

ARGUMENTATION-BASED INQUIRY IN POST-PANDEMIC SCIENCE EDUCATION: EFFECTS ON SCIENCE LEARNING COMPETENCE, MOTIVATION, AND ACADEMIC ACHIEVEMENT

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Abstract

The emerging educational challenges following the Covid-19 pandemic have highlighted the need for teaching methods that actively engage students in scientific inquiry and support meaningful learning. Although Argumentation-Based Inquiry (ABI) has shown promise in science education, evidence regarding its effectiveness in addressing post pandemic learning needs remains limited. This study aimed to examine the effects of the ABI teaching in a seventh-grade science course on students' science learning competence, motivation toward science, and academic achievement. The study followed a quasi-experimental pre-test-post-test control group design. The participants were 44 seventh-grade lower secondary school students assigned to experimental and control groups. Data were collected using 'Competence Scale for Learning Science', 'Motivation Scale in Science Education' and 'Interaction of Light with Matter Academic Achievement Test'. The data were analysed using parametric and non-parametric statistical methods. The findings revealed that students in the ABI group showed significant within-group improvements in science learning competence, motivation, and academic achievement from pre-test to post-test. ANCOVA results, after controlling for pre-test scores, showed a significant group effect on academic achievement and the communication dimension of science learning competence. Neither gender nor number of siblings was associated with significant factors. Correlation analyses showed significant positive relationships between science learning competence and both motivation and academic achievement, whereas motivation and academic achievement were not significantly correlated. The findings suggest that ABI has the potential to support students' science learning processes, particularly scientific communication and academic achievement; however, further research with larger samples is needed to confirm its broader effects.

Keywords: post pandemic, argumentation-based inquiry, science learning competence, motivation toward science education, academic achievement

Introduction

The ongoing global COVID-19 pandemic has had a considerable impact on daily life and has resulted in substantial changes to educational processes. During this period, online learning environments have emerged as a rapid solution for sustaining learning activities. Nevertheless, these arrangements have engendered a variety of challenges for all education stakeholders. According to the findings of Winburn (2024), students demonstrated an inadequate level of academic progress during the period of the pandemic, exhibiting substantial learning losses. A systematic review by Cruz et al. (2025) encompassing 57 studies in 38 countries demonstrated that each year of school closure corresponds to approximately 1.1 years of learning loss. While the reopening of schools led to some improvements, it was observed that learning loss persisted (Cruz et al., 2025).

The lack of motivation observed in students during the pandemic has been considered a significant risk factor increasing learning losses (Baz, 2021). Student motivation in the learning process is one of the fundamental variables that directly affect learning performance (Schunk, 1991). Motivation is considered a key factor in science learning because it encourages students to achieve learning goals (Nacaroglu et al., 2025). Higher levels of intrinsic motivation are associated with better academic achievement (Mallick, et al., 2017). In contrast, low motivation may hinder learning and reduce academic success (Balayo & Plaza, 2025). Furthermore, motivation has been demonstrated to affect not only academic achievement (OECD, 2017) but also the acquisition of science learning competence (Eymirlioğlu, 2019; Nacaroglu et al., 2025).

Science learning competence, comprising scientific inquiry and communication, is regarded as a core aspect of scientific literacy (Chang et al., 2011). However, studies conducted under pandemic conditions demonstrate that students encounter challenges in their communication and interaction processes over time (Macias et al., 2022). Positioning argumentation as a fundamental aspect in the design of inquiry-based learning environments helps students address conceptual and epistemological goals concurrently (Ünal Çoban, 2013). The Argumentation-Based Inquiry (ABI) approach is a distinctive pedagogical strategy that enables students to proactively construct and evaluate scientific knowledge. Scientific argumentation emphasises that students present their claims based on data and evidence (Erduran, 2007). Studies have shown that ABI supports students in developing scientific explanations for natural phenomena (Aydeniz et al., 2012; Erduran, 2007). Although argumentation-based inquiry has been widely studied in science education, limited research has simultaneously investigated its impact on students' science learning competence, motivation, and academic achievement in post-pandemic middle school settings.

Further research is needed to clarify what influences students' motivation following the COVID-19 pandemic (Balayo & Plaza, 2025). Reducing learning losses and identifying teaching approaches to compensate for these losses is important. Previous research has provided limited evidence on the effects of ABI on seventh-grade students' learning in the light unit (Demirel, 2021). In this context, given that the production process of scientific knowledge involves activities such as opinion, data, hypothesis, and evaluation, it is essential to foster students' scientific learning competence, academic achievement, and science learning motivation in a comprehensive manner. Additionally, it has been posited that research on students' complex psychological motivation processes is inadequate in the post-pandemic period (Winburn, 2024).

Literature Review

Science Learning Competence

Scientific inquiry involves examining the natural world through evidence-based processes and developing explanations about observed phenomena (Bybee, 2006). When used as a teaching method, it encompasses activities in which students learn scientific information and develop an understanding of how this scientific information is obtained (NRC, 1996). When students participate in an inquiry-based learning environment, they tend to acquire scientific concepts, learn scientific methods, understand the nature of science, develop the skills necessary to become an independent researcher, and demonstrate scientific abilities and attitudes (NRC, 1996). Scientific literacy consists of three dimensions: (1) content knowledge (scientific concepts), (2) the nature of science, and (3) scientific inquiry (Akerson et al., 2023). To enable students to become scientifically literate individuals, they need to develop scientific competencies such as problem identification, scientific research, data collection, product design, analysis, and interpretation (Chang et al., 2011).

Chang et al. (2011) defined scientific learning competencies as two subscales: inquiry competencies and communication competencies. Inquiry competencies include asking questions and proposing hypotheses, planning, data collection and experimentation, and data analysis and interpretation. Self-expression, evaluation, interaction, and negotiation are communication competencies. Communication competencies are among the important achievements in science education. It is recommended that science classrooms be created where students can express themselves comfortably, where their opinions and interpretations are valued, and where they can apply their argumentation skills (Özdem Yılmaz et al., 2017). For example, reading, writing, engaging in scientific discussions, and exchanging ideas require students to use their communication competences. Argumentation-based science teaching, a student-centred approach recommended by the curriculum, is an effective method for creating such a learning environment. However, current research has largely focused on outcome variables, providing limited information on how argumentation-based teaching is reflected in different teaching contexts and student profiles. This gap highlights the need for experimental research examining how argumentation-based learning environments foster the development of science learning competencies. Studies like these are important for both strengthening the theoretical basis of argumentation-based science education and guiding the design of experimental teaching methods.

Motivation in Science Learning

Motivation plays an important role in learning by directing students' efforts toward achieving specific goals (Zimmerman & Schunk, 2012). It influences learners' willingness to participate, persist, and engage in learning activities (Schunk, 1991). In science education, motivation encourages students to take an active role in learning, ask questions, and participate in inquiry-based activities. Both cognitive and affective/social factors are effective in the learning and retention of information (Ozsoy-Gunes et al., 2024). Students with higher motivation are more likely to participate actively in learning activities, persist in their efforts, and regulate their learning. Especially in science education, where abstract and complex concepts are present, motivation supports students' willingness to exert mental effort and persevere in challenging learning tasks.

In the science curriculum, more emphasis should be placed on motivation to ensure the holistic development of cognitive, affective, and psychomotor skills (Eymirlioğlu, 2019). Ulusoy (2007) stated that motivation is effective in learning domains, and Zimmerman (2000) stated that individuals with high motivation are ready to learn. Motivation toward science education is a variable structure; it is affected by the characteristics of teachers and students, the learning environment, and the methods and techniques used. Therefore, the reasons that reduce motivation should be identified and taken into consideration by teachers (Uzun & Keleş, 2010). Accordingly, teaching methods that support active participation, inquiry, and scientific process skills have been shown to contribute to positive attitudes toward science (Ünal Çoban, 2013). However, despite the widespread recognition of motivation as a significant emotional component of science learning, limited attention has been paid to how specific teaching methods, particularly argumentation-based learning environments, regularly influence students' motivational processes. Theoretically, this highlights the need for well-designed experimental research examining the role of argumentation-based teaching in enhancing students' motivation in science learning. Investigating how argumentation supports motivational elements such as engagement, perseverance, and interest is required to strengthen the theoretical foundation of motivation-centred teaching design in science education.

Academic Achievement in Science Education

Academic achievement in science education is a broad construct encompassing students' depth of understanding of concepts and their scientific reasoning abilities. Therefore, success in science education is not merely a measure of achievement, but a result of students' intellectual engagement, science learning competencies, and motivation (Eymirlioğlu, 2019). Science learning competence supports students' ability to regulate their learning, while motivation promotes continued engagement in scientific activities (Nacaroglu et al., 2025). Academic achievement is shaped by cognitive and affective factors. Post-pandemic learning losses, reduced participation, and educational inequalities have increased the need for effective approaches to support science achievement (Aydın Ceran & Ergül, 2022). The decline in student performance and motivation reported prior to the pandemic (Bathgate et al., 2015) has become more pronounced again during the pandemic, underscoring the need for teaching approaches that encourage the structuring of science content through meaningful interactions and active student participation. Argumentation-Based Inquiry (ABI) supports students in developing conceptual understanding and recognising how scientific knowledge is constructed, thereby contributing to scientific literacy (Özdem Yılmaz et al., 2017). However, studies that holistically examine academic achievement in an experimental setting for middle school students in conjunction with science learning competence and motivation are limited after the pandemic.

Argumentation-Based Science Learning

Argumentation plays an important role in scientific practice and science education (Simon et al., 2006). Current science education standards (NGSS, 2013; NRC, 2012) emphasise students' development and evaluation of scientific explanations as central elements of science learning. Argumentation is defined as supporting claims with data, warrants, and justifications (Toulmin, 1958). In science education, argumentation refers to scientific discourse in which claims are critically examined and validated through evidence-based thinking (Jiménez-Aleixandre & Erduran, 2007). From this perspective, argumentation enables students to construct scientific knowledge by thinking, evaluating counterarguments, and persuading based on evidence. Research shows that argumentation supports reasoning skills by encouraging students to think critically, use evidence, and justify their ideas like scientists (Hasançebi, 2014). To foster deeper learning and scientific literacy, structured scientific discussions give students the chance to express, review, and expand their conceptual understanding (Erduran & Jimenez-Aleixandre, 2007).

ABI integrates inquiry and argumentation by encouraging students to ask questions, develop claims, and justify their ideas through discussion and reflection (Yoon et al., 2025). This approach is consistent with science education standards that emphasise inquiry, evidence-based reasoning, and scientific communication as essential components of scientific literacy (NRC, 2012). Previous studies have reported that ABI supports higher-order thinking, scientific inquiry, and argumentation skills (Choi et al., 2010). In these learning environments, teachers guide the learning process while students actively construct, discuss, and evaluate scientific ideas.

Previous research has mainly examined the effects of argumentation-based teaching on outcomes such as achievement, attitudes toward science, scientific process skills, critical thinking, and conceptual understanding (Aydeniz et al., 2012). However, most of this research has concentrated on outcome variables, paying little attention to how argumentation-based teaching functions in various student characteristics and teaching contexts. From a theoretical perspective, this gap emphasises the need for additional empirical studies grounded in argumentation theory to gain a deeper understanding of how argumentation-based learning settings foster students' scientific and intellectual growth.

Research Aim and Research Questions

Argumentation has gained increasing attention in science education research, with growing literature examining its effects on conceptual learning, academic achievement, discussion skills, attitudes, scientific process skills, and motivation (Bahcivan et al., 2025). However, research on motivation remains comparatively limited (Aydoğdu, 2017). The COVID-19 pandemic has further been shown to adversely affect students' academic motivation and achievement (Suarsi & Wibawa, 2021), underscoring the need to further investigate middle school students' science motivation in the post-pandemic period (Güzel, 2021).

Studies in the literature indicate that gender is commonly addressed as a variable (Danielsson et al., 2023), as potential cognitive and affective differences between female and male students may significantly influence the interpretation of learning process outcomes and experimental intervention effects (Tomassini, 2021). In the post-pandemic period, evaluating the gender variable is also important in assessing science learning competence, learning losses, and motivation. In contrast, it can be said that the number of siblings variable is addressed more limitedly. While the number of siblings variable has a place in psychology studies (Rodgers et al., 2000), it is a variable that is addressed more limitedly in educational research. Sibling relationships, however, can represent one of the most enduring connections an individual maintains over a lifetime (Dunn, 2014), influencing cognitive, social, and emotional development throughout the siblings' lives (Dunn, 2014). The lockdowns experienced during the pandemic also increased family interaction, giving siblings more opportunity for verbal exchange and disagreement. According to Cavagnetto (2010), argumentation is a type of communication that facilitates the application and creation of scientific knowledge. The argumentative potential of sibling relationships is in line with the framework of argumentation studies and should not be ignored in research. As a result, it emphasises the necessity of taking a comprehensive approach to addressing how these factors affect science learning abilities, motivation, and achievement. These variables also intersect with motivation, whose critical role in academic achievement and future career paths leads researchers to stress the need for strategies to enhance or sustain student motivation in the post-pandemic period (Balayo & Plaza, 2025). Accordingly, evaluating the effect of ABI on science learning competencies, motivation, and academic achievement within the framework of demographic variables is considered important. This study examined the effects of ABI on science learning competencies, motivation, and academic achievement among lower-secondary school students, considering gender and number of siblings, and addressed the following research questions:

1. Does argumentation-based inquiry lead to significant improvements in science learning competence, motivation toward science, and academic achievement compared to regular classroom teaching?
2. Are these improvements affected by gender and number of siblings?
3. What are the relationships between science learning competence, motivation toward science, and academic achievement?

Research Methodology

General Background

To examine the effects of the ABI learning on students' science learning competencies, motivation toward science education, and academic achievement, a quantitative quasi-experimental pre-test post-test design was employed during the "Interaction of Light with Matter" unit. In quasi-experimental designs, the effects of an intervention are examined by creating experimental (EG) and control (CG) groups. To assess the intervention's effect on the

dependent variables and identify causal relationships, pre- and post-intervention measurements were obtained. The ABI approach was implemented with the experimental group (EG). ABI integrates scientific inquiry with argumentation to promote active knowledge construction through evidence-based reasoning. The research compared the outcomes of students receiving ABI-based teaching with those receiving teaching on the regular science curriculum. The CG received the regular science curriculum. Lessons were delivered using the prescribed curriculum and textbook through the regular teaching practices typically utilized in the science classroom without ABI in the 2022-2023 academic year.

Sample

The participants consisted of seventh-grade students attending a public lower-secondary school located in the city centre in the western region of Türkiye. The school served students from the local urban community with the same socioeconomic backgrounds. A purposive convenience sampling strategy was employed. Two intact classes, both taught by the same science teacher, took part in the study, with one class serving as the EG and the other as the CG. The sample consisted of 44 students in total, evenly divided into two groups of 22. The demographic breakdown of the sample by gender is shown in Table 1.

Table 1.
Gender Characteristics of the Participants

Gender	CG (n)	CG (%)	EG (n)	EG (%)	Total (n)	Total (%)
Female	9	40.9	10	45.5	19	43
Male	13	59.1	12	54.5	25	57
Total	22	100	22	100	44	100

The distribution of the number of siblings (sister/brother) among the students is given in Table 2. As shown in Table 2, 45% of the students were only children, 41% had one sibling, and 14% had two or more siblings.

Table 2.
Distribution of Participants by Number of Siblings

Number of siblings	f	%
Only child	20	45
1 sibling	18	41
2 or more siblings	6	14
Total	44	100

Data Collection Tools

Three different tools were used to get the data. The first was the 29-item “Competence Scale for Learning Science” (CSLS), which was first created by Chang et al. (2011) and translated into Turkish by Şenler (2014). Greater perceived proficiency in science learning is reflected in higher scores on this scale. “Competence in Scientific Inquiry” and “Competence in Communication” are the two sub-dimensions of the instrument.

The second tool was the 22-item “Motivation Scale in Science Education” (MSSE), which was first created by Glynn et al. (2011) and translated into Turkish by Işın (2019). Structured as a Likert-type scale, higher scores reflect greater motivation toward science learning. Higher scores on this Likert-type scale indicate a greater desire to understand science. The scale assesses five dimensions of motivation: intrinsic interest, career orientation, self-efficacy, grade orientation, and self-determination.

The third tool was the “Interaction of Light with Matter Academic Achievement Test” (ILMAAT), developed by Demirel (2021), consisting of 25 multiple-choice items. The test had an average discrimination value of .50 and an average difficulty index of .662.

Data Collection Process

Ethical approval was obtained from the Scientific Research Ethics Committee of Çanakkale Onsekiz Mart University (Approval Date: 29.12.2022, Decision No: 23/06) prior to the start of data collection, along with the necessary research permission from the Turkish Ministry of National Education. The study was carried out over a seven-week period during the second semester of the 2022 - 2023 academic year, conducted by the first author, who is a science teacher. During this period, pandemic conditions had returned to normal, and students continued to wear masks only when necessary. This research was implemented as part of the 7th-grade “Interaction of Light with Matter” unit, in accordance with the 2018 Science curriculum. Lessons were conducted in two consecutive 40-minute sessions, totalling four hours per week. Both study groups were administered the CSLS, MSSE, and ILMAAT tests in the first and seventh weeks of the study. Ten lesson plans were developed for EG, aligned with the ABI approach. The activities were structured to foster discussion and active engagement through questions relevant to students’ daily experiences. Within these discussions, students were guided to construct claims drawing on their own knowledge and experience, supporting them with sufficient evidence. The design of the argumentation activities was prepared by drawing on previous studies (Demirel, 2021; Hasançebi, 2014). The lesson plans were reviewed by two science education experts and an experienced science teacher, and necessary corrections were made based on their feedback. Before starting the intervention process, a preliminary activity introducing the EG and ABI processes was conducted. The “Mystery Event” scenario (Hasançebi, 2014) was used to introduce students to argumentation practices. In this activity, students assumed the role of detectives by collecting clues, developing hypotheses, and discussing their reasoning with their peers. Through this process, they understood the relationship between questions, claims, and evidence, and successfully learned by developing basic argumentation skills.

Based on the students’ preferences, four heterogeneous groups of five to six students each were formed in the EG. Although students worked collaboratively during discussions, each student individually completed the ABI Form to structure their argumentation processes and support their reflected writing (Sections of the Form: My Question; My Initial Thoughts; Experiments I Conducted to Answer My Question; My Findings; My Claims; My Evidence; How Do My Ideas Compare to Others; How Have My Views Changed?). Students were allowed to use textbooks and other available resources in the argumentation process. The teacher guided the discussions and asked thought-provoking questions to spark curiosity and encourage students to freely express their ideas. Processes such as formulating research questions, building claims, gathering evidence, and evaluating alternative perspectives were carried out collaboratively within groups. The weekly practice schedule for both groups is presented in Table 3.

Table 3.

Comparison of Educational Procedures Implemented in the Experimental and Control Groups

Week	Experimental Group	Control Group
1. Week	Introduction to the ABI Process and Pre-Tests; Mystery Event Activity/ Parental Consent Form/MSSE - CSLS - ILMAAT	Pre-Tests / Parental Consent Form MSSE-CSLS-ILMAAT
2. Week	Light Absorption and White Light Colour Wheel ABI Activity, Worksheets/ ABI Form	Light Absorption and White Light Colour Wheel taught following the regular Turkish Science Curriculum through teacher explanation, textbook activities, question–answer, and curriculum-recommended experiments.
3. Week	Light Absorption and Reflection ABI Activity Worksheets/ ABI Form	Light Absorption and Reflection taught following the regular Turkish Science Curriculum through teacher explanation, textbook activities, question–answer, and curriculum-recommended experiments.
4. Week	Image Formation in Mirrors (Plane, Concave, Convex) ABI Activity, Worksheets/ ABI Form	Image Formation in Mirrors (Plane, Concave, Convex) taught following the regular Turkish Science Curriculum through teacher explanation, textbook activities, question–answer, and curriculum-recommended experiments.
5. Week	Refraction of Light ABI Activity Worksheets/ ABI Form	Refraction of Light taught following the regular Turkish Science Curriculum through teacher explanation, textbook activities, question–answer, and curriculum-recommended experiments.
6. Week	Applications of Thin and Thick-Edged Lenses ABI Activity, Worksheets/ ABI Form	Applications of Thin and Thick-Edged Lenses taught following the regular Turkish Science Curriculum through teacher explanation, textbook activities, question–answer, and curriculum-recommended experiments.
7. Week	Conducting Post Tests MSSE - CSLS - ILMAAT	Post-Tests MSSE-CSLS-ILMAAT

Note. MSSE: Motivation Scale in Science Education, CSLS: Competence Scale for Learning Science', ILMAAT: Interaction of Light with Matter Academic Achievement Test

The two groups differed solely in terms of the teaching approach employed. The EG participated in ABI activities, whereas the CG followed the regular Turkish Science Curriculum. In the CG, lessons were conducted with teacher explanations, textbook and workbook-based activities, question–answer sessions, curriculum-recommended experiments, Educational Information Network (EBA) videos when appropriate, and whole-class discussions using the interactive whiteboard and blackboard.

Data Analysis

Descriptive statistics were calculated for all instruments, and the assumptions of normality and reliability were examined. To assess normality, skewness and kurtosis coefficients were examined alongside the Shapiro–Wilk test. Tabachnick and Fidell (2013) suggested that a normal distribution can be assumed when skewness and kurtosis values fall within the ± 1.5

range. As all values fell within this range and Shapiro–Wilk test results were non-significant ($p > .05$), the data were considered normally distributed. Therefore, parametric statistical analyses were used.

Instrument reliability was assessed via Cronbach's alpha coefficients. The obtained values were within acceptable ranges for research purposes, indicating satisfactory measurement reliability. For the *MSSE*, Işın (2019) reported a reliability coefficient of $\alpha = .83$ for the Turkish adaptation, whereas the present study yielded a slightly lower value of $\alpha = .82$. As for the *CSLS*, the original study reported an overall reliability coefficient of $\alpha = .95$, with sub-dimension coefficients of $\alpha = .90$ for 'inquiry' and $\alpha = .92$ for 'communication'. In this study, the reliability coefficient of the entire scale was determined as $\alpha = .89$, while the sub-dimension coefficients were determined as $\alpha = .76$ for 'inquiry' and $\alpha = .75$ for 'communication'. As for the *ILMAAT*, the original researcher reported a KR-20 reliability coefficient of .74, whereas in this study, the KR-20 value was calculated as .61. Although the KR-20 coefficient (.61) falls below the widely cited .70 threshold, it remains within the range that George and Mallery (2016, p. 240) classify as questionable rather than unacceptable, a classification also reported by Karagöz (2017). Therefore, the academic achievement findings should be interpreted with appropriate caution. Nevertheless, methodological studies have questioned the use of .70 as a universal cutoff for reliability coefficients. Taber (2018), drawing on Schmitt (1996), argues that no single reliability coefficient can be considered universally acceptable and that instruments with relatively low reliability may still be appropriate depending on their intended purpose. This consideration is particularly relevant for achievement tests assessing multiple related but distinct concepts, for which lower reliability coefficients are not uncommon (Berger & Hänze, 2015).

Following assumption checks, appropriate statistical tests were selected. Pre-test and post-test scores were compared between the EG and CG using independent samples *t*-tests. Post-test differences were further examined using one-way ANCOVA, with pre-test scores as covariates. Paired samples *t*-tests were conducted to evaluate within-group changes. Effect sizes were calculated using Cohen's *d* and interpreted according to Cohen's (1988) guidelines (.20 = small, .50 = moderate, .80 or higher = large) (Gravetter & Wallnau, 2007, p.257).

Gender was analysed using Mann - Whitney U test, whereas the Kruskal - Wallis test was applied to the number of siblings (Gravetter & Wallnau, 2007). Because subgroup sizes were below 20 participants and normality assumptions were not satisfied for several subgroups, the assumption was met for all ANCOVA analyses. While the *CSLS* scores did not meet the homogeneity of error variances assumption, this issue was considered minor given the equal sample sizes across groups ($n = 22$), as ANCOVA remains robust to moderate violations under such balanced conditions. Therefore, ANCOVA was retained to examine post-test differences while controlling for pre-test scores. Additionally, Pearson's correlation analysis was carried out to investigate the relationships among the post-test scores obtained from the *MSSE*, *CSLS*, and *ILMAAT*.

Research Results

Comparison of the EG and CG in Science Learning Competence

Within group changes in science learning competence were analysed using paired samples *t*-tests. The findings are presented in Table 4.

Table 4

*Results of the Paired-Samples *t* Test for the CG and EG in Science Learning Competence*

Test	Group	<i>n</i>	<i>M</i>	<i>SD</i>	<i>t</i> (21)	<i>p</i> (2-tailed)
Pre-Test	CG	22	3.62	0.36	3.83	< .001*
Post Test		22	3.09	0.58		
Pre-Test	EG	22	3.57	0.64	-6.55	< .001*
Post Test		22	4.44	0.14		

Note. CG = control group; EG = experimental group. **p* < .05

Paired-samples *t*-tests showed significant within-group changes in science learning competence. Scores in the CG decreased from pre-test to post-test ($t(21) = 3.83, p < .001$), whereas those in the EG increased over the same period ($t(21) = -6.55, p < .001$). These findings indicate that students who participated in the ABI teaching showed improvement in science learning competence, whereas the CG did not demonstrate a similar pattern of change.

The post-test differences were examined using ANCOVA (Table 5).

Table 5

Analysis of Covariance Results for Science Learning Competence Scores

Source	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Total CSLS	2.54	1.40	.119	.060
Inquiry	2.35	1.40	.113	.055
Communication	4.77	1.40	.035*	.107

Note. Pre-test scores were entered as covariates in all analyses.

As shown in Table 5, after controlling for pre-test scores, the effect of group on the total CSLS score was not statistically significant, $F(1,40) = 2.54, p = .119, \eta^2 = .060$. Although the EG had a higher adjusted post-test mean ($M = 4.44$) than the CG ($M = 3.09$), this difference was not statistically significant.

Similarly, no significant group effect was found for the inquiry dimension, $F(1,40) = 2.35, p = .113, \eta^2 = .055$, despite the higher adjusted mean of the EG ($M = 4.47$) compared to the CG ($M = 3.09$).

In contrast, a statistically significant group effect was found for the communication dimension, $F(1,40) = 4.77, p = .035, \eta^2 = .107$. After controlling for pre-test scores, the EG obtained a higher adjusted post-test mean ($M = 4.42$) than the CG ($M = 3.07$), indicating that the ABI approach was associated with higher communication scores.

Comparison of the EG and CG in Motivation Toward Science

Within-group changes in motivation toward science were evaluated using paired-samples *t*-tests (Table 6).

Table 6
Paired-Samples t Test of the CG and EG in Motivation Toward Science

Test	Group	n	M	SD	$t(21)$	p	Cohen's d
Pre-Test	CG	22	3.71	0.38	1.92	.068	0.41
Post-Test		22	3.50	0.49			
Pre-Test	EG	22	3.66	0.51	-3.76	.001*	-0.80
Post-Test		22	4.09	0.33			

Note. CG = Control Group; EG = Experimental Group. Cohen's d was used to estimate effect size. * $p < .05$

Motivation remained unchanged in the CG ($p = .068$, $d = 0.41$) but increased significantly in the EG ($p = .001$, $d = 0.80$, large effect). Thus, a within-group increase was observed only in the EG.

Post-test motivation scores were further compared using ANCOVA, with pre-test scores entered as covariates (Table 7).

Table 7
Analysis of Covariance Results for Motivation Toward Science Scores

Source	F	df	p	ηp^2
Total Motivation	2.36	1.40	.132	.056
Intrinsic motivation	2.34	1.40	.134	.055
Career motivation	1.00	1.40	.322	.024
Self-efficacy motivation	1.87	1.40	.179	.045
Grade motivation	0.03	1.40	.857	.001
Self-determination motivation	1.63	1.40	.208	.039

Note. Pre-test scores were entered as covariates in all analyses.

As shown in Table 7, after controlling for pre-test motivation scores, the group effect was not statistically significant for total motivation or any of its sub-dimensions (all $p > .05$). Despite the EG's adjusted mean scores being higher than those of the CG in all dimensions, the differences were not statistically significant.

Pre-Test and Post-Test Scores of the EG and CG in Academic Achievement

A paired-samples t -test was conducted to examine the change in academic achievement (ILMAAT) scores within the CG and EG (Table 8).

Table 8
Paired-Samples t Test Results for ILMAAT Scores

Test	Group	<i>n</i>	<i>M</i>	<i>SD</i>	<i>t</i> (21)	<i>p</i>	<i>Cohen's d</i>
Pre-Test	CG	22	7.23	1.51	-9.36	< .001*	-1.995
Post-Test		22	14.14	3.68			
Pre-Test	EG	22	7.55	2.38	-11.84	< .001*	-2.523
Post-Test		22	17.96	4.38			

Note. CG = Control Group; EG = Experimental Group. * $p < .05$

Paired-samples t-tests showed increases in ILMAAT scores in both groups. The CG achieved higher post-test scores than pre-test scores ($p < .001$, $d = 2.00$). Similarly, the EG showed a significant increase over the same period ($p < .001$, $d = 2.52$).

Independent-Samples t-Test Results for Academic Achievement (ILMAAT)

Independent-samples t-tests were used to compare the academic achievement scores of the EG and CG, as given in Table 9.

Table 9
Independent-Samples t Test Results by ILMAAT

Test	Group	<i>n</i>	<i>M</i>	<i>SD</i>	<i>t</i> (42)	<i>p</i>	<i>Cohen's d</i>
Pre-Test	CG	22	7.23	1.51	-0.53	.600	-.159
	EG	22	7.55	2.39			
Post-Test	CG	22	14.14	3.68	-3.13	.003*	-.944
	EG	22	17.96	4.38			

Note. CG = Control Group; EG = Experimental Group. * $p < .05$

No significant difference was found between groups at pre-test ($p = .600$), indicating comparable baseline achievement ($d = -0.16$). At post-test, however, the EG achieved significantly higher scores than the CG, corresponding to a large effect size ($d = -0.94$).

Post-test academic achievement was further examined using ANCOVA, with pre-test scores entered as covariates (Table 10).

Table 10
Analysis of Covariance Results for ILMAAT

Source	<i>F</i>	<i>df</i>	<i>p</i>	ηp^2
Group	9.64	1.41	.003*	.190

Note. Pre-test academic achievement scores were entered as the covariate. * $p < .05$.

After adjusting for pre-test academic achievement scores, the effect of group on post-test academic achievement proved statistically significant, $F(1,41) = 9.64$, $p = .003$, $\eta p^2 = .190$. The EG's adjusted post-test mean score ($M = 17.84$) was higher than that of the CG ($M = 14.25$), suggesting that students who received ABI teaching demonstrated significantly greater academic achievement compared to those taught through the regular science curriculum.

Gender Differences in Science Learning Competence, Motivation and Academic Achievement

A Mann-Whitney U test was performed to determine whether students' pre-test and post-test scores on the CSLS, MSSE, and academic achievement measures differed by gender within the EG and CG. Results are presented in Table 11.

Table 11
CSLS Mann-Whitney U Test by Gender

	Group	Test	Gender	<i>n</i>	<i>M</i>	Sum of Ranks	<i>U</i>	<i>p</i>
CSLS	CG	Pre-Test	Female	9	12.72	114.50	47.500	.462
			Male	13	10.65	138.50		
		Post-Test	Female	9	15.50	112.50	49.500	.556
			Male	13	10.81	140.50		
	EG	Pre-Test	Female	10	14.25	142.50	32.500	.070
			Male	12	9.21	110.50		
MSSE	CG	Pre-Test	Female	9	12.78	115.00	47.000	.441
			Male	13	10.62	138.00		
		Post-Test	Female	9	12.44	112.00	50.000	.568
			Male	13	10.85	141.00		
	EG	Pre-Test	Female	10	11.10	111.00	56.000	.792
			Male	12	11.83	142.00		
ILMAAT	CG	Pre-Test	Female	9	11.61	104.50	57.500	.948
			Male	13	11.42	148.50		
		Post-Test	Female	9	11.72	105.50	56.500	.896
			Male	13	11.35	147.50		
	EG	Pre-Test	Female	10	14.55	145.50	29.500	.038*
			Male	12	8.96	107.50		
		Post-Test	Female	10	12.25	122.50	52.500	.620
			Male	12	10.88	130.50		

Note. CG = control group; EG = experimental group. * $p < .05$

According to the results in Table 11, no significant gender differences were observed in CSLS and MSSE scores at pre-test or post-test, in either the CG or the EG. These findings

indicate that students' science learning competence and motivation did not significantly differ by gender in either group before or after the intervention.

As shown in Table 11, no gender-based difference was found in the CG's ILMAAT scores at pre-test or post-test. In the EG, a significant gender difference appeared at pre-test but not at post-test. Due to this pre-test difference, a non-parametric ANCOVA was conducted (Table 12).

Table 12

Non-Parametric ANCOVA Test Results for ILMAAT by Gender

Source	SS	df	M	F	p
Corrected Model	9.505	1	9.505	0.301	.586
Intercept	0.177	1	0.177	0.006	.941
Gender	9.505	1	9.505	0.301	.586
Error	1327.85	42	31.615		
Total	1337.35	44			

The final academic achievement scores of CG and EG students did not differ significantly by gender.

*Number of Siblings Differences in Science Learning Competence,
Motivation and Academic Achievement*

A Kruskal–Wallis test was conducted to determine whether CSLS, MSSE, and ILMAAT scores varied according to the number of siblings; results are presented in Table 13.

Table 13
CSLS Kruskal Wallis Test Results by Number of Siblings

	Group	Test	Number of Siblings	<i>n</i>	<i>M</i>	χ^2	<i>p</i>
CSLS	CG	Pre-Test	Only child	4	10.63	3.141	.208
			1 sibling	13	10.04		
			2 or more siblings	5	16.00		
		Post-Test	Only child	4	10.25	4.840	.089
			1 sibling	13	9.73		
			2 or more siblings	5	17.10		
	EG	Pre-Test	Only child	16	10.69	2.666	.264
			1 sibling	5	12.10		
			2 or more siblings	1	21.50		
		Post-Test	Only child	16	12.28	1.200	.549
			1 sibling	5	10.10		
			2 or more siblings	1	6.00		
MSSE	CG	Pre-Test	Only child	3	14.00	1.425	.490
			1 sibling	13	10.15		
			2 or more siblings	5	13.00		
		Post-Test	Only child	4	12.50	0.122	.941
			1 sibling	13	11.35		
			2 or more siblings	5	11.10		
	EG	Pre-Test	Only child	16	10.97	0.665	.717
			1 sibling	5	12.30		
			2 or more siblings	1	16.00		
		Post-Test	Only child	16	12.06	0.471	.790
			1 sibling	5	9.80		
			2 or more siblings	1	11.00		
ILMAAT	CG	Pre-Test	Only child	4	4.63	8.191	.017*
			1 sibling	13	11.58		
			2 or more siblings	5	16.80		
		Post-Test	Only child	4	11.38	1.279	.527
			1 sibling	13	10.46		
			2 or more siblings	5	14.30		
	EG	Pre-Test	Only child	16	12.28	1.193	.551
			1 sibling	5	8.80		
			2 or more siblings	1	12.50		
		Post-Test	Only child	16	11.13	0.261	.877
			1 sibling	5	12.80		
			2 or more siblings	1	11.00		

* $p < .05$

As presented in Table 13, the analysis did not reveal significant differences in CSLS and MSSE pre-test or post-test scores based on the number of siblings in either the CG or EG (p

> .05). Accordingly, students' science learning competence and students' motivation did not significantly vary according to the number of siblings in either group at either measurement point.

As indicated in Table 13, a significant difference emerged within the control group (CG) at the pre-test stage ($p < .05$). Mean rank values show that students with two or more siblings achieved higher pre-test academic achievement scores than only children. Post-test scores did not differ significantly ($p > .05$), suggesting that the initial difference disappeared after teaching. In the EG, academic achievement did not vary by number of siblings at either pre-test or post-test, indicating that sibling number was unrelated to achievement under the experimental condition.

Relationship Between Science Learning Competence, Motivation Toward Science Education, and Academic Achievement

The relationships among students' science learning competence, motivation toward science education, and academic achievement were examined using Pearson correlation analysis, with results reported in Table 14.

Table 14
Correlation Between Science Learning Competence, Motivation, and Academic Achievement

	1	2	3
1. CSLS	-		
2. MSSE	.468**	-	
3. ILMAAT	.470	.177	-

Note. $n = 44$. Pearson correlation coefficients are reported. $p < .01$.

Results of the Pearson correlation analysis showed a significant positive association between science learning competence and motivation toward science education, $r = .468$, $p = .001$. Similarly, science learning competence was positively and significantly correlated with academic achievement, $r = .470$, $p = .001$. These findings indicate that students with higher levels of science learning competence tended to report higher motivation toward science education and achieve higher academic performance. However, the relationship between motivation toward science education and academic achievement was not statistically significant, $r = .177$, $p = .250$.

Discussion

This study examined the effects of ABI-based teaching on science learning competence (CSLS), motivation toward science education (MSSE), and academic achievement (ILMAAT), as well as the roles of gender and number of siblings in these variables.

Science Learning Competence

Science learning competencies are fundamental skills that students, as future scientists, are expected to develop (Kanyonga et al., 2024). These competencies enable students to generate scientific knowledge and develop evidence-based solutions to problems. In addition, they foster abilities such as analysis, interpretation, evaluation, and reasoning (Kanyonga et al., 2024). Prior to the intervention, no statistically significant difference was observed between the EG and

CG in the present study. Although independent post-test comparisons showed higher science learning competence scores in the EG, ANCOVA indicated that this difference was no longer statistically significant after controlling for pre-test performance. The paired-samples analyses indicated that students in the EG improved their science learning competencies from pre-test to post-test. The observed improvement in the EG suggests that ABI may have supported students' engagement in scientific discussion, experimentation, data collection, and analysis. Although the adjusted overall CSLS scored did not differ significantly between groups after controlling pre-test performance, a significant advantage was observed for the communication dimension, suggesting that ABI particularly supported students' scientific communication skills. This finding should be interpreted cautiously, because the relatively small sample may have reduced statistical power. Although the ANCOVA results were not statistically significant, the effect size for the total CSLS score and the inquiry dimension were in the medium range (Cohen, 1988). This pattern suggests that the lack of statistical significance may be related to limited statistical power rather than absence of an educational effect, a limitation also reported in ABI studies with small samples (Koçoğlu & Kanadlı, 2024). The stronger effect observed for the communication dimension is consistent with the CSLS framework, which treats inquiry and communication as related but distinct competencies (Chang et al., 2011). It is also compatible with the view that argumentation is inherently a discursive practice (Osborne, 2010), which may explain why communication skills improved more readily than broader inquiry skills.

An unexpected finding was the significant decline in science learning competence scores within the CG. Although this study was not designed to determine the underlying causes, several factors may account for this outcome. Students in the control group followed regular curriculum teaching without structured opportunities for scientific discussion, argumentation, or evidence-based reasoning, which may explain why they did not develop these competencies to the same extent as the ABI group. Post-pandemic learning adjustment (Gajderowicz et al., 2026; Cruz et al., 2025; Aydın Ceran & Ergül, 2022) and differences in student engagement (Macias et al., 2022) may have also contributed. As these possibilities were not directly tested, they should be interpreted with caution.

Gender did not produce statistically significant differences in CSLS scores at either the pre-test or post-test. Although female students in the EG obtained higher post-test mean scores than male students, this difference was not statistically significant. Several studies support this finding. For instance, Pekel (2021), and Eymiroğlu (2019) reported no substantial gender-based differences in science learning competencies. However, although several studies have found results favouring female students (Aslan Efe & Özmen Ülük, 2018), there are also studies that have identified outcomes in favour of male students (Kanyonga et al., 2024).

Regarding science learning competence, no statistically significant differences were found between the groups based on the number of siblings. These findings indicate that the number of siblings does not function as a determinant of science learning competencies. Although sibling interaction provides opportunities for language development and conflict resolution through frequent interpersonal exchanges (Rodgers & Fasulo, 2022), the present study suggests that this variable did not influence students' ability to manage the argumentation process.

Motivation Toward Science Education

Before the intervention, the motivation levels of students about science were similar across the groups. Paired-samples analyses revealed that students in the EG showed a significant increase in overall motivation from pre-test to post-test, whereas the CG showed a modest, non-significant decline. However, after controlling for pre-test motivation, the ANCOVA results indicated no statistically significant group differences for overall motivation or any of its sub-dimensions. This finding should be interpreted cautiously, as the relatively small sample may

have reduced statistical power. Although motivation increased in the EG and declined slightly in the CG, the between-group analysis may not have been sufficiently sensitive to detect this difference (Koçoğlu & Kanadlı, 2024). The pattern also differed across the motivational sub-dimensions. Intrinsic motivation and self-efficacy showed a stronger tendency in favour of the EG, whereas grade motivation changed very little. This pattern is consistent with the view that intrinsic motivation and self-efficacy develop through active engagement and mastery experiences (Schunk, 1991; Zimmerman & Schunk, 2012), both of which are supported by ABI. In contrast, grade motivation is more closely related to external assessment practise common to both groups. However, the lack of substantial between-group differences does not necessarily indicate that the two teaching approaches were equally effective. Although motivation scores increased in the EG during the intervention, both pre-test and post-test motivation scores remained lower than those reported before the pandemic (Işın, 2019), suggesting that the effects of pandemic-related disruptions may have persisted. This interpretation is supported by studies showing that changes in learning environments during the pandemic had lasting effects on students' motivation. Lindberg (2025), for example, reported that online learning, social isolation, and mental health challenges reduced intrinsic motivation and weakened students' sense of competence and relatedness, with these effects continuing after the return to face-to-face education. Nevertheless, the evidence is not entirely consistent. Smith et al. (2021) found that most motivational perceptions remained stable during the early stages of the pandemic, with only interest in learning changing significantly. Taken together, these studies indicate that the impact of the pandemic on motivation may vary according to students' developmental stage, the timing of assessment, and the motivational dimension examined. Further research is needed on the long-term effects of the pandemic on motivation in science education.

The within-group improvement in the EG is consistent with earlier research indicating that argumentation-based teaching may improve students' motivation for science (Aydoğdu, 2017). However, the present findings suggest that these gains may not always translate into significant differences compared with the regular science curriculum.

No significant gender-based difference emerged in motivation toward science, consistent with several studies (Kang, 2023) showing that gender does not meaningfully influence science motivation. Other research, however, has found that female students report higher motivation levels (Schumm & Bogner, 2016), suggesting that the gender-motivation relationship may be context-dependent. Likewise, motivation scores did not differ significantly by number of siblings. Onuk (2022) similarly found no significant relationship between the number of siblings and science learning motivation among gifted students, supporting the finding that sibling number did not affect students' motivation levels in the present study.

Academic Achievement

Both the regular science curriculum and the ABI approach improved students' academic achievement. However, after controlling for pre-test performance, the EG achieved significantly higher post-test scores than the CG. This finding suggests that ABI contributed to students' achievement beyond the effects of the regular science curriculum. Through structured argumentation, evidence evaluation, and refutation processes, students may have engaged in a more active thinking process, contributing to a deeper conceptual understanding of the Interaction of Light with Matter. These findings are consistent with previous research demonstrating the impact of argumentation-based teaching on improving academic achievement (Aydoğdu, 2017; Cavagnetto, 2010). This pattern is further corroborated by a recent mixed-research synthesis encompassing 72 quantitative and 22 qualitative studies, which confirmed the consistent positive effect of argumentation-based teaching on student achievement across diverse educational contexts (Koçoğlu & Kanadlı, 2024). Similarly, Kruit et al. (2024)

demonstrated that argumentation-based teaching tools can simultaneously enhance students' content knowledge and argumentation skills, further supporting the effectiveness of the ABI approach observed in the present study.

This improvement is particularly meaningful in the light of the learning losses reported after the COVID-19 pandemic. Using TIMSS 2023 data from 84 education systems, Gajderowicz et al. (2026) found that student achievement in mathematics and science remained 0.11 SD below pre-pandemic trends worldwide, with larger declines in countries that experienced longer school closures. However, studies on argumentation-based teaching have not reported consistent results. Differences across studies may be related to variation in implementation, teaching duration, and classroom context (Koçoğlu & Kanadlı, 2024). The positive findings of the present study may therefore be associated with the structured and curriculum-aligned implementation of ABI.

No significant difference was found between genders in academic achievement. Although female students had higher average grades, the achievements were relatively evenly distributed. Similarly, no significant differences were observed based on the number of siblings. While sibling dynamics have been associated with academic self-efficacy and educational goals (Krejcová et al., 2019), current findings indicate that such background variables did not significantly influence achievement outcomes in this study and other studies (Rodgers et al., 2000). Overall, the findings suggest that integrating argumentation into science teaching can contribute to higher academic achievement and deeper learning.

Relationships Among Variables

The correlation analysis revealed significant positive relationships between science learning competence and both motivation toward science education and academic achievement. Students with higher science learning competence also reported higher motivation toward science education and achieved higher academic achievement. This finding is consistent with previous research indicating a positive association between science learning competencies and science learning motivation (Eymirlioğlu, 2019; Nacaroglu et al., 2025). One possible explanation for this relationship lies in the communication dimension of science learning competence. As originally conceptualized by Chang et al. (2011), it encompasses negotiation and evaluation skills that are theoretically grounded in argumentation-based science learning frameworks (Osborne, 2010). Because the intervention explicitly targeted these skills through structured argumentation, evidence evaluation, and refutation, students who developed stronger communication competencies may also have become more engaged and motivated in science learning. These findings also indicate that science learning competencies, including inquiry, evidence evaluation, and scientific reasoning, are closely related to students' engagement and achievement in science.

However, the relationship between motivation toward science education and academic achievement was not statistically significant. These results indicate that improvements in motivation do not necessarily coincide with higher academic performance. Although motivation is an important component of learning processes, academic achievement may also be influenced by additional factors, such as conceptual understanding, prior knowledge, and learning strategies. A similar pattern has been reported in post-pandemic research. For instance, Smith et al. (2021) found that most motivation-related perceptions among high school students remained largely stable during the early stages of the pandemic, whereas science and mathematics achievement declined internationally (Gajderowicz et al., 2026). Overall, these findings indicated that motivational and cognitive outcomes may develop differently and may respond in the same way to teaching interventions and broader contextual factors.

Conclusions and Implications

The findings of this study suggest that ABI supported seventh-grade students' science learning outcomes in the post-pandemic period. Students in the EG demonstrated significant improvements in science learning competence, motivation toward science education, and academic achievement compared with their pre-test scores. Furthermore, ANCOVA results showed significant between-group effects only for the communication dimension of science learning competence and academic achievement after controlling for pre-test scores. Correlation analyses further indicated that science learning competence was positively associated with both motivation toward science education and academic achievement. However, motivation and academic achievement were not significantly correlated, suggesting that cognitive and affective outcomes may not necessarily develop at the same rate following teaching interventions.

These findings suggest that ABI can be considered a valuable teaching approach for supporting students' active participation in science learning competence, particularly by encouraging scientific communication, evidence-based reasoning, and engagement with scientific ideas. Therefore, science teacher education programmes may provide more opportunities for pre-service and in-service teachers to develop the knowledge and skills required to effectively implement ABI. In addition, curriculum developers may consider incorporating structured argumentation-based inquiry activities into different science units to support students' scientific competencies and learning outcomes.

Several limitations should be considered when interpreting these findings. First, the relatively small sample ($n = 44$) may have reduced statistical power, making it more difficult to detect group differences for some outcome variables. Second, since the intervention was implemented in a specific educational setting and focused on a single science topic, further research with larger, more diverse samples and different content areas is needed. Third, the study examined the immediate effects of ABI, and longitudinal research is required to determine whether improvements in science learning competence, motivation, and academic achievement are sustained over time.

Future research may also investigate how contextual factors, such as classroom environment, teacher expertise, and students' prior experiences, influence the effectiveness of ABI. Overall, this study contributes to the growing body of research demonstrating the potential of ABI as an effective educational approach for enhancing science learning outcomes in post-pandemic science education.

Notes

This article is derived from the M.Sc. thesis entitled "The Effect of Argumentation-Based Science Learning Approach Used in 7th Grade Science Course on Students' Science Learning Competence, Motivation and Achievement", completed by Eda Kara under the supervision of Assoc. Prof. Dr. Seda Çavuş Güngören. Part of the findings of this study was presented at the 3rd Postgraduate Teacher Studies Congress, held on May 9-12, 2024, in Çanakkale, Türkiye, and published as a conference abstract in the conference proceedings.

During the preparation of this manuscript, ChatGPT (OpenAI) and Grammarly AI were used solely for language editing and proofreading. All AI-assisted outputs were reviewed and approved by the authors, who take full responsibility for the final manuscript.

Declaration of Interest

The authors declare no competing interests.

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