalent bond, while the third operational cycle focused on scenarios related to the applications of ionic compounds, covalent compounds, and metals. The test qualities showed difficulty ranging from 0.36 to 0.50, a discrimination index between 0.61 and 0.93, and the reliability of 0.86. The rubric for assessing scientific argumentation skills demonstrated an inter-rater reliability of 0.93.

Aunt Daeng was cooking curry in a new pot. After finishing the meal, she found burnt stains at the bottom of the pot. She wanted to clean the burnt stains, but at home, she only had salt and baking soda, no dishwashing liquid. The two substances have the following properties:

Substance	Properties
Salt (NaCl)	Neutral pH, white crystalline powder, odorless, dissolves well in water, increases water conductivity, produces Na^+ and Cl^- ions in water.
Baking Soda ($NaHCO_3$)	Mildly alkaline, a fine white crystalline powder, water-soluble, odorless, and when dissociated and reacted, it helps reduce acidity.

Aunt Daeng watched a video demonstrating how to use substances to clean a pot with heavy black stains, using three different formulas:

1. Mix 1 tablespoon of salt with enough water to make a thick paste. Apply to the stained area of the pot, leave for 45 minutes, then gently scrub with a sponge.
2. Mix 2 cups of baking soda with 1/2 cup of water. Apply the mixture to the black stains, leave for about 30 minutes, then gently scrub off the stains with a sponge.
3. Mix 1 cup of baking soda with 1/2 cup of salt. Apply the mixture to the black stains, leave for about 40 minutes, then scrub off the stains with a sponge.

Based on the information above, if you were Aunt Daeng, which method would you choose to clean the burnt stains on the pot?

Noon is a first-year university student who has recently moved into a dormitory and wants to cook her own dinner to save money. She is currently deciding between buying a pot or pan made of aluminum and one made of steel. To make an informed decision, she is considering the properties of both materials.

Aluminum conducts heat well and distribute it evenly, making it suitable for cooking methods that require consistent heat, such as stir-frying, frying, and boiling. In addition, aluminum cookware is lightweight, making it easy to lift and move.

On the other hand, pots or pans made of steel retain heat effectively, allowing food to cook thoroughly and stay warm for longer periods. Steel is also more durable than aluminum, meaning it can last longer and withstand more use. Moreover, steel is safer for health, as it does not react with food, reducing the risk of metal contamination.

The Little Girl and the Oil Stain on Her Shirt

One evening at a small house, little Mind was playing with oil paints at the garden table. She accidentally spilled some paint onto her white T-shirt. Shocked, she looked at the oil stain on her shirt, knowing her mother would surely scold her.

"Mom, I spilled oil paint on my shirt," Mind said quietly.

Her mother came over to examine the stain. "Oh, Mind, I told you not to play with oil paint alone," she said firmly.

"I know, I'm sorry," Mind replied, hanging her head.

"Give me the shirt. Let me see if I can wash it out," her mother said.

She took the t-shirt to the sink, turned on the water, and tried to scrub the stain by hand. However, the oil paint remained stubbornly stuck to the fabric.

"Why won't it come out, Mom?" Mind asked.

"Because oil paint is made up of non-polar molecules," her mother explained. "Water is a polar molecule, and polar molecules attract other polar molecules, but they don't attract non-polar ones."

"So what should I do?" Mind asked.

"I have a special dishwashing liquid designed to remove oil stains," her mother replied. "Dishwashing liquids contain chemicals with non-polar molecules. These can attract the oil paint molecules and help lift them from the fabric."

Her mother applied the dishwashing liquid to the stain and gently scrubbed it with a sponge. Slowly, the stain faded and came off the shirt.

"Yay! The paint stain is gone!" Mind cheered.

From this experience, Mind learned that chemical substances with appropriate polarity are key to cleaning different types of stains.

Figure 1: Sample scenarios in each cycle of the operation.

3. Observation form for scientific argumentation behavior observation: This form was used to observe and assess students' levels of scientific argumentation skills. It also served as a basis for developing and improving learning activities aimed at enhancing students' scientific argumentation abilities.

Data Collection

In this study, the researcher collected data during the first semester of the 2024 academic year, covering 11 lesson plans with a total of 22 hours. The data collection was conducted over three operational cycles, with the following collection procedures:

1. Planning: The researcher surveyed the current issues and learning environment of tenth-grade students at Mueang Mahawichanukool School to identify problems and explore suitable learning strategies. The assessment revealed that students lacked key scientific argumentation skills such as warrants, evidence, supportive arguments, and counter arguments due to limited analytical thinking. To address this, the researcher adopted an argument-driven inquiry approach and reviewed the curriculum to design 11 lesson plans on chemical bonding for the first semester of the 2024 academic year. The plans were reviewed by the advisor and subject-matter experts for alignment and appropriateness, revised based on their feedback, and prepared for implementation in the next research phase.

2. Action: The revised lesson plans, which were updated based on feedback from the advisor and experts, were implemented with the target group, starting from the first operational cycle through to the third operational cycle. The learning management plan for each operational cycle is presented in Table 1.

Table 1: The learning management plan for each operational cycle.

Cycles	**Learning management**	**Time (hr.)**
1	Lesson plan 12: Lewis dot symbols and the formation of ionic bonds	2
	Lesson plan 13: Chemical formulas and nomenclature of ionic compounds	2
	Lesson plan 14: Energy and the formation of ionic compounds	2
	Lesson plan 15: Properties of ionic compounds and ionic equations and net ionic equations	2
2	Lesson plan 16: Formation and types of covalent bonds	2
	Lesson plan 17: Writing formulas and naming covalent compounds	2
	Lesson plan 18: Bond length and bond energy of covalent compounds	2
	Lesson plan 19: Molecular shape and polarity of covalent molecules	2
3	Lesson plan 20: Intermolecular forces and properties of covalent compounds	2
	Lesson plan 21: Covalent network structures	2
	Lesson plan 22: Metallic bonds and the applications of ionic compounds, covalent compounds, and metals	2
Total		**22**

The learning process was designed based on an argument-driven inquiry by Sampson & Gleim (2009) which consists of the following eight steps:

1) Identifying the task: This step introduces the topic of study, connects students' prior knowledge with new concepts, and stimulates their interest. A problem and the subject of investigation are clearly defined.

2) Gathering information: Students work in groups to design experiments or conduct inquiries, gather information, and analyze the data obtained from their experiments and investigations.

3) Constructing arguments: Students will synthesize the information obtained from their inquiry, engage in idea exchange, and collaborate to solve problems within their group. They will provide justifications by explaining how their claims are supported by the evidence and evaluate whether the reasoning is accurate and consistent with the data.

4) Argumentation activities: Students present, support, and critique their explanations and opinions through classroom presentations and discussions. These discussions allow students to articulate and justify the arguments they have constructed, as well as to challenge the opinions of others that are considered inconsistent with scientific concepts.

5) Writing an investigation report: This step involves students writing about the outcomes of their investigation in the form of a report or a written reflection. It enables them to

express their own ideas clearly and concisely. The report should include key components such as claims, evidence, and reasoning.

6) Peer evaluation: Students evaluate their peers' reports and decide whether the report is acceptable or needs revision based on the criteria provided in the evaluation form, without identifying the evaluator as part of the knowledge review process.

7) Revising the report: In this step, students revise or rewrite their reports based on the feedback from the evaluator and then submit the revised report to the teacher for further review.

8) Reflective discussion: Summarize the results of the investigation and the concepts derived from the inquiry or experiment, ensuring they align with established theories and laws.

3. Observation: Students were observed and assessed during the argument-driven inquiry. Data was collected on the development of their scientific argumentation skills through the scientific argumentation skills test, and an observation form for scientific argumentation behavior observation. This data was used to reflect on the outcomes of the learning process.

4. Reflection: The researcher reflected on the learning outcomes of the argument-driven inquiry by using the observation form for scientific argumentation behavior observation post-lesson reflection and the scientific argumentation skills test at the end of each operational cycle. The results were analyzed to identify issues encountered in each scientific argumentation behavior during the learning process. These identified issues were then used to improve and adjust the learning management to address these problems next to the operational cycle.

Data Analysis

1. Quantitative Data Analysis: Students' scientific argumentation skills were assessed using the scoring rubric outline in Table 2, and the collected data were transformed into scores ranging from 0 to 10, which were then categorized into levels: very good (8-10 points), good (6-7 points), moderate (4-5 points), low (2-3 points), and very low (0-1 points) and then the scores of each argumentation component will be analyzed using elementary statistics including mean, standard deviation, and percentage.

2. Qualitative Data Analysis: The scientific argumentation behavior was analyzed using content analysis methods. The data from observations were analyzed and interpreted based on the components of scientific argumentation, which include claims, warrant, evidence, counter arguments, and supportive argument. And then the data were summarized for reporting the research findings, divided into the problems encountered and the solutions implemented in each operational cycle.

Table 2: Rubric for assessing scientific argumentation skills.

Questions	Components of an argument	Scoring criteria		
		0	1	2
1	Claim	No claim	The claim is complete but incorrect	The claim is both complete and correct.
	Warrant	No reasoning is provided, or the reasoning provided does not connect the claim to the evidence.	The reasoning provided connects the claim to the evidence, but it is insufficient.	The reasoning provided connects the claim to the evidence and is supported by scientific methods.
2	Evidence	There is no evidence to support the claim, or the evidence provided does not support the claim.	There is some appropriate but insufficient evidence to support the claim.	There is sufficient and appropriate evidence to support the claim.
3	Counter Argument	No argument is presented.	A counter argument is presen but the explanation is inappropriate.	A counter argument is presented appropriately, with a suitable explanation.
	Supportive Argument	No counter argument is provided.	A counter argument is provided, but the reasoning and evidence are insufficient.	A counter argument is provided with sufficient reasoning and evidence.

RESULTS AND DISCUSSION

The survey of the scientific argumentation skills of 10 tenth-grade students before the instructional through argument-driven Inquiry. The results showed that only one student at a good level of scientific argumentation skills, four students at a moderate level, four students at a low level, and one student at a very low level, as shown in Table 3.

Table 3: Results of the scientific argumentation skills assessment before entering the first operational cycle.

ID	Scientific argumentation skills					Total (Score 10)	Level
	Claims (Score 2)	Evidence (Score 2)	Warrant (Score 2)	Counter Arguments (Score 2)	Supportive Argument (Score 2)		
1	1	1	1	0	0	3	Low
2	2	0	0	0	0	2	Low
3	2	1	0	1	1	5	Moderate
4	2	1	0	0	2	5	Moderate
5	2	1	1	1	0	5	Moderate
6	2	1	1	0	1	5	Moderate
7	2	0	1	0	0	3	Low
8	2	1	1	2	1	7	Good
9	2	0	1	0	0	3	Low
10	1	0	0	0	0	1	Very low

From Table 3, students exhibited difficulties in nearly all aspects of scientific argumentation. They struggled with warrant, evidence, supportive argument, and counter-argumentation. These challenges were attributed to a lack of analytical thinking skills. Therefore, the researcher selected all ten students as the target group to develop their scientific argumentation skills through argument-driven inquiry**.**

The results of developing scientific argumentation skills after implementing argument-driven inquiry in the first operational cycle. At the end of the learning process of the first operational cycle, the researcher employed a scientific argumentation skills test encompassing all five components of argumentation: 1) claims, 2) evidence, 3) warrant, 4) counter arguments, and 5) supportive argument. The results were analyzed and evaluated to identify issues for reflection. The assessment results of scientific argumentation skill in the first operational cycle were presented in Table 4.

Table 4: The assessment results of scientific argumentation skills after the learning process in the first operational cycle.

ID	Scientific argumentation skills					Total (Score 10)	Level
	Claims (Score 2)	Evidence (Score 2)	Warrant (Score 2)	Counter Arguments (Score 2)	Supportive Argument (Score 2)		
1	1	1	1	0	1	4	Moderate
2	2	0	0	0	0	2	Low
3	2	1	0	1	1	5	Moderate
4	2	1	0	0	2	5	Moderate
5	2	2	1	2	0	7	Good
6	2	1	1	0	1	5	Moderate
7	2	0	1	0	1	4	Moderate
8	2	1	1	2	1	7	Good
9	2	0	1	0	0	3	Low
10	2	0	0	0	0	2	Low
$\bar{x}$	1.9	0.7	0.6	0.5	0.7	4.4	
S.D.	0.32	0.68	0.52	0.85	0.66	1.8	

From Table 4, the students' scientific argumentation skills were assessed as follows: two students (20%) at a good level, five students (50%) at a moderate level, and three students (30%) at a low level. When considering the average scores for each component of argumentation, the students scored the highest in the claim ($\bar{x}$ = 1.9), followed by evidence ($\bar{x}$ = 0.7), supportive argument ($\bar{x}$ = 0.7), warrant ($\bar{x}$ = 0.6), and counter arguments ($\bar{x}$ = 0.5), respectively. The problems encountered in the first operational cycle included students' lack of confidence in using evidence, unclear connections between warrants and evidence, and insufficient scientific writing skill.

An example of a student's response from the scientific argumentation skills tests the first operational cycle.

1. Which formula should Aunt Daeng choose to remove the black stains in the pot, and why? *(Claim and Warrant: 4 score)*

Student A: Formula three, because baking soda helps remove the black stains, and salt does as well.

Student B: Formula two contains the highest amount of baking soda, which has properties that effectively break down burnt stains from pots, softening the stains and making them easier to remove.

2. What information supports Aunt Daeng's decision to use that formula to clean the burnt stains in the pot? *(Evidence: 2 score)*

Student A: Information from the table.

Student B: The information in the table indicates that baking soda is soluble in water and effective in cleaning, particularly for removing food stains with acid residues allowing time for the chemical reaction to take place.

3. If a friend gives an answer different from yours in Question 1, what do you think their reasoning might be, and how would you persuade them to agree with your viewpoint? *(Counterargument and supportive argument: 4 score)*

Student A: Explain in a way that both parties understand and persuade the friend to consider the perspective.

Student B: We should first listen to our friend's reasoning, and if they have a different opinion, we can respond by explaining that both salt and baking soda are good at absorbing moisture and can also help reduce acidity.

Based on the problems encountered in the first operational cycle, In the second operational cycle, the researcher used questions to stimulate students to make connections between evidence and warrant for claims. The researcher emphasized that there was no right or wrong when it came to finding supporting evidence for one's claims. The students were trained to write scientific explanations by using prompting questions that encouraged them to explain their arguments and reasoning, while also pointing out how evidence and reasoning were interconnected. According to the study by Suwannatrai & Sangpradit (2023), teachers incorporated questions related to scientific problems into their lesson plans. This approach helped establish connections between prior knowledge and new concepts while also encouraging students to think critically and present their own claims, along with the warrant used to support those claims. The assessment results of scientific argumentation skill in the second operational cycle were presented in Table 5.

Table 5: The assessment results of scientific argumentation skills after the learning process in the second operational cycle.

ID	Scientific argumentation skills					Total (Score 10)	Level
	Claims (Score 2)	Evidence (Score 2)	Warrant (Score 2)	Counter Arguments (Score 2)	Supportive Argument (Score 2)		
1	2	0	1	0	0	3	Low
2	0	1	0	0	0	1	Very low
3	2	0	1	0	1	4	Moderate
4	2	1	1	2	1	7	Good
5	2	1	2	2	1	8	Very good
6	2	1	0	1	1	5	Moderate
7	2	1	1	0	0	4	Moderate
8	2	2	1	2	2	9	Very good
9	2	0	2	0	0	4	Moderate
10	2	1	2	1	0	6	Good
$\bar{x}$	1.8	0.8	1.1	0.8	0.6	5.1	
S.D.	0.63	0.63	0.74	0.92	0.70	2.42	

From Table 5, the students' scientific argumentation skills were assessed as follows: two students (20%) at a very good level, two students (20%) at a good level, and four students (40%) at a moderate level, one student (10%) is at a low level and one student (10%) is at a very low level. When considering the average scores for each component of argumentation, the students scored the highest in the claims ($\bar{x}$ = 1.8), followed by use of warrant ($\bar{x}$ = 1.1) evidence ($\bar{x}$ = 0.8) counter arguments ($\bar{x}$ = 0.8) and supportive argument ($\bar{x}$ = 0.6) respectively. The problems encountered in the second operational cycle include some students still struggling to articulate their claims clearly and accurately. While they were able to gather additional supporting evidence, it remained insufficient and lacked clarity. Furthermore, some students faced difficulties in counter arguments and supportive arguments.

An example of a student's response from the scientific argumentation skills tests the second operational cycle.

1. Do you agree or disagree with the statement that polar substances can clean all types of stains? Why or why not? *(Claim and Warrant: 4 score)*

Student A: I disagree, because some types of stains, such as oil or paint stains, are non-polar substances, which cannot be dissolved or removed with water, a polar substance.

Student B: I disagree that polar substances can clean all types of stains, because polar substances can only clean stains that are made of similar polar substances, such as water. However, for stains that are non-polar, like oil or paint stains, polar substances cannot attract or clean them effectively.

2. What information supports your opinion in question 1? *(Evidence: 2 score)*

Student A: Mind's mother tried washing the stain with water, but it did not come off. She had to use dishwashing liquid, which contains non-polar substances that were able to remove the stain.

Student B: When Mom tried to wash the shirt with plain water, which is a polar substance, it could not remove the oil paint stain.

3. If a friend gives an answer different from yours in Question 1, what do you think their reasoning might be, and how would you persuade them to agree with your viewpoint? *(Counterargument and supportive argument: 4 score)*

Student A: If a friend agrees, you should consider their reasoning first. Then, explain the correct principles in a credible manner to persuade them.

Student B: They might think that plain water or general cleaning products, which are often polar substances, can clean all types of stains. You can persuade them by explaining that non-polar stains require non-polar substances to be effectively removed.

In the third operational cycle, the researcher implemented strategies to address the problems identified in the second operational cycle by reviewed the claims and data from other groups, asking students to take notes, and inquired whether they wanted to change their answers. This was done to help students recognize arguments different from their own. Additionally, learning media, such as survey boards, were used to help students visualize and use evidence to support their claims and supportive arguments. The consists of a study by Sampson & Gleim (2009), which prepares a list of necessary materials for inquiry-based learning, such as samples, models, slides, experimental equipment, and facilitate data collection to support claims. Regarding counter arguments and supportive arguments, providing alternative claims requires reviewing students' counter arguments, encouraging analytical thinking to develop counter arguments, guiding discussions to remain focused, and summarizing key points. The assessment results of scientific argumentation skill in the third operational cycle were presented in Table 6.

Table 6: The assessment results of scientific argumentation skills after the learning process in the third operational cycle.

ID	Claims (Score 2)	Evidence (Score 2)	Warrant (Score 2)	Counter Arguments (Score 2)	Supportive Argument (Score 2)	Total (Score 10)	Level
	Scientific argumentation skills						
1	2	1	1	0	1	5	Moderate
2	1	1	1	0	1	4	Moderate
3	2	1	1	2	2	8	Very good
4	2	1	1	0	1	5	Moderate
5	2	1	2	2	1	8	Very good
6	2	1	1	0	1	5	Moderate
7	2	1	2	0	0	5	Moderate
8	2	2	2	2	2	10	Very good
9	2	1	1	0	1	5	Moderate
10	2	0	2	2	0	6	Good
$\bar{x}$	1.9	1	1.4	0.8	1	6.1	
S.D.	0.32	0.47	1.03	0.6	0.67	1.91	

From Table 6, the students' scientific argumentation skills were assessed as follows: three students (30%) at a very good level, one student (10%) at a good level and six students (60%) at a moderate level. When considering the average scores for each component of argumentation, the students scored the highest in the claims ($\bar{x}$ = 1.9), followed by use of warrant ($\bar{x}$ = 1.4) evidence ($\bar{x}$ = 1.0) supportive argument ($\bar{x}$ = 1.0) and counter arguments ($\bar{x}$ = 0.8) respectively. The problems encountered after completing the third operational cycle reveal that students have improved their argumentation skills, but inconsistently. They lack skills in data analysis which results in arguments that are not comprehensive and lack depth. Some students forget to consider other counter arguments and focus solely on supportive arguments.

An example of a student's response from the scientific argumentation skills tests the third operational cycle.

1. What type of material should Noon choose for her pan, and why? *(Claim and Warrant: 4 score)*

Student A: Noon should choose to use a pan made of aluminum because aluminum conducts heat well, allowing food to cook quickly and evenly.

Student B: Noon should choose a pan made of iron because iron retains heat for a long time, making it suitable for slow-cooking or baking dishes that require extended cooking time. It is also highly durable.

2. What information supports Noon's choice of that material? *(Evidence: 2 score)*

Student A: Aluminum distributes heat evenly and is lightweight, making it convenient for everyday use, especially for students who may have limited time.

Student B: Iron is strong and durable, does not leach metal contaminants into food, and has a long lifespan, making it more cost-effective than frequently replacing aluminum cookware.

3. If a friend gives an answer different from yours in Question 1, what do you think their reasoning might be, and how would you persuade them to agree with your viewpoint? *(Counterargument and supportive argument: 4 score)*

Student A: If my friend chooses an iron pan, they might think that iron is strong and safer for health. However, I would explain that in daily life, Noon may need to be cooked quickly and frequently, so the fast heat distribution of aluminum might be more suitable. With careful use, aluminum can also be safe.

Student B: Encourage your friend to consider that although iron pans are heavier, they are more durable and safer for health, especially for those looking to save in the long term.

To further address the identified problems, emphasis should be placed on using guiding questions to help students regularly assess the clarity of the connections between their claims and evidence such as "How are physical properties such as thermal conductivity and heat retention of these two materials related to the type of metallic bonding they possess?" "If the goal is to cook food that requires high and sustained heat, such as baking or stewing, which material would you recommend for Noon to use? Justify your answer using the relevant properties of the material." "How is the fact that iron does not react with food related to the chemical inertness of metals, and is this property important for cooking safety" This question encourages students to think about the evidence supporting their conclusion. Students are expected to explain their observations, such as electrical conductivity in solution or solubility in different solvents. In the argument-driven inquiry instructional model, the emphasis is on having students analyze and reason through the evidence themselves, with the teacher acting as a facilitator. This process requires time and continuous practice. Regarding alternative claims and supportive counterarguments, students may be encouraged to create their own learning materials using designated equipment. This approach aims to enhance their analytical skills, strengthen their ability to connect evidence with claims, and facilitate the identification of differences between claims for argumentation. Each component of this process requires sufficient time for skill development and reinforcement. The summary of the development of scientific argumentation skills after receiving instruction through argument-driven inquiry, upon completion of the operational cycles, is presented in Table 7.

Table 7: The individual levels of scientific argumentation skills across all three operational cycles

ID	Cycles		
	1	**2**	**3**
1	Moderate	Low	Moderate
2	Low	Very low	Moderate
3	Moderate	Moderate	Very good
4	Moderate	Good	Moderate
5	Good	Very good	Very good
6	Moderate	Moderate	Moderate
7	Moderate	Moderate	Moderate
8	Good	Very good	Very good
9	Low	Moderate	Moderate
10	Low	Good	Good

From Table 7, it can be observed that ten students showed an improvement in their scientific argumentation skills in the third operational cycle. However, in the second operational cycle, two students demonstrated a decrease in their scientific argumentation skills, but this improved again in the third operational cycle and some students' argumentation skills remained stable. This decline occurred because the students were unable to provide supportive argument and counter arguments, which led to a decrease in their overall scores and, consequently, their ability to argue scientifically. Additionally, the content in the second operational cycle, which focused on topics such as writing chemical formulas, naming covalent compounds, bond length, bond energy, molecular shape, and intermolecular forces in covalent, was complex and difficult to understand, requiring more time to study. In line with the research by Tongprapai, et al. (2016) found that some students' argumentation skills remained stable or needed improvement due to insufficient time for studying the content. Additionally, students believed they had sufficient knowledge about the issues used to respond to the given situations. When examining the average scores of each argumentation component across the three operational cycles, the results show the developmental progress as illustrated in Figure 2.

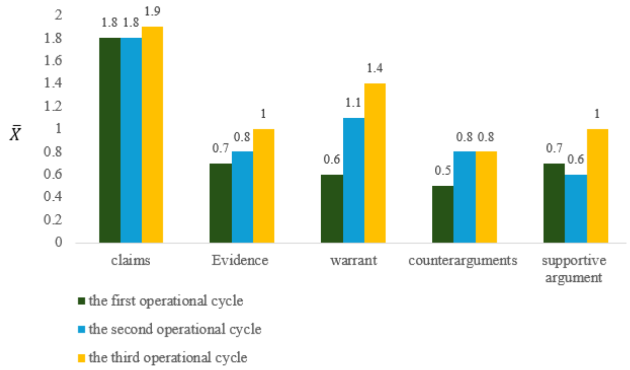

Figure 2: The results of the development of the components of scientific argumentation skills.

From Figure 2, It was found that, following the instructional intervention, all components of students' argumentation showed improvement. The highest score was in the claim ($\bar{x}$ = 1.9), followed by warrant ($\bar{x}$ = 1.4), evidence ($\bar{x}$ = 1.0), supportive arguments ($\bar{x}$ = 1.0), and counter arguments ($\bar{x}$ = 0.8), respectively. This indicates that students demonstrated strong abilities in presenting their claims and gradually developed structured warrant, evidence, counterargument, and supportive argument. These findings align with the research conducted by Suwannatrai & Sangpradit (2023), which found that students' average scientific argumentation skills after instruction were significantly higher than before instruction at a .05 significance level. Students scored the highest in the claim component because identifying claims involves stating answers based on their investigations. In argumentation situations, students are provided with information or guiding questions, which help them clearly formulate their claims, leading to higher scores in this aspect. This finding is consistent with the study by Sampson, Grooms & Walker (2012), which defines a claim as a conclusion, prediction, explanation, or other response to a given question.

The warrant component showed a significant improvement among students. This development can be attributed to the learning activities in the exploration and investigation stages, where questions were used to stimulate students' critical thinking and encourage them to express their opinions. Additionally, students engaged in discussions to clarify doubts, and instructional media were provided to facilitate inquiry-based learning, enabling students to better understand and visualize concepts. This finding is consistent with the study by Grooms, et al. (2016), which emphasizes that asking questions during inquiry-based learning, questioning the methods used to obtain answers, providing guidance and support, and explaining or offering directions for students' uncertainties can effectively enhance their ability to provide warrant.

In the aspect of evidence, the exploration phase of the learning activity is when students investigate and gather evidence to support their claims. The teacher integrates instructional materials into the inquiry process to help students use them as evidence to substantiate their claims. Examples of these materials include the Lewis structure puzzle board, molecular shape models, and the Born-Haber cycle diagram. This is consistent with the findings of Sampson & Gleim (2009) stated that preparing essential materials for inquiry-based learning-such as samples, models, slides, and experimental equipment-facilitates the collection of evidence to support claims. However, providing instructional materials alone is often insufficient, as some students may encounter difficulties in interpreting or effectively applying these resources. Therefore, implementing instructional support is essential. Teachers can provide scaffolding through activities such as modeling how to analyze information from diagrams, using guiding questions to link observations to scientific principles, or incorporating graphic organizers. These strategies help strengthen students' ability to purposefully use evidence. For example, asking questions like "What does this model represent?" or "How does this evidence support your claim?" can assist students in making meaningful connections between the materials and underlying scientific concepts.

In the aspects of supportive arguments and counter arguments, students engage in temporary argument construction and argumentation activities. In the temporary argument construction phase, each student group summarizes their findings from the inquiry, with the teacher providing guidance to stimulate students' analytical thinking and to help them make connections between evidence and warrant. The teacher also reviews the arguments of each group to identify differences that lead to the argumentation phase. During the argumentation activity, the teacher prepares questions to stimulate discussion and encourage students to think critically. The discussion is controlled to stay on topic, and the key points from each group are summarized. This approach aligns with Sampson & Gleim (2009), which stated that when providing alternative arguments, it is essential to review students' arguments, stimulate critical thinking to find counter arguments, and control the discussion to stay focused on the key points.

However, in terms of using evidence, counter arguments, and supportive arguments, the development was not as expected. This is because some students still lacked skills in analytical thinking, systematic problem-solving, and critical thinking. Walker & Sampson (2013) pointed out that students must be able to evaluate the accuracy of information and analyze what constitutes reliable evidence to construct well-reasoned arguments. Within the argument-driven inquiry framework, students are placed in situations where they must pose questions, conduct investigations, present data, and engage in argumentation with others. This process enables them to learn systematic problem-solving, rather than simply finding the correct answer. Scientific argumentation is therefore a process that inherently relies on analytical thinking, systematic problem-solving, and critical thinking. Without these skills, students will be unable to construct evidence-based arguments, analyze information rationally, or respond to counter arguments effectively.

Moreover, most students lacked strong writing skills, which require time and structured practice to develop. While they could verbally present their group's ideas, they struggled with writing argumentation notes particularly in summarizing and selecting relevant information resulting in brief and underdeveloped explanations, especially regarding evidence, counter arguments, and supporting points. This aligns with Kamart (2022), who noted that using evidence is the most challenging aspect of argumentation, as verifying reasoning is more complex than stating opinions. Similarly, Sandoval and Millwood (2005) emphasized that effective use of evidence requires a deep understanding of both context and content. To address these difficulties, the researcher implemented instructional scaffolding strategies to support students' gradual development. These included tools such as argumentation boards, chemical models, and survey boards to visualize relationships between claims, evidence, and data , as well as contextual practices that link scientific concepts to real-world scenarios. The lessons incorporated analytical questioning and group-based activities as scaffolds to help students build confidence and fluency in constructing evidence-based arguments.

Regarding counterarguments, it was found that students in the second and third operational cycles showed consistent but unchanging development. This may be attributed to the fact that some students often neglected to clearly articulate their peers' differing claims. Instead, they tended to explain why their peers might have responded in a certain way and attempted to persuade them to agree with their own claim. This pattern reflects a lack of analytical skills in examining the question or situation thoroughly. Many students tended to skim through the text, which often led to misinterpretation or omission of key details. Skills such as analytical thinking, reading comprehension, and information synthesis are not developed overnight but require continuous practice and reinforcement. This finding is consistent with Wu & Tsai (2007), who found that students who were unable to construct counter arguments often relied on limited perspectives and tended to focus solely on presenting supportive arguments. These students typically lacked an understanding that effective argumentation involves identifying weaknesses in opposing viewpoints and presenting rebuttals. Potential strategies for development include training students to reason from multiple perspectives, encouraging the use of evidence to shift viewpoints, and having students engage with a variety of texts or data before beginning an argument. Additionally, students can be guided to evaluate both their own and their peers' arguments using a checklist that includes whether a counterargument is present. Finally, incorporating reflective writing after argumentation activities can help students articulate why they agree or disagree with reasons.

In terms of supportive arguments, it was found from Figure 1 that although the average score of supported arguments increased from the first operational cycle to third operational cycle, a decline was observed in the second operational cycle. This suggests that the topic of covalent bonding may involve complexities that affect students' ability to construct arguments, as a result, analyzing and incorporating evidence to supported arguments became more challenging. This finding is consistent with Sandoval & Millwood (2005), who noted that students are more effective in using evidence when they have a clear understanding of both the content and the context of the problem. This is consistent with the research by Songsil (2017), which found that most students still lacked the skills to support arguments, especially when faced with counter arguments. Furthermore, it was observed that most students were unable to identify counter arguments and often relied on emotional responses. Providing support arguments is an advanced cognitive process that requires the ability to analyze, synthesize, and evaluate information comprehensively. To enhance student learning, several instructional strategies can be adopted. These include using guiding questions such as "What evidence supports your claim?" or "How do you connect this data to your claim?" to encourage systematic thinking. Students can compare and analyze examples of different arguments to learn how to logically connect claims with evidence. Activities can be designed where students practice using evidence in various contexts to develop a deeper and more flexible understanding for application.

CONCLUSION AND IMPLICATIONS

The research on enhancing the scientific argumentation skills of grade 10 students on the topic of chemical bonding through argument-driven inquiry revealed that after completing all three operational cycles, students' scientific argumentation skills improved progressively in each operational cycle. By the final operational cycle, three students demonstrated very good argumentation skills, one student showed good skills, and six students displayed moderate skills. When considering the components of argumentation, it was found that students showed development in every aspect. Throughout the third operational cycles, continuous development was observed, particularly in the components of warrant and evidence, while most students were already proficient in identifying claims. This skill development was fostered by the argument-driven inquiry process, which provides a clear structure and encourages students to design experiments, observe phenomena, analyze data, and communicate their findings using scientific reasoning and evidence. The process also promotes discussion, idea exchange, and the practice of analytical thinking, enabling students to distinguish facts from opinions and assess the credibility of information.

The findings revealed that the argument-driven inquiry approach is an effective instructional strategy for promoting students' scientific argumentation skills, reasoning abilities, communication, and collaboration. When systematically integrated into learning activities such as laboratory experiments, group discussions, evidence-based writing, and student presentations provide ongoing opportunities for students to construct and respond to arguments. However, the development of counter arguments and supportive arguments remains limited, as these require higher order thinking skills, including analysis, synthesis, and scientific writing. Although these skills can be cultivated, they demand time, continuity, and structured support from the teacher. Furthermore, the use of component-based assessment for each student in every cycle revealed fluctuations in skill development, particularly in the second operational cycle, where some students' scores noticeably declined. This suggests that the complexity of the content may affect students' ability to counter arguments and supportive arguments. The effectiveness of argument-driven inquiry was also reflected in the integration of creative instructional tools and activities, such as survey boards, argumentation boards, and molecular models, which fostered a classroom environment that encouraged students to share ideas, express their reasoning, and support their claims with evidence. These tools, along with well-designed guiding questions, enabled students to connect data, evidence, and warrant more effectively. To maximize the effectiveness of argument-driven inquiry, teachers must not only understand the core principles of the approach but also be capable of designing aligned activities and learning materials, while cultivating a classroom culture that fosters analytical thinking, evidence-based argumentation, and respectful dialogue among students.

Recommendations for Application

1. Design learning activities aligned with content and student context: Teachers should adapt instructional content to suit students' proficiency levels, particularly in abstract chemistry topics such as chemical bonding. The use of models, visual media, and simulated scenarios is recommended to help learners grasp the overall concepts more clearly and enhance their understanding.

2. Gathering information phase: This phase is critical for argumentation, and teachers must pay special attention to it. Teachers should use questioning techniques to encourage students to express their opinions and emphasize the need for reliable information, as students may lack confidence in the data they have gathered, which could impact the temporary argumentation phase.

3. Constructing arguments phase: At this stage, teachers should design activities that allow all students to observe and present the temporary arguments of each group. This is necessary because some students might not fully grasp or listen attentively. For instance, teachers could use a survey board where students can present and display their arguments at the front of the classroom or have students write their temporary arguments on the board.

4. Argumentation activities phase: This phase is crucial and requires significant attention from the teacher, as students may experience self-doubt or fear of giving incorrect answers, which may hinder their willingness to present and argue with peers. Teachers should review previous group claims and use guiding questions like, "Do you have the other answers?" Students'

presentations are not right or wrong but should be based on the evidence they have gathered. This stage may require additional time for students to adjust since they may not be accustomed to such teaching methods.

5. Time management in activities: As this inquiry-based learning activity takes considerable time, teachers should manage activity durations appropriately. The argumentation scenarios should not be too complex if there is limited time for learning.

6. Improving argumentation test design: The research found that students wrote brief responses in the argumentation assessment and often failed to connect or expand their ideas. The test questions should be more specific, such as requiring students to provide at least two reasons or link their opinions to other related issues. Additionally, the data collection methods should align with the nature of the students.

Recommendations for Future Research

1. Sample Size and Contextual Limitations: This study was conducted with a small sample school, which limits the generalizability of the findings to broader educational contexts. Therefore, future research should involve a larger and more diverse student population across various school settings to enhance the reliability and applicability of the results.

2. Duration of Implementation: This study was conducted over only three operational cycles, which may be insufficient to reflect long-term development particularly in the components of counter arguments and supportive counterarguments. It is recommended that future research extends the implementation period or increases the number of operational cycles to explore stable and sustained changes.

3. Investigating factors affecting the stability of argumentation development: While students showed improvement in their argumentation skills, some experienced inconsistent progress with both higher and lower levels. Future research should investigate factors influencing the instability of development, or extend the research duration to track long-term development, which may depend on the school context and individual differences.

4. Investigating the development of counter arguments and supportive counterarguments: This study found that students demonstrated the least improvement in counterargument skills. Moreover, their ability to justify rebuttals declined in the second cycle. Therefore, it is necessary to investigate the factors that influence the development of these skills, or to explore instructional strategies that can effectively enhance students' counterargument abilities.

5. Exploring collaborative skills and problem-solving abilities: This study revealed that, in the development of scientific argumentation skills, students worked in groups and exchanged ideas to solve problems together. Future research should explore how argument-driven inquiry can foster collaborative skills or problem-solving abilities.

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