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Display of Scientific Argumentative Skills in a Metacognitive Inquiry Driven Classroom

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Abstract

This study explored the effectiveness of Metacognitive Argument-Driven Inquiry (MADI) strategy on the scientific argumentative skills of Grade 10 students. It used total population sampling through the selection of 50 Grade 10 students of Buenaventura Alandy National High School, who belong to the Science Enhanced Program and the Special Program in Foreign Language. Preparation and selection of instruments underwent extensive planning and validation process by experts and the revision followed. Collection of data included pre-assessment result that measured students' cognitive levels based on SOLO Taxonomy and post-assessment performance in scientific argumentative skills on the five dimensions: critical thinking, creative thinking, problem solving, evaluation of evidence, and logical reasoning, respectively. One-group posttest-only design was used as the research design to explore the effect of MADI through structured teaching of 4 phases of metacognitive learning process; Tacit, Aware, Strategic and Reflective. Data was analyzed using frequency, percentage, Pearson r and ANOVA. Findings revealed that most of the students were at developing level in prestructural/unistructural, and multistructural levels. There was a wide gap between relational and extended abstract levels which consisted mostly of students belonging to the beginning level. After the MADI strategy was applied, most of the students obtained scores in closely approximating mastery for critical thinking, creative thinking, and evidence evaluation, while a number of students attained mastered level in problem solving and logical reasoning. The results also showed there is no significant correlation between cognitive levels and scientific argumentative skills and there is no significant difference in the scientific argumentative skills when group according to cognitive level as students performed comparably regardless of their cognitive standing. It suggests that MADI can be used in science class to strengthen students' argumentative skills in secondary schools.

Keywords: Scientific Argumentative Skills, Metacognitive Argument-Driven Inquiry (MADI) Strategy, Grade 10 Students

1. Introduction

Science is the foundation of human advancement because it fuels innovation, expands human knowledge, and helps societies address complex real-world challenges through evidence-based reasoning and systematic inquiry (American Association for the Advancement of Science, 2020). As a result, science education is no longer focused solely on delivering content knowledge but also on developing students' ability to think critically, reason scientifically, and communicate ideas clearly and accurately (National Academies, 2021). Central to this goal is scientific argumentation, which involves constructing claims, supporting them with evidence and reasoning, and critically evaluating alternative explanations (Sarıgöz, 2023). In an increasingly science- and technology-driven society, scientific argumentation has become an essential skill for scientific literacy and informed citizenship. Educational systems worldwide have shifted from traditional content transmission toward inquiry-based learning approaches that actively engage students in scientific investigation and reasoning. The OECD defines scientific literacy as the capacity to explain phenomena scientifically, evaluate inquiry processes, and interpret evidence-based data. Supporting this, Cahyani et al. (2024) observed that inquiry-oriented laboratory activities help develop students' scientific argumentation skills, although learners demonstrate varying levels of competence that require structured support. Scientific argumentation is considered one of the most cognitively demanding yet educationally valuable classroom activities because it integrates content knowledge, reasoning, metacognition, and communication. Furthermore, Jin and Kim (2021) found that scientific argumentation enhances conceptual understanding and is strongly associated with critical thinking, scientific literacy, analytical thinking, and scientific reasoning. Similarly, Hendratmoko et al. (2024) emphasized that inquiry and debate activities improve students' ability to support claims with evidence and defend counterclaims, making argumentation a vital 21st-century science learning practice.

Research consistently shows that inquiry-based instructional approaches are effective in strengthening students' scientific reasoning and argumentation skills. Lestari et al. (2024), through a quasi-experimental study, demonstrated that students who used an inquiry-based science argumentation instructional model achieved significantly higher scientific literacy skills compared to those exposed to guided inquiry and discovery learning approaches. Such approaches transform students from passive recipients of information into active participants who engage in sense-making, evidence evaluation, and reasoned argumentation. Consequently, inquiry-based instruction promotes not only content mastery but also reflective learning, problem-solving abilities, and self-directed learning.

In response to these global educational trends, the Philippine K to 12 Science Curriculum promotes learner-centered and inquiry-based science instruction (Department of Education, 2024). The curriculum emphasizes the use of evidence in constructing explanations and aims to produce scientifically, technologically, and environmentally literate learners who are critical thinkers, informed decision-makers, effective communicators, and responsible citizens. Science learning is therefore redefined not as memorization of facts but as active participation in reasoning, reflection, and scientific argumentation. Despite these curricular reforms, however, many Filipino secondary school students still struggle to construct coherent, evidence-based scientific arguments. Research highlights that identifying relationships between claims and evidence, evaluating justifications, and analysing scientific reasoning remain among the most difficult competencies for students to master. These challenges were observed at Buenaventura Alandy National High School, where Grade 10 students enrolled in the Science Enhanced Program (SEP) and Special Program in Foreign Language (SPFL) demonstrated below-proficiency performance levels, with Mean Percentage Scores of 64% and 63%, respectively. These findings revealed gaps in students' ability to construct and evaluate scientific arguments, even among learners in specialized academic programs, emphasizing the need for targeted instructional interventions.

To address these concerns, the study introduces the Metacognitive Argument-Driven Inquiry (MADI) strategy, which combines inquiry-based learning, scientific argumentation, and metacognitive regulation within a single instructional framework. MADI requires students to construct claims, support them with evidence and reasoning, and actively reflect on their own thinking processes. Jin and Kim (2021) noted that engaging students in evidence-based argumentation strengthens conceptual understanding and analytical thinking, while Hendratmoko et al. (2024) highlighted the importance of inquiry and debate activities in improving students' ability to defend and critique arguments. What makes MADI distinctive is its emphasis on metacognitive regulation, which involves planning, monitoring, controlling, and evaluating one's thinking processes during learning tasks. Wang et al. (2021) found that metacognitive scaffolding in science inquiry significantly improved students' conceptual understanding, integrated science process skills, and confidence in scientific reasoning. Overall, MADI promotes reflective and inquiry-driven learning by encouraging students not only to investigate scientific phenomena and construct arguments but also to critically evaluate and improve their own reasoning processes. Guided by the principles of inquiry-based learning and metacognition, the study aims to determine whether MADI can significantly improve students' scientific argumentative skills, particularly in critical thinking, creative thinking, problem solving, evidence evaluation, and logical reasoning. The study also seeks to contribute to the growing body of literature on reflective and inquiry-driven science instruction in Philippine secondary education.

2. Objectives of the Study

The study aimed to determine the effectiveness of the Metacognitive Argument-Driven Inquiry (MADI) strategy on the scientific argumentative skills of Grade 10 students at Buenaventura Alandy National High School. Specifically, it sought to identify the cognitive levels of students based on their assessment scores in terms of prestructural, unistructural, multistructural, relational, and extended abstract levels; determine the post-assessment performance of students after the implementation of the MADI strategy as to critical thinking, creative thinking, problem-solving, evidence evaluation, and logical reasoning; examine the significant relationship between students' cognitive levels and their scientific argumentative skills; and evaluate whether there is a significant difference in the scientific argumentative skills of students when grouped according to cognitive level after the implementation of the MADI strategy.

3. Methodology

This study employed a one-group posttest-only research design to evaluate the scientific argumentative skills of Grade 10 Science students after the implementation of the Metacognitive Argument-Driven Inquiry (MADI) strategy at Buenaventura Alandy National High School. The study aimed to determine whether MADI could improve students' scientific argumentative skills based on their cognitive levels. According to Choueiry (2020), this design involves applying an intervention followed by a single post-assessment to measure the dependent variable. The design is particularly appropriate in educational settings where random assignment and control groups are difficult to establish (Capili & Anastasi, 2024; Arevalo & Reyes, 2025). In this study, MADI served as the instructional intervention, while the post-assessment measured students' scientific argumentative performance after the treatment.

The respondents were selected Grade 10 students from the Science Enhanced Program (SEP) and Special Program in Foreign Language (SPFL) using total population sampling. These students were chosen because they belonged to advanced academic programs expected to develop higher-order thinking skills, including scientific argumentation. However, recent Mean Percentage Scores (MPS) in Science were low, with SEP students scoring 64% and SPFL students 63%, indicating weaknesses in scientific reasoning and evidence-based argumentation. The study identified gaps in students' ability to think critically, make logical inferences, regulate their own thinking, and engage in scientific argumentation. Therefore, these groups were considered appropriate participants for the MADI intervention. Inclusion criteria required students to be officially enrolled in Grade 10 SEP or SPFL sections, present during both assessment for cognitive level, post-assessment performance, and exposed to the complete intervention. Students who did not meet these conditions were excluded from the study.

Three researcher-designed instruments were utilized in the study: a test for cognitive level, a post-assessment performance test on scientific argumentative skills, and lesson implementation plans for the MADI strategy. The test for cognitive level is a 40-point test, consisted of 18 multiple-choice items and 2 open-ended questions based on the SOLO Taxonomy, which classifies cognitive performance into Prestructural, Unistructural, Multistructural, Relational, and Extended Abstract levels. The test focused on

Grade 10 Science least-learned competencies, particularly Boyle's Law, Charles's Law, and the Kinetic Molecular Theory. Rubrics and scoring systems were adapted from established studies by Biggs and Collis (1982), Adeniji et al. (2022), Yuanita et al. (2023), and Triana et al. (2023). The second instrument was a 40-point post-assessment performance designed to measure scientific argumentative skills across five dimensions: critical thinking, creative thinking, problem solving, evidence evaluation, and logical reasoning. The third instrument consisted of Lesson Implementation Plans specifically designed for the MADI strategy. These plans incorporated four metacognitive phases: Tacit, Aware, Strategic, and Reflective. The MADI strategy incorporated the MADI Investigation Process, which consisted of eight stages adapted from Argument-Driven Inquiry (ADI) by Sampson and Gleim (2009) and the Claim-Evidence-Reasoning (CER) framework was based on McNeill and Krajcik (2008, 2011), while additional support for inquiry and argumentation practices was provided by Kaçar and Balım (2021) and Antonio and Prudente (2021), who highlighted the effectiveness of metacognitive regulation in improving conceptual understanding and scientific argumentation.

The research procedure followed three phases: pre-implementation, implementation, and post-implementation. During the pre-implementation phase, approval was secured from the Schools Division Office and school principal, while informed consent and assent were obtained from students and parents in compliance with DepEd Order No. 16 s. 2017. Instruments were pilot tested to establish reliability and validity. Students were then assessed using the test for cognitive level based on SOLO Taxonomy categories.

During the implementation phase, the MADI strategy was applied consistently in Grade 10 Science lessons during the fourth quarter. The four MADI phases guided instruction and activities. In the Tacit phase, students activated prior knowledge and identified misconceptions. In the Aware phase, lesson objectives and content were clarified, and initial argument construction began. The Strategic Phase served as the core learning component of the instructional process, wherein students applied appropriate learning strategies to achieve the intended learning outcomes through the MADI Investigation Process. This phase involved scientific investigations, collaborative inquiry, argument construction using the Claim-Evidence-Reasoning (CER) framework, and peer discussions aligned with the students' cognitive levels. Students explored concepts such as Boyle's Law, Charles's Law, and the Kinetic Molecular Theory through differentiated and scaffolded learning activities, as well as active engagement in the eight stages of the MADI Investigation Process: (1) Identification of the Task and Research Question, (2) Designing the Investigation and Collect and Analyze Data, (3) Develop a Tentative Argument through the use of CER framework, (4) Argumentation Session, (5) Write an Investigation Report, (6) Double Blind Group Peer Review, (7) Editing and Reflection and (8) Revises and Submits the Final Investigation Report (Sampson and Gleim, 2009). Finally, the Reflective phase allowed students to evaluate their learning, revise their arguments based on peer and teacher feedback, and connect scientific concepts to real-life applications.

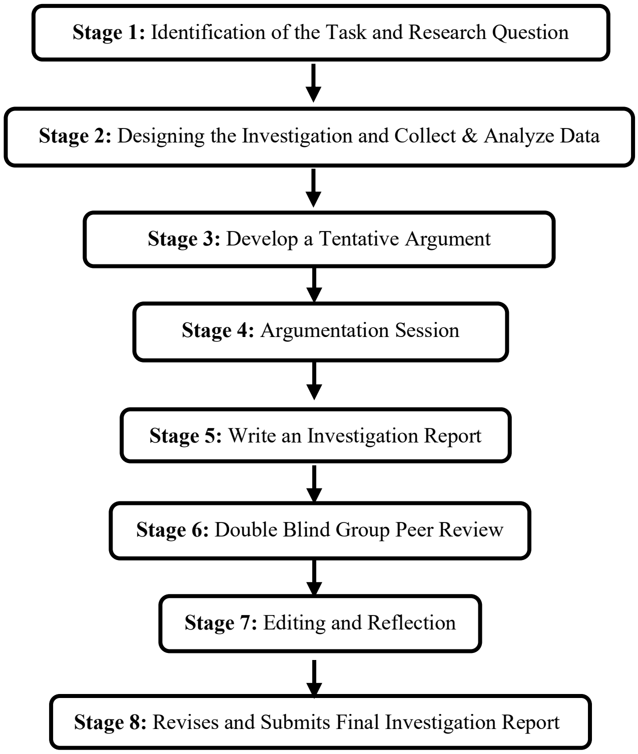

Figure 1. Structural Flow of MADI Investigation Process

In the post-implementation phase, students completed the post-assessment performance test to measure scientific argumentative skills in terms of critical thinking, creative thinking, problem solving, evidence evaluation, and logical reasoning.

Results were compared according to students' cognitive levels to determine whether significant relationships and differences existed among groups after the MADI intervention. Data were encoded and analyzed ethically and confidentially in accordance with DepEd research and data privacy guidelines.

Frequency distribution and percentage were first used to classify students according to SOLO cognitive levels and to describe their post-assessment performance (Creswell & Creswell, 2018). Means and standard deviations were then computed to determine the overall performance and variability of the respondents' scores. Statistical analyses were conducted using SPSS version 26.0 with a significance level set at 0.05. Pearson Product-Moment Correlation Coefficient (Pearson r) was employed to determine the relationship between cognitive levels and scientific argumentative skills after the implementation of the MADI strategy (Field, 2018). Furthermore, Analysis of Variance (ANOVA) was used to identify significant differences in scientific argumentative skills across cognitive-level groups (Pallant, 2020).

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4. Results and Discussion

Table 1. Students' Cognitive Levels Based on Assessment Scores in Terms of Prestructural/Unistructural

Performance Score	f	%	Verbal Interpretation
81-100	7	14	Advanced
61-80	10	20	Proficient
41-60	32	64	Developing
21-40	1	2	Beginning
0-20	--	--	Needs Improvement
Total	50	100	

Legend: f= frequency, %=percentage

Table 1 presents the results of students at the prestructural/unistructural level, where most were classified under the developing level, with scores ranging from 41–60% or 3–4 points. This indicates that students had limited and incomplete understanding of the concepts. At this level, students could identify isolated ideas such as "pressure goes up" or "volume changes," but were unable to explain the relationships among these concepts in situational and computational questions, resulting in partial rather than scientific explanations. A good proportion of students reached the proficient level, scoring 61–80% (5 correct answers), demonstrating a better understanding of simple gas law relationships and the ability to apply equations in basic situations, although they still struggled with tasks requiring deeper explanation and application. Only a few students attained the advanced level, scoring 81–100% (6–7 correct answers), showing deeper and more consistent understanding through accurate application of scientific concepts and concise explanations in both computational and situational items. In contrast, only one student belonged to the beginning level, scoring 21–40% (2 points), which reflected very limited understanding and difficulty recalling of fundamental gas laws and Kinetic Molecular Theory concepts.

These findings reflect the unistructural level of the SOLO Taxonomy, where students focus on only one aspect of a concept without making connections to related ideas. For example, students recognized that "pressure increased" but could not explain why or relate it to decreasing volume. This is consistent with the findings of Kaharuddin and Hajeniati (2020), who reported that students' answers were correct but limited and largely based on rote learning. They also found that students struggled to apply concepts in unfamiliar or real-life situations, which may explain why many students could not explain situations such as a tire blowing out using Boyle's Law. While students demonstrated basic knowledge of gas laws, more effective teaching strategies are needed to help them progress toward the multistructural and relational levels of the SOLO Taxonomy, where meaningful conceptual connections can be developed.

Table 2. Students' Cognitive Levels Based on Assessment Scores in Terms of Multistructural

Performance Score	F	%	Verbal Interpretation
81-100	5	10	Advanced
61-80	16	32	Proficient
41-60	19	38	Developing
21-40	10	20	Beginning
0-20	--	--	Needs Improvement
Total	50	100	

Legend: f= frequency, %=percentage

Table 2 shows that most students were at the developing level (41–60%), obtaining 7–9 correct responses, which indicates a multistructural but still unintegrated understanding of Boyle's Law, Charles's Law, and the Kinetic Molecular Theory. These students could identify several ideas, such as pressure, volume, temperature, and particle motion, but struggled to connect these ideas into a complete scientific explanation. When answering situational questions, such as those involving syringe compression or gas behavior under varying conditions, students often recognized only some relevant concepts while overlooking other important relationships. Many students also reached the proficient level (61–80%), demonstrating stronger understanding and application of gas laws and Kinetic Molecular Theory across different question types. These students were generally able to identify and apply multiple correct concepts; however, their explanations often remained broad or generalized, suggesting that they still needed deeper conceptual integration to improve comprehension and application. Only a small number of students achieved the advanced level (81–100%), corresponding to 13–16 correct answers. These students displayed a more developed multistructural response pattern, showing the ability to recognize nearly all key concepts and apply them accurately in experimental and situational involving gas laws. Meanwhile, students at the beginning level (21–40%), with only 4–6 correct responses, demonstrated minimal understanding. They were able to identify only one or two simple concepts and had difficulty recognizing additional relationships within the problems. Their answers were usually incomplete, especially for items requiring of multiple scientific concepts.

These findings align with the characteristics of multistructural thinking in the SOLO Taxonomy, where students can identify and explain several related ideas but cannot yet synthesize them into a unified understanding. According to the SOLO framework, learners at this level recognize multiple aspects of a concept but fail to establish meaningful relationships among them. Similar findings were reported by Sumagaysay and Valdez (2025), who observed that students were able to explain individual scientific concepts but struggled to integrate them into coherent and comprehensive scientific explanations. Consistent with this, the present study found that most students remained at the developing and proficient levels of multistructural thinking, as they could identify and describe several components of Boyle's Law but were still unable to fully connect pressure, volume, and particle behavior into an integrated scientific explanation.

Table 3. Students' Cognitive Levels Based on Assessment Scores in Terms of Relational

Performance Score	F	%	Verbal Interpretation
81-100	--	--	Advanced
61-80	6	12	Proficient
41-60	10	20	Developing
21-40	22	44	Beginning
0-20	12	24	Needs Improvement
Total	50	100	

Legend: f= frequency, %=percentage

Table 3 reveals that the majority of students were at the beginning level (21–40%), with scores ranging from 2–3 correct answers. These students demonstrated limited understanding of Boyle's Law, Charles's Law, and the Kinetic Molecular Theory, as they could recognize isolated concepts such as increases in pressure or temperature but were unable to integrate these ideas into complete scientific explanations. When answering situational problems involving pistons or heated gases, students often focused on only one variable and failed to explain the relationships among pressure, volume, and particle motion, resulting in inaccurate responses. A considerable number of students also fell under the needs improvement level (0–20%), indicating very minimal understanding of how scientific concepts are interconnected. These students struggled to select correct answers and frequently made errors in scientific reasoning tasks, particularly those requiring explanations based on the Kinetic Molecular Theory. Their responses reflected difficulty in applying related concepts to explain changes in gas behavior scientifically.

Some students reached the developing level (41–60%) with 4–5 correct answers, suggesting that they could recognize and apply more than one concept but still lacked the ability to connect them meaningfully. For example, students could state that heating increases pressure or that volume decreases when pressure is applied, yet they failed to explain these relationships through particle motion and scientific principles. Only a small proportion of students attained the proficient level (61–80%), scoring 8–9 correct answers. These students were better able to integrate and apply multiple concepts, clearly explaining phenomena such as how increased particle motion due to higher temperature raises pressure and how pressure is inversely related to volume. Notably, no student reached the advanced level (81–100%), indicating that none consistently demonstrated complete, integrated, and scientifically accurate explanations across all tasks.

Overall, the findings indicate a substantial gap in students' cognitive abilities, with most learners demonstrating only surface-level understanding rather than relational or integrative thinking. These results support the findings of Appiah et al. (2025), who observed that senior high school students often remained at lower levels of the SOLO Taxonomy because they struggled to use basic concepts in developing relational understanding. The study attributed these difficulties to limited exposure to tasks requiring higher-order thinking, synthesis, and integration of knowledge. They further recommended the use of multiple representations and hands-on activities to foster deeper conceptual understanding. Similarly, the present findings highlight the need for more inquiry-driven instructional approaches that encourage students not only to gather information but also to synthesize, connect, and integrate scientific concepts into meaningful understanding.

Table 4. Students' Cognitive Levels Based on Assessment Scores in Terms of Extended Abstract

Performance Score	**F**	**%**	**Verbal Interpretation**
81-100	--	--	Advanced
61-80	--	--	Proficient
41-60	2	4	Developing
26-40	26	52	Beginning
0-25	22	44	Needs Improvement
Total	50	100	

Legend: f= frequency, %=percentage

Table 4 reveals that most students were at the beginning level (26–40%), showing limited understanding of Boyle's Law and Charles's Law when applied to real-life situations. Their responses were generally short and lacked scientific explanation. For example, students answered with simple statements such as "air gets in," "volume goes up," or "temperature rises," but failed to explain the relationships among pressure, volume, and temperature using scientific principles. Many students were also categorized under the needs improvement level (0–25%), indicating very low comprehension and difficulty applying gas law concepts to unfamiliar situations. Their answers were often incomplete, unclear, or unrelated to the questions. Only a few students reached the developing level (41–60%), where they demonstrated partial understanding of concepts such as the relationship between pressure and volume or temperature and volume. However, their explanations still lacked logical flow and integration of ideas needed for complete scientific reasoning. Notably, no students achieved the proficient nor advanced levels, suggesting that students generally struggled to produce clear, complete, and well-reasoned explanations using scientific concepts or applied these concepts to new contexts.

This pattern aligns with previous research, which emphasizes that higher-order thinking skills develop only when students are consistently exposed to cognitively demanding tasks (Liu et al., 2024).

Higher-order thinking skills include metacognition, problem-solving, critical thinking, and creativity, all of which are essential for meaningful scientific understanding. However, students in this study appeared to operate mostly at lower levels of cognitive processing, limiting their ability to generate or respond to questions requiring deeper reasoning. Similarly, the 2023 OECD PISA report highlights that students across contexts continue to struggle with complex reasoning and problem-solving tasks at higher cognitive levels, indicating insufficient opportunities for deep learning and conceptual transfer. With limited engagement in higher-order cognitive processes, students have fewer opportunities to meaningfully integrate scientific concepts and develop critical thinking skills.

Table 5. Post-Assessment Performance Scores of the Grade 10 Students as to Critical Thinking

Performance Score	F	%	Verbal Interpretation
81-100	23	46	Mastered
61-80	27	54	Closely Approximating Mastery
41-60	--	--	Average Mastery
21-40	--	--	Low Mastery
0-20	--	--	No Mastery
Total	50	100	

Legend: f= frequency, %=percentage

Table 5 shows that after the implementation of the MADI strategy, Grade 10 students demonstrated strong performance in critical thinking. Most students achieved closely approximating mastery (61–80%) at 54%, while 46% reached the mastered level (81–100%), with no students falling under lower levels of mastery. Students at the closely approximating level showed good conceptual understanding and were able to interpret data and apply gas laws to familiar situations, such as identifying inverse relationships between variables. However, they still experienced some difficulty with more complex, context-based questions requiring deeper explanation of real-world phenomena. In contrast, students at the mastered level demonstrated advanced or strong critical thinking skills, showing the ability to analyze, interpret, and apply gas laws and kinetic molecular theory in explaining real-life situations such as pressure changes, diffusion, and effects of temperature.

These results suggest that the MADI strategy effectively enhanced students' critical thinking through consistent engagement in inquiry-based tasks, argument construction, laboratory investigations, and real-world applications. Students regularly analyzed experimental data involving pressure, volume, temperature, and mass, and were required to construct scientific explanations based on evidence. Additionally, real-life application tasks such as explaining breathing, airplane pressure, and gas expansion encouraged learners to connect scientific concepts to everyday experiences. Higher-order thinking skills (HOTS) questions embedded in the lessons further supported students in analyzing problems, evaluating conditions, and constructing logical explanations, which contributed to their improved performance. These findings are supported by Weng et al. (2022), who emphasized that student-centered and active learning approaches promote higher-order thinking skills, including critical thinking and problem-solving. They further noted that deep learning occurs when students actively engage with authentic situations, connect prior knowledge with new concepts, and apply scientific ideas to real-world contexts. The results of this study align with these findings, as most students reached either mastery or closely approximating mastery levels, indicating that the instructional approach effectively strengthened their critical thinking abilities.

Table 6. Post-Assessment Performance Scores of the Grade 10 Students as to Creative Thinking

Performance Score	F	%	Verbal Interpretation
81-100	17	34	Mastered
61-80	31	62	Closely Approximating Mastery
41-60	2	4	Average Mastery
21-40	--	--	Low Mastery
0-20	--	--	No Mastery
Total	50	100	

Legend: f= frequency, %=percentage

Table 6 reveals that most students at the closely approximating mastery level (61-80%) in a score range 5-6 were able to produce appropriate and diversified ideas. However, these ideas are not expressed with sufficient detail and explanation. For example, in designing an environmental friendly greenhouse or explain the increase of snack packs size in a high altitude, these students could give reasonable and practical answers or solutions (ventilation/cooling mechanism and venting gas) and connects it to gas laws behavior. Their answers were basically from general ideas, did not specifically explain on how these responses relate to Charles's Law and Kinetic Molecular Theory.

A good proportion of students reached the mastered level (81–100%) demonstrated high creative thinking; showing fluency, flexibility, and originality on their responses. They proposed multiple solutions, such as ventilation systems, reflective materials, or pressure relief devices, and provided clear scientific explanations linking these to gas behavior. These students were able to integrate concepts accurately and justify their ideas using scientific principles. A small number of students were at the average mastery level (41–60%), giving basic and limited responses with minimal elaboration.

The development of creative thinking was supported by MADI activities that required students to generate hypotheses, design investigations, create concept maps, propose explanations, and suggest improvements to experiments. Collaborative inquiry, feedback, and revision further encouraged students to refine and expand their ideas, fostering more diverse and innovative responses. These findings align with Paz-Baruch et al. (2025), who emphasized that creativity improves through meta-creativity involving planning, monitoring, and regulating creative problem-solving processes. Similarly, Rivas et al. (2022) found that metacognitive argumentation promotes deeper reasoning and more innovative thinking by requiring students to justify ideas, evaluate counterarguments, and refine explanations, leading to higher-level creative and conceptual understanding.

Table 7. Post-Assessment Performance Scores of the Grade 10 Students as to Problem Solving

Performance Score	f	%	Verbal Interpretation
81-100	30	60	Mastered
61-80	18	36	Closely Approximating Mastery
41-60	2	4	Average Mastery
21-40	--	--	Low Mastery
0-20	--	--	No Mastery
Total	50	100	

Legend: f= frequency, %=percentage

Table 7 shows that most students achieved the mastered level (81–100%, score 7–8), demonstrating strong problem-solving skills in applying gas laws such as Boyle's Law and Charles's Law. These students accurately performed multi-step computations, correct substitutions, and unit conversions, and were able to solve both numerical and conceptual problems, including analyzing kinetic energy in relation to temperature. Some students were at the closely approximating mastery level (61–80%), showing good problem-solving ability but making minor errors in calculations, substitutions, or unit conversions, especially in more complex or multi-step tasks. There are only a few students that are in the average mastery level (41-60%) which suggests that students have fundamental problem-solving skills but have inconsistencies in accuracy and application. Although these students may be familiar with the formula, they still struggle to apply it to problem situations, resulting in computational errors and incorrect responses.

This improvement can be attributed to the implementation of the MADI strategy, which strengthened students' problem-solving skills through guided practice, computation activities, and step-by-step data analysis throughout the inquiry process. Students were consistently engaged in applying gas law formulas, performing calculations, and addressing experimental problems, which enhanced both their accuracy and systematic approach to solving tasks. They were also encouraged to identify and resolve errors during investigations, further improving their problem-solving abilities.

This finding is supported by Setiawan and Jumadi (2023), who reported that argument-driven inquiry approaches effectively develop students' problem-solving skills by engaging them in constructing and defending evidence-based explanations grounded in logical reasoning and computation. Similarly, metacognitive regulation plays a crucial role in enhancing problem-solving performance, as students who actively monitor, evaluate, and regulate their thinking tend to demonstrate improved accuracy, systematic procedures, and better transfer of learned strategies to new problem contexts (Halmo et al., 2024).

Table 8. Post-Assessment Performance Scores of the Grade 10 Students as to Evidence Evaluation

Performance Score	f	%	Verbal Interpretation
81-100	21	42	Mastered
61-80	28	56	Closely Approximating Mastery
41-60	1	2	Average Mastery
21-40	--	--	Low Mastery
0-20	--	--	No Mastery
Total	50	100	

Legend: f= frequency, %=percentage

Table 8 reveals that most students (61–80%), with scores ranging from 5–6 correct answers, were classified under the closely approximating mastery level. Students within this range were able to observe scientific evidence and use it to explain phenomena such as the marshmallow in a syringe and the effect of hot and cold water on a balloon. They were able to describe the relationships between volume, pressure, temperature, and gas behavior; however, their explanations, while valid and relevant, typically lacked specific details and clear logical rationale.

Meanwhile, a good number of students achieved the mastered level (81–100%) demonstrated a strong ability to evaluate evidence effectively. They were able to correctly identify significant observations and use these to justify their scientific explanations. Moreover, they successfully connected experimental results with the scientific concepts being investigated, such as changes in size or expansion, producing responses that were accurate, appropriate, and clearly linked to both the observed phenomena and the supporting evidence. Only a small number of students (2%) were classified under the average mastery level (41–60%). These students were able to identify some correct observations, but their explanations were often vague, incomplete, or contained errors, showing difficulty in explaining changes using gas laws and the Kinetic Molecular Theory.

Overall, the development of students' evidence evaluation skills can be attributed to their engagement in MADI-based activities such as investigations, data collection, argument construction, CER-based reasoning, and peer review, which provided structured opportunities to select, evaluate, and justify scientific evidence across different contexts. This aligns with Dawson and Carson (2020), who found that argumentation-based instruction improves students' ability to use evidence in decision-making, and Setiawan and Jumadi (2023), who emphasized that structured inquiry and argument-driven approaches strengthen students' reasoning and evidence evaluation skills in science learning.

Table 9. Post-Assessment Performance Scores of the Grade 10 Students as to Logical Reasoning

Performance Score	f	%	Verbal Interpretation
81-100	27	54	Mastered
61-80	21	42	Closely Approximating Mastery
41-60	2	4	Average Mastery
21-40	--	--	Low Mastery
0-20	--	--	No Mastery
Total	50	100	

Legend: f= frequency, %=percentage

Table 9 reveals that the highest proportion of students fall under the mastered level (81–100%), indicating excellent logical reasoning abilities. These students were able to organize ideas in a sequential and coherent manner, apply scientific knowledge accurately, and provide clear and adequate explanations. For example, in questions such as why a soda can releases gas when opened or how inflatable boats expand after prolonged exposure to heat, they were able to clearly explain how changes in pressure, volume, and temperature influence gas behavior in relation to Boyle's Law, Charles's Law, and the Kinetic Molecular Theory.

Meanwhile, 42% of students belong to the closely approximating mastery level (61–80%), with scores of 5–6 correct answers. These students demonstrated a well-organized thinking process and appropriate use of scientific concepts, allowing them to present situations in a logical sequence. However, their explanations were less elaborated and lacked clear justification for each step of reasoning. Only 4% of students were classified under the average mastery level (41–60%), showing basic logical reasoning skills. Although they presented some valid ideas, their reasoning and arguments were often unclear and poorly structured, making it difficult to support their answers using scientific principles.

The development of students' logical reasoning skills can be attributed to the structured and reflective nature of the MADI strategy, which integrated inquiry-based tasks, evidence-based discussions, and the CER framework. Through argumentation sessions, students were able to defend their claims, evaluate opposing ideas, and refine their reasoning based on peer feedback, thereby strengthening their ability to think systematically and draw sound conclusions.

Supporting this, Dignath and Veenman (2021) found that metacognitive interventions embedded in subject-specific tasks, particularly science experiments, significantly enhance logical reasoning and argument quality compared to traditional instruction. Similarly, Dent and Koenka (2016) emphasized that metacognitive regulation—planning, monitoring, and evaluating one's reasoning strongly predicts learning in science, as it helps students internalize logical consistency during complex problem-solving tasks. These studies support the present findings, suggesting that the metacognitive component of the MADI strategy played a key role in developing students' reflective thinking and logical precision.

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Table 10. Correlations between Students' Cognitive Levels and Scientific Argumentative Skills

Cognitive Levels	**Scientific Argumentative Skills**				
	Critical Thinking	**Creative Thinking**	**Problem Solving**	**Evidence Evaluation**	**Logical Reasoning**
Prestructural/ Unistructural	*-0.285	0.001	-0.021	-0.16	0.146
Multistructural	*0.296	0.161	0.043	0.253	0.246
Relational	0.138	-0.149	*-0.322	-0.091	0.087
Extended Abstract	0.083	0.063	-0.076	-0.04	0.237

Legend: 0.00 to ±0.20= Negligible or very weak correlation, ±0.21 to ±0.40, Weak correlation, ±0.41 to ±0.70Moderate correlation, ±0.71 to ±0.90Strong correlation, ±0.91 to ±1.00Very strong correlation

Table 10 reveals that generally there is no significant relationship between students' cognitive levels and scientific argumentative skills after the implementation of the MADI strategy, except for three specific dimensions: the correlation between the prestructural/unistructural level and critical thinking, the multistructural level and critical thinking, and the relational level and problem solving.

A negative correlation between the prestructural/unistructural cognitive level and critical thinking suggests that students who performed lower in prestructural/unistructural tasks tended to perform higher in critical thinking. This finding is supported by the data, where Table 1 shows that most students were at the developing level in prestructural/unistructural tasks, demonstrating limited and fragmented understanding of Boyle's Law, Charles's Law, and the Kinetic Molecular Theory. In contrast, Table 5 indicates that all students reached closely approximating mastery to mastered levels in critical thinking, which explains the inverse relationship observed. This result may be attributed to the learning process, where students, despite initial reliance on basic recall, were still able to engage in higher-order thinking through analysis, interpretation, and explanation during MADI activities.

Another important finding is the positive relationship between the multistructural level and critical thinking, which indicates that students who could identify and organize several scientific concepts also performed better in tasks requiring critical thinking. Table 2 shows that many students were able to recognize multiple concepts, and Table 5 further confirms strong performance in critical thinking tasks. The ability to handle multiple ideas simultaneously supported students in analyzing data and constructing coherent explanations, suggesting that multistructural thinking contributes to the development of critical thinking skills.

Finally, a negative relationship was found between the relational level and problem solving, where students with lower relational performance tended to perform better in problem-solving tasks. Table 3 shows that most students were at the beginning level in relational thinking, with only few reached higher level, indicating difficulty in integrating concepts such as pressure, volume, temperature, and particle motion. In contrast, Table 7 shows that most students achieved mastered and closely approximating mastery levels in problem solving. This suggests that students were still able to succeed in procedural tasks such as equation manipulation, substitution, and step-by-step computation, especially due to repeated guided practice and structured problem-solving activities within the MADI strategy. Additionally, the absence of a significant relationship involving the extended abstract level is likely due to the limited variation in scores, as most students were clustered at lower performance levels.

Overall, these findings align with recent literature emphasizing that higher-order thinking develops through sustained exposure to cognitively requiring and metacognitively guided instruction. Dignath and Veenman (2021) highlight that metacognitive strategies enhance students' ability to plan, monitor, and evaluate their thinking, leading to deeper conceptual processing. Similarly, Antonio and Prudente (2021)

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emphasize that argumentation in science supports the shift from memorization to higher-order reasoning through evidence-based explanation and reflection. These studies support the present findings, suggesting that despite initial cognitive limitations, students were able to develop scientific argumentative skills through the MADI strategy.

Table 11. Difference in Scientific Argumentative Skills Among Grade 10 Students According to Cognitive Levels

Scientific Argumentative Skills	**Cognitive Level**	**Mean (M)**	**SD**	**F-value**	**p-value**
Critical Thinking	Relational	6.67	0.81	1.238	0.320
	Unistructural	6.40	0.63		
	Multistructural	6.76	0.83		
Creative Thinking	Relational	6.33	1.36	0.691	0.519
	Unistructural	6.00	0.84		
	Multistructural	6.34	1.04		
Problem Solving	Relational	7.00	1.26	0.938	0.416
	Unistructural	6.87	1.24		
	Multistructural	6.41	1.21		
Evidence Evaluation	Relational	6.50	1.04	0.112	0.895
	Unistructural	6.33	0.97		
	Multistructural	6.48	1.15		
Logical Reasoning	Relational	6.67	1.03	1.159	0.343
	Unistructural	5.93	1.10		
	Multistructural	6.34	1.07		

If p-value ≤ .05: Statistically Significant
If p-value > .05: Not Significant

Table 11 shows that there is no significant difference in scientific argumentative skills among Grade 10 students when grouped according to cognitive levels. Students at the unistructural, multistructural, and relational levels performed similarly in critical thinking, creative thinking, problem solving, evidence evaluation, and logical reasoning. Mean scores across all skills indicate that students were generally performing at closely approximating mastery to mastered levels, consistent with Table 5, where students demonstrated strong critical thinking skills with a high performance in analyzing scenarios, interpreting data, and explaining scientific concepts using gas laws in real-life contexts such as balloons and aerosol cans. For creative thinking, students across all levels showed similar abilities to generate ideas and propose solutions, although the depth and detail of responses varied slightly, as reflected in Table 6. Likewise, problem-solving scores showed minimal differences, indicating that all groups were able to apply formulas, perform computations, and complete multi-step tasks effectively, consistent with Table 7. In evidence evaluation, students similarly used observations and experimental data to support explanations (Table 8), while in logical reasoning, they were able to organize ideas and explain phenomena in a structured manner (Table 9), suggesting that even lower cognitive level students could still produce coherent scientific responses when guided.

These outcomes are attributed to the structure of the MADI strategy, which consists of four phases: Tacit, Aware, Strategic, and Reflective. In the Tacit phase, simple tasks were used to activate prior knowledge, allowing the teacher to identify what students already knew and their misconceptions about gas laws and the Kinetic Molecular Theory. These initial activities served as the baseline for introducing new concepts. During the Aware phase, students engaged in activities designed to clarify the lesson's purpose, while the teacher introduced key information and guided them toward the intended learning outcomes, helping them focus on the upcoming topics. The Strategic phase, considered the core of the learning process, involved the eight stages of MADI Investigation Process; : (1) Identification of the Task and Research Question, (2) Designing the Investigation and Collect and Analyze Data, (3) Develop a Tentative Argument through the use of CER framework, (4) Argumentation Session, (5) Write an Investigation Report, (6) Double Blind Group Peer Review, (7) Editing and Reflection and (8) Revises and Submits the Final Investigation Report. This process enabled students to actively construct, justify, and refine scientific explanations while developing higher-order thinking skills. The Reflective phase further strengthened learning by encouraging students to evaluate their understanding and apply scientific concepts in real-world contexts.

These findings are supported by Dignath & Veenman (2021), who found that metacognitive instruction embedded in inquiry-based learning improves reasoning and argumentation across different learner profiles. Their work suggests that structured metacognitive scaffolding can reduce differences in prior cognitive ability by promoting planning, monitoring, and self-evaluation. Consistent with this, the results of this study indicate that the MADI strategy helped equalize students' performance across cognitive levels, highlighting that instructional design and learning experiences play a stronger role in developing scientific argumentation skills than initial cognitive classification.

5. Conclusions

Based on the findings, the study concluded that generally there is no significant correlation between students' cognitive levels and their scientific argumentative skills, except for three dimensions: prestructural/unistructural with critical thinking, multistructural with critical thinking, and relational with problem-solving. Thus, the null hypothesis posited is partially sustained. Additionally, there is no significant difference in scientific argumentative skills among Grade 10 students when grouped by cognitive level across all five dimensions: critical thinking, creative thinking, problem-solving, evidence evaluation, and logical reasoning. This indicates that students performed comparably regardless of their cognitive standing. Therefore, the null hypothesis is sustained.

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