

## The Effects of an Argument-Based Inquiry Approach On Improving Critical Thinking and the Conceptual Understanding of Optics among Pre-Service Science Teachers

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### Abstract

The aim of this study was to investigate the effect of the university-level application of an Argument-Based Inquiry Approach, as compared to the traditional laboratory teaching method, on the ability of students to learn about optics and to demonstrate critical thinking. In this quasi-experimental study, pretest-posttest scores and CCDTI were used as data collection tools. The study sample consisted of a total of 44 students receiving lessons in science education and laboratory applications in two separate classes within the Faculty of Education at a small university in the north of Turkey in the school year 2013-2014. While the students in the control group carried out experiments using the traditional laboratory method, the students in the experimental group carried out activities in groups of three to four based on research using the ABI approach. Students in both groups performed seven activities. In the study, we used pretest and posttest results. The Cronbach's alpha reliability coefficient of the test was determined to be 0.71. In addition, the CCDTI scale, adapted into Turkish, was used at the beginning and end of the study in an attempt to determine the change in students' capacity for critical thinking. The findings show that university-level use of the ABI approach provides a statistically significant contribution to students' success in learning optics. Moreover, it was established that the argument-based approach produces significant differences in students' capacity for and tendencies towards critical thinking compared to the traditional method.

**Keywords:** Argument-based inquiry approach, Critical thinking, Science education, Scientific achievement, SWH.

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## Introduction

In a clear statement of the goals of science education, the “American National Science Education Standards” (Collins, 1998) emphasize the need for all students to achieve a series of recognized standards and be scientifically literate (NRC, 1996). With a large range of meanings, “science literacy” can be variously expressed as the attainment of knowledge and the ability to separate the unscientific from the scientific; understanding science and its applications; knowing what is scientifically important; thinking scientifically; using scientific skills in problem-solving; having the knowledge to be able to share relevant information across science-based subjects; understanding the relation of science to culture; knowing the benefits and risks of science, and manifesting critical thinking about science and scientific experiences (Norris & Phillips, 2003). In Turkey, the aim of science education is to produce scientifically literate individuals (Doğan, Çakıroğlu, Bilican & Çavuş, 2009; MNE, 2013). The curriculum for science in primary education institutions in Turkey was revised in 2013 and defines scientifically literate individuals as follows:

Scientifically literate individuals are those who investigate and question, make effective decisions, solve problems, have trust in themselves, are open to cooperation, make effective contact with others, practice lifelong learning with an awareness of sustainable development, have knowledge of, skills relating to, and positive attitudes, perceptions and values regarding the sciences, as well as an understanding of the relationship of the sciences to technology, society and the environment and who also demonstrate [the required] psychomotor skills (MNE, 2013 p.3).

Rather than skills and common applications, science literacy focuses on the structuring of knowledge, the understanding of scientific concepts and the education of individuals who are interested in scientific subjects and discussion (Hand & Prain, 2002). However, it is not possible for students to succeed educationally by simply repeating the scientific facts, laws and knowledge they are expected to learn in classes (Deboer, 2000). With regard to the spreading of science literacy and the inculcation of science literacy in individuals, the use of language has now assumed greater significance and a number of researchers have conducted studies and made suggestions concerning the effective use of language in science education (Alverman 2004; Gee, 2004; Hand *et al.*, 2003; Lemke, 1990; Yore, Bisanz & Hand, 2003). Students are required to understand the importance of language in comprehending science, demonstrate how scientists use linguistic processes in structuring science and understand how scientists are influenced by studies from different researchers. Students should also be given opportunities to improve understanding of all these processes in science lessons (Hand *et al.*, 2003).

Language is the basic instrument for using scientific concepts, communicating information when carrying out scientific activities and for understanding and sharing scientific results (Yore *et al.*, 2003). Language has four basic components: reading, speaking, listening and writing (Eming, 1977). Reading is defined as the act of making sense out of printed or digital text. An individual needs to understand what she/he is reading in order to learn from it. This goal can be attained only if reading is supported by the power of understanding (Ocak, 2004). Another important component of language, speaking, is the communication established between the individual and other people through language, allowing exchange of emotions, thoughts and information (Özbay, 2005). Listening, on the other hand, is the process of paying attention to and evaluating what is being said and/or read aloud in order to understand it. As the primary resources for success in verbal communication, speaking and listening form a whole and provide the basis of educational activities by being used in the exchange of information, explanations, representations and assessments which pass between teacher and student and from student to student in the educational environment (Karadüz, 2010; Özbay, 2005). On the other hand, writing is an epistemological instrument that enables learners to structure their knowledge and develop concepts and which guides them in attaining science literacy (Hand, Prain, Lawrence & Yore, 1999). It is known that the use of writing by students as a means of learning enables them to learn concepts and develop science literacy, understand the cause and effect relations involved in

scientific articles, and also become successful writers, producing their own scientific texts (Hand & Prain, 2002).

The components of language, speaking, listening, reading and writing are also the basic components of the process of advancing an argument, a process which demonstrates an individual's science literacy. Being basically scientifically literate involves the skill of recognizing and refuting an argument even if in only a limited way (Osborne, 2005), but the process of advancing an argument is a linguistic activity involving dialogue where individuals discuss opposing opinions with each other (Chin & Osborne, 2010). Argumentation is important for students as it promotes reflective thinking and the process of reasoning. In the social context, argumentation requires students to pose questions, give explanations, refute them with alternative ideas, and give answers defending their own ideas as well as trying to convince those mounting their own counter-arguments (Chin & Osborne, 2010). Posing questions to students is important as it reveals their prior knowledge and enables them to begin to make and sustain relevant arguments. When the process of argumentation is used as a model, students can use the assertions, data and reasoning from their activities as elements of their own arguments (Osborne, 2005). Connections between these elements determine the level of argument. In this regard, making connections between assertions and evidence, the formulation of evidence-based reasoning and questioning or refuting the soundness of the connections between evidence and assertions are among the most important elements in developing a strong argument (Andrews, 2007). The development of these factors not only improves the quality of arguments, but also enables students to structure their field of information at the conceptual level and to develop their science literacy.

### ***Argumentation in Science Education***

Rather than giving basic calculations showing how the natural world functions or explaining the sum of events, science involves the restructuring of theories that explain how the events have occurred. Considered from this perspective, science comprises the theoretical explanations of events, and these explanations are themselves open to refutation and change (Erduran, Simon & Osborne, 2004). Since scientific research aims both to formulate and justify the procedures carried out to better understand the world, as well as the beliefs and knowledge involved, argumentation has an important place in the research process (Kaya & Kılıç, 2008). The aim of science lessons, however, is for students to understand scientific thinking, develop skills of reasoning, review beliefs about the nature of knowledge and develop their ability to work in cooperation with each other (MNE, 2006). Attention should be paid to argumentation in order to achieve these goals in a better and more balanced way (Osborne, 2005).

Class activities in which discussion is promoted enable students to develop conceptual knowledge, research skills and an understanding of the epistemology of science (Driver et al., 2000). Since scientific knowledge is formulated and developed through the process of hypothesizing and seeking proof, evaluating evidence and then advancing an opposing argument, students need to be given an impetus for discussion and encouraged to make arguments or counter-arguments (Osborne, 2005). Such argumentation enables them to understand both the epistemology of a science and the concept of science itself much better (Osborne, 2005). For this reason, it is important to use science classes to advance arguments that will attain and produce knowledge. One of the approaches enabling arguments to be mounted is the Argumentation Based Inquiry, originally named 'SWH'.

### ***Argument-Based Inquiry***

The ABI approach is a tool that efficiently and meaningfully integrates the components of language into the learning process in science education with the help of contents such as discussion, written expression of thoughts, written and oral reflection, and by comparing effective reading with the knowledge acquired from reading with a personal bias. Language is involved in every phase of the ABI approach in terms of developing activities involving argumentation-based research and inquiry and in supporting learning in an integrated way.

ABI is an approach that aims to enable students to actively conduct research to promote conceptual learning and to effectively use language at every stage both in the laboratory and classroom environments and outside the lesson (Hand & Keys, 1999). This approach enables students to think about scientific concepts, shape their thoughts in a “question-claim-evidence” structure and defend them in written and oral language activities. The ABI approach consists of a framework to guide activities as well as metacognitive support to prompt student reasoning about data (Hand, 2008). ABI furnishes teachers with a template of suggested strategies to enhance learning from activities (see Table 1). As a whole, the activities and metacognitive framework seek to provide authentic, meaning-producing opportunities for learners (Hand, 2008). In learning environments where the approach is applied effectively, the teacher enables students to form questions, design experiments to seek an answer to their questions, make observations and collect data during well-designed experiments, make assertions that may answer their questions at the end of these observations, and express in a written form their reflections about how their opinions have changed during the process. Students not only record the aforementioned process in their ABI reports, but also orally examine every component in small and large group discussions and compare their differing judgments with information obtained from various resources. Hand (2008, p.7) stated that, “*SWH is a pedagogical tool to encourage students to ‘unpack’ scientific meaning and reasoning*”. The ABI is provided in order to promote scientific thinking and reasoning through activities in which learners are able to become aware of the foundations of their knowledge and can then explicitly monitor their own learning. Because the ABI focuses on the forms of scientific thinking, it has the further potential to increase learners’ understanding of the nature of science, enrich their conceptual understanding and engage them further in the theory and practice of science.

**Table 1.** *The templates for the ABI: Teacher template and student template*

The Argument-Based Inquiry, Part I: A template for teacher–designed activities to promote laboratory understanding	The Argument-Based Inquiry, Part II: A template for students
<ol style="list-style-type: none"> <li>1. Exploration of pre-instructional understanding through individual or group concept mapping.</li> <li>2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions.</li> <li>3. Participation in scientific activities.</li> <li>4. Negotiation phase I – writing personal accounts of scientific activity (e.g. writing journals).</li> <li>5. Negotiation phase II – sharing and comparing data interpretations in small groups (e.g. making a group chart).</li> <li>6. Negotiation phase III – comparing scientific ideas to textbooks or other printed resources (e.g. writing group notes in response to focus questions).</li> <li>7. Negotiation phase IV – individual reflection and writing (e.g. creating a presentation such as a poster or report for a larger audience).</li> <li>8. Exploration of post-instructional understanding through concept mapping.</li> </ol>	<ol style="list-style-type: none"> <li>1. Beginning Ideas – What are my questions?</li> <li>2. Tests – What did I do?</li> <li>3. Observations – What did I see?</li> <li>4. Claims – What can I claim?</li> <li>5. Evidence – How do I know? Why am I making these claims?</li> <li>6. Reading – How do my ideas compare with others?</li> <li>7. Reflection – How have my ideas changed?</li> </ol>

In examining the applications of the ABI approach we can conduct evaluations from both the perspective of teachers and students. According to some studies, teachers applying the ABI approach in their classes demonstrate effective teaching that enables them to create an effective learning environment and an increase in the number of applications increases success (in terms of the effect on students) (Günel, 2006; Omar, 2004). Moreover, ABI provides professional development for teachers in enabling them to realize their educational objectives (Williams, 2007). The national and international literature includes studies examining how ABI applications can increase conceptual

understanding (Mohammed, 2007) and science success in students (Greenbowe, Poack, Burke & Hand, 2007; Author *et al.*, 2010; Nam, Choi & Hand, 2011); how ABI is able to produce equal levels of success for students with different initial levels (Akkuş, Günel & Hand, 2007; Kınır, Geban & Günel, 2012); how the application is effective in disadvantaged groups (Yeşildağ-Hasançebi & Günel, 2013); and how students using it develop positive attitudes towards science (Author, 2014). Apart from these positive effects, there has recently been an emphasis on whether or not the ABI approach increases the skill of critical thinking. In this context, there are a very limited number of relevant studies (Taylor, Therrien & Hand, 2012; Chen, Hand & Benus, 2014; Jang, Fostvedt & Hand, 2014).

This study focuses on investigating the effect of the ABI approach on the success of students in learning about optics and developments in their ability to think critically. The research questions guiding this study are as follows:

- 1) Is there a significant mean difference between the groups exposed to the ABI approach and those following a traditionally designed science course with respect to students' knowledge of optics?
- 2) Is there a significant mean difference between the groups exposed to the ABI approach and those following a traditionally designed science course with respect to students' capacity for critical thinking?

## Methods

### Research Design

The present study used a quasi-experimental and pre/post-test design with control and treatment groups to examine whether argumentation activities improved students' conceptual understanding in test questions and in their scores for critical thinking. Researchers randomly selected one class as a treatment group and the other as the control group. The study took place within the context of the subject of 'Optics', taught for 7 weeks in spring 2014. Both treatment and control groups were simultaneously administered the same pre/post-test and CCDTI scale to examine the impact of the argumentation activities.

### Participants

The study sample consisted of 44 third-year students receiving education in two separate classes at the Department of Science Teaching at a university in northwest Turkey in the first term of the 2013-2014 school year. The students were randomly assigned into an experimental 'application' group and a comparison group of 23 and 21 students respectively.

### Procedure

The study was conducted over a period of 7 weeks structured in such a way as to involve 7 Optics topics in lessons regarding Science Laboratory Applications. Table 2 shows the topics studied according to the order of discussion. Students in the treatment group performed experiments in the laboratory environment on the basis of questions they wanted to investigate with regard to that week's subject, determined by themselves during 4 course hours every week, in groups of 3 to 4. They produced general evaluations by interpreting the data and observations from the experiments and finally made assertions about them. They presented and defended their assertions and evidence in a full group discussion in the classroom. Small group discussions took place during this process and the full group discussion where all the information was shared took place at the end of the process. During the process, the instructor helped the students to attain their goal with the aid of lesson planning, application, evaluation at every stage and through making immediate decisions. Questions posed by the instructor, who was constantly directing the course of the lesson, enabled the students to formulate their own questions around the main idea of the lesson, carry out experiments/observations and make assertions. Students reported the research questions they had generated at convenient points throughout the lesson and recorded the data and their observations, inferences and assertions in the ABI student templates, as well as changes occurring in their thinking as a result of their investigations, discussions, comparisons and reading. These procedures were repeated for 7 weeks.

**Table 2. Subjects**

Week	Subject
1 <sup>st</sup>	Light and shadow
2 <sup>nd</sup>	Reflection
3 <sup>rd</sup>	Mirrors (plane mirror and convex mirror)
4 <sup>th</sup>	Mirror systems
5 <sup>th</sup>	Refraction
6 <sup>th</sup>	Lens (converging lens and diverging lens)
7 <sup>th</sup>	Lens systems

Students in the comparison/control group, on the other hand, carried out their experiments using the traditional laboratory method. In this method, the students carried out the experiments as envisaged by researchers in the laboratory textbooks in small groups (of 3 to 4), in parallel with the subjects in the application group. They also used the textbooks to advise them what to do in every phase of the experiment and where to write down the results. During this process, the instructor discussed the objectives and results of the experiment with each group and how it was carried out, asked the students questions about what they needed to know theoretically and answered their questions. At the end of the process, the students prepared the experiment results in accordance with the traditional laboratory format (title and purpose, outline of procedure, data and observations, result and discussion).

#### **Data Source**

In the study, we used the field information test that was prepared for the topic of ‘Optics’ and the scale of critical thinking disposition outlines below.

*The California Critical Thinking Disposition Inventory (CCTDI):* The CCTDI scale was formulated as a result of the Delphi Project organized by the American Philosophy Association (Facione, 1990). The scale, which consists of 75 items in its original form, involves 7 sub-dimensions (truth-seeking, open-mindedness, analyticity, systematicity, self-confidence, inquisitiveness, maturity). The CCTDI scale, which was originally in English, was translated into Turkish by Kökdemir (2003) to be used in subjects whose mother tongue is Turkish. It was translated into Turkish by a total of eight individuals, four psychologists with specific expertise, three other general psychologists and one lecturer in a Department of Translation and Interpreting. Even though almost none of the translations showed any incompatibility with the others, it was specifically restructured in line with the suggestions of the expert translator. Once the translation process was completed, the factor structure of the scale was examined. For that purpose, 913 students (468 female and 445 male) aged 17-28 ( $X=20.08$ ,  $Sd=1.80$ ) were given a scale battery containing the CCTDI. At the end of the application, confirmatory factor analysis was applied to confirm the factors in the original form of the scale for construct validity. As a result of the analysis, 24 items were excluded from the scale and the scale was reduced to 51 items. Two factors (open-mindedness and maturity) were combined in the scale, which does not significantly differ from the original scale.

As mentioned above, six dispositions of critical thinking were described. These are analyticity, self-confidence, inquisitiveness, open-mindedness, systematicity and truth seeking (Facione, 1990). *Analyticity* expresses the ability to concentrate on potentially problematic situations, the constitution of assumptions regarding possible results or consequences and the ability to use evidence even if it makes the problem more challenging. The analytically-inclined individual is alert to potential difficulties both conceptually and in his/her actions. In general, while solving problems he/she constantly tries to apply anticipatory interventions, explicit reasoning and fact-finding procedures as ways to solve problems. *Open-mindedness* is a construct that describes the tendency to be tolerant, with a sensitivity to different opinions. An open-minded individual is someone who respects others’ different ways of thinking. The *Inquisitive* person is someone who knows the value of being well-informed, wants to learn how things work and appreciates the value of learning even it does not produce results immediately. *Self Confidence* refers to the level of trust in one’s own

reasoning process. Individuals thinking critically and having self-confidence trust themselves to make reasonable decisions and believe that the others also have trust in them, because they believe that they know how to decide what to do and how to bring investigations to a successful conclusion in an appropriate way when asked. *Truth seeking* individuals want to find out the truth, are bold in asking questions and honest and objective during an inquiry even when the findings do not support their interests or preconceived notions. A truth-seeking person prefers to establish the truth and favors discussion rather than competition. *Systematicity* refers to the tendency to be organized, neat, focused and diligent in any investigation. No specific kind of thought or action (i.e. linear or non-linear) is given priority. A systematic individual strives to approach particular issues, inquiries and problems in a neat and focused way. The number and internal coefficient of consistence (alpha) of each dimension are shown in Table 3.

**Table 3.** *Sub dimension of CCTDI and internal coefficient of consistence (alpha)*

Factor	Items	Internal coefficient of consistence (alpha)
F1 (Analyticity)	13	.75
F2 (Open-mindedness)	14	.75
F3 (Inquisitiveness)	11	.78
F4 (Self-confidence)	8	.77
F5 (Truth-seeking)	9	.61
F6 (Systematicity)	8	.63

This Likert scale used the following responses: ‘strongly disagree’ (1 point), ‘disagree’ (2 points), ‘partially disagree’ (3 points), ‘partially agree’ (4 points), ‘agree’ (5 points) and ‘strongly agree’ (6 points). The CCTDI is used in evaluating the critical thinking tendency or, to put it more comprehensively, the degree of complexity manifest in a person’s ability to think critically, rather than measuring a skill (Kökdemir, 2003). In order to determine the reliability of the scale to be used in the study, the scale was applied to 331 third-year undergraduate students receiving education in the Department of Science Teaching at two universities located in different regions and the Cronbach’s alpha value was determined as 0.83. The CCTDI was applied at the beginning and at the end of the study in an attempt to determine any change in the critical thinking of students in this study.

*Pre/Post-test:* In the study, a ‘success test’ consisting of 10 multiple-choice and 10 conceptual questions was used as the data collection tool. The success test was applied as the pre-test and post-test. The test questions were selected from different resources (Çolakoğlu, 2002; Hewitt, 2002) appropriate for the student levels and from the National Test exams (in the state student selection and placement systems in Turkey). Table 4 shows a signal table regarding the questions and Attachment 1 gives a sample question. In order to provide content validity, opinions were procured from two academics who were experts in Physics and Language Studies respectively and some corrections were made to the test. At the end of the application, the Cronbach’s alpha reliability coefficient of the test was determined as .67. An answer key was formed for the conceptual questions and the conceptual questions were scored by an expert researcher independent from the researchers and with the students’ names anonymized.

**Table 4:** *Pre/Post-test Table of Specifications*

Subject	Cognitive Taxonomy					
	Knowledge	Comprehension	Apply	Analyze	Synthesis	Evaluate
Light and Shadow	C3	C7	5,7	C9	6	
Reflection	C3	2,9, C8	3,4,8,10, C5,C6,	C9		
Refraction	C3	2, C1,C8	1,3, C2,C4	C9		C11

Note: Multiple choice questions are shown as numerals (1,2,3,...etc.), conceptual questions are shown as C1, C2,...etc.

## Statistical Analysis

### Analysis of Covariance

To address the research questions, a one-way analysis of covariance (ANCOVA) was conducted to analyze potential differences between the two groups in terms of their achievements in the multiple-choice questions and the conceptual questions in the post-test and post-CCDTI. Scores on the pretest and pre-CCDTI were included as the covariate, scores on the post-test and post-CCDTI were used as the dependent variable and the group was included as the independent variable in the model. The statistical significance was determined at an alpha level of .05 for all statistical tests. Non-significant results were not reported.

### Effect Size

In this study, effect size was recorded to recognize the magnitude of the effect of the application on students' learning and CCDTI using Cohen's *d*, which is widely used in social science because it enables us to measure "the difference between the means relative to the variation within the groups" (Hays, 1994). The criteria for identifying the magnitude of an effect size is as follows: (a) A trivial effect size is below 0.2 standard deviation units; (b) a small effect size is between 0.2 and 0.5 standard deviation units; (c) a medium effect size is between 0.5 and 0.8 standard deviation units; and (d) a large effect size is 0.8 or more standard deviation units (Sheskin, 2004).

### Assumption Test

Prior to conducting statistical analysis, three general statistical assumptions were made in this study: normality, linearity, and homogeneity. A simple graphical method and normal probability plots of model residuals were used to examine the assumption of normality. Analyses showed that the assumption of normality was met by the test. Similarly, the assumption of linearity was addressed by plotting standardized residual values against the predicted values, and the assumption of homogeneity was examined by using Levene's test for equal variances. The result indicated that this study did not violate the assumption of homogeneity in the post-test ( $F(1, 42) = 0.393, p = .534$ ) and post-CCDTI ( $F(1, 42) = 1.391, p = 0.245$ ). A two-step analysis was carried out. First, one-way ANOVA models were estimated to investigate performance differences in the pre-multiple choice question (PRMCQ), pre-conceptual question (PRCQ) and Pre-California Critical Thinking Disposition scores (PRCCDTI) between control and ABI groups. This analysis was carried out prior to the implementation of the argumentation activities. Second, a one-way ANCOVA model was estimated using the post-multiple choice question (POMCQ), post-conceptual question (POCQ), Post-California Critical Thinking Disposition scores (POCCDTI) as the response variable, PRMCQ, PRCQ and PRCCDTI as the covariate, and the group as the independent variables.

## Results

### Statistical Pre-Post-test

Before testing the hypotheses, it was important to determine whether the groups differed prior to the treatment. The descriptive statistics for the pre-test for each group are given in table 5. ANOVA results indicated that there was no statistically significant mean difference between the treatment group ( $M = 2.22, SD = 2.64$ ) and the control group ( $M = 1.38, SD = 2.25$ ) with respect to pre-CQ scores ( $F(1, 42) = 1.266, p = 0.267$ ). There was also no statistically significant mean difference between the treatment group ( $M = 8.74, SD = 5.92$ ) and the control group ( $M = 7.00, SD = 4.48$ ) with respect to pre-MCQ scores ( $F(1, 42) = 1.187, p = 0.282$ ).



**Table 5:** Descriptive statistics for the pre-test: means, standard deviations, and sample sizes.

	CG			TG			Total		
	n	Mean	SD	N	Mean	SD	n	Mean	SD
PRCQ	21	1.38	2.25	23	2.22	2.64	44	1.82	2.47
PRMCQ	21	7.00	4.48	23	8.74	5.92	44	7.91	5.30

Note: Maximum score for PRCQ = 45, maximum score for PRMCQ = 27. SD: standard deviation.

To assess whether the scores on two measures could be used as covariates in ANCOVAs, correlation coefficients were computed among these pre-measured variables and the post-test variables (table 6). Weak to moderately significant correlations existed between the pre-test scores and the post-test scores. Therefore, to reduce error variance, to obtain a more powerful statistical test, and to statistically compensate for the initial differences between the application and control group, scores on the PRCQ, and the PRMCQ were used as co-variates.

**Table 6.** Correlation coefficients between each of the co-variate variables and the dependent measures.

	PRCQ	PRMCQ	POCQ	POMCQ
PRCQ	1			
PRMCQ	.187	1		
POCQ	.433**	.121	1	
POMCQ	.267	.313*	.393**	1

\*\*Correlation is significant at the 0.01 level (two-tailed).

\* Correlation is significant at the 0.05 level (two-tailed).

Two post-test scores were analyzed: the conceptual question scores and the multiple choice question scores. ANCOVAs were computed for each of the post-test scores using the general linear model procedure in the Statistical Program for the Social Sciences. Table 7 presents the adjusted means, standard errors, and sample sizes for the post-test scores.

**Table 7.** Adjusted means, standard errors, and sample sizes for each condition for POCQ and POMCQ.

	CG			TG			Total		
	n	Mean	SE	n	Mean	SE	n	Mean	SE
POCQ	21	20.60	1.15	23	24.54 <sup>a</sup>	1.09	44	22.84	0.91
POMCQ	21	12.15	1.44	23	16.47 <sup>a</sup>	1.36	44	14.32	1.05

Note: Maximum score for POCQ = 45 (five for each question), maximum score for POMCQ = 27. SE, standard error.

<sup>a</sup> The mean is significantly higher than the other groups at the 0.05 level.

*The conceptual questions (POCQ) and the multiple-choice questions (POMCQ) for the post-test:* The findings indicated that there was a significant mean difference between the groups with respect to POCQ scores when the effects of PRCQ mean scores were controlled ( $F(1, 40) = 6.106, p=0.018$ ) and to POMCQ scores when the effects of PRMCQ mean scores were controlled ( $F(1, 40) = 4.716, p=0.036$ ). Students in the treatment group had higher mean scores for POCQ and POMCQ than those in the control group. The size of the mean difference for POCQ between the groups was medium (Cohen's  $d = 0.58$ ) and the size of the mean scores for POMCQ between the groups was medium (Cohen's  $d = 0.53$ ). This indicated that the differences detected between the groups arose as a result of the treatment and those differences had a practical significance.

### Statistical Pre-Post CCDTI

It was important to determine whether the groups differed prior to the treatment. The descriptive statistics for the pre-CCDTI for each group are given in Table 8. ANOVA results

indicated that there was a statistically significant mean difference between the treatment group ( $M = 231.39$ ,  $SD = 15.52$ ) and the control group ( $M = 208.67$ ,  $SD = 17.25$ ) with respect to pre-CCDTI scores ( $F(1, 42) = 21.171$ ,  $p = 0.000$ ).

**Table 8.** Descriptive statistics for the pre-CCDTI: means, standard deviations, and sample sizes.

	CG			TG			Total		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
Pre-CCDTI	21	208.67	17.25	23	231.39	15.52	44	220.55	19.83

Note: Maximum score for PRCCDTI = 350. SD: standard deviation.

Two post-CCDTI scores were analyzed: ANCOVAs were computed for the post-CCDTI scores using the general linear model procedure in the Statistical Program for the Social Sciences. Table 9 presents the adjusted means, standard errors, and sample sizes for the post-CCDTI scores.

**Table 9.** Adjusted means, standard errors, and sample sizes for each condition on Post-CCDTI.

	CG			TG			Total		
	n	Mean	SE	n	Mean	SE	n	Mean	SE
Post-CCDTI	21	213.22	4.38	23	233.84 <sup>a</sup>	4.15	44	224.00	4.10

Note: Maximum score for Post-CCDTI= 350. SE, standard error.

<sup>a</sup> The mean is significantly higher than the other groups at the 0.05 level.

*The post-CCDTI:* The findings indicated that there was a significant mean difference between the groups with respect to Post-CCDTI scores when the effects of Pre-CCDTI mean scores were analyzed ( $F(1, 43) = 9.713$ ,  $p=0.003$ ,  $n = 0.192$ ). Students in the treatment group had higher mean scores for Post-CCDTI than those in the control group. The mean difference for Post-CCDTI between the groups was of a medium size (Cohen's  $d = 0.74$ ). This demonstrated that the differences detected between the groups had arisen from the effects of the treatment and that these differences had a practical significance.

## Discussion

The findings of this study show consistency with other national and international studies and with other results regarding ABI, which is an argumentation-based heuristic application. This supports the contention that ABI increases the conceptual understanding of students. In addition, it was determined at the conclusion of the study that students in the group where argumentation-based inquiry was used had a greater ability to think critically compared to those in the control group. These findings indicate that argumentation-based inquiry increases conceptual understanding and improves the skill of thinking critically.

The application of the ABI approach will enable students to develop a better conceptual understanding of concepts in physics. The primary reason for this is that the learning encountered and experienced by students during the application of the ABI approach is a natural result of their immediate environment. During this process of learning, students are involved in carrying out investigations, planning experiments, presenting evidence to explain the significance of experimental results, justifying their experiments and developing assertions about the possible solutions to their questions. In order to form assertions, the students have to display their skills in scientific argumentation by generalizing and finding connections between results produced and by making explanations using examples from their experiments. Such profound discussion of concepts within a real social context enables them to understand the concepts better (Cavagnetto, 2010; Kingir, Geban & Günel, 2012).

Argumentation plays an important role in producing and sustaining the theories, models and explanations of scientists. They produce, deploy and reinforce their arguments using assertions drawn from experimental evidence. One of the objectives of scientific research is to form and justify the beliefs, assertions and procedures followed in order to better understand the universe, which makes discussion very important in this process. Almost all the concepts taught in science lessons manifest this form of scientific knowledge (Jimenez-Aleixandre, Rodriguez & Duschl, 2000). The fact that students are both able to understand scientists better and also to comprehend the scientific procedures they themselves are going through as they acquire scientific knowledge is considered a critical component of science literacy (Hand, Lawrence & Yore, 1999). In this process students become much better aware of what they are doing and why they are doing it. Being involved in their own learning makes them feel like scientists themselves and encourages them to gain further knowledge.

Moreover, students learn how to make scientifically significant claims about the world through applying an argument-based method (Ford, 2012). This process of interpretation includes (a) understanding the structure of scientific knowledge and results with regards to the goals of a society; (b) understanding the process of criticizing assertions, presenting evidence and making arguments; (c) knowing how to communicate different views regarding the application of science and scientific results, and (d) how scientific progress is repeatedly achieved through this communication. In evaluating Ford's perspective, even though each item can be considered separately, we also have to accept them as parts of a consistent whole. While interpretation is important in the process of structuring knowledge, it is fair that criticism occurs during the process of this structuring, particularly when we focus on the structuring of argument (Ford, 2012). The questions posed, assertions made, and evidence gathered and deployed in ABI classes are the key components of argumentation (Hand, 2008; Keys *et al.*, 1999; Norton-Meier, *et al.*, 2008). Students' participation in the process of argumentation is essential for meaning-making and the advancement of science literacy as it develops their ability to reason and improves their cognitive, metacognitive, communication, and critical thinking skills (Hand *et al.*, 1999; Jimenez- Aleixandre & Erduran, 2007).

Although an individual may have the ability to think, this does not mean that she/he will. Students generally fail to use the skills they are taught and this might result from not being used or habituated to thinking critically (Tishman, Jay & Perkins, 1993). Individuals who have critical thinking skills may not use them if they lack the necessary disposition towards critical thinking. Individuals with this disposition are more willing to think critically, so developing this tendency is one of the fundamental requirements for an individual's being able to use and apply critical thinking (Ertuş Kılıç & Şen, 2014). The most important result of this study is that the ABI approach increases the critical thinking tendencies of students. Individuals with more developed tendencies towards critical thinking can be defined as enthusiastic individuals with the skills in reasoning, giving justifications, collecting evidence, being sensitive to different views, wishing to gain knowledge, making decisions and questioning (Facione, 1990). The aforementioned features can also be gained through the process of argumentation. According to the results of this study, the reason for the increase in students' critical thinking in the application group compared to the control group is that they experienced the process of their own learning. Considered from the cognitive perspective, the process of argumentation involves the application of reasoning (Kuhn, 1993). When lessons are conducted based on argumentation, students express their own thoughts about a subject, an event or body of events. When children advance a strong argument which enables them to express their knowledge or thoughts, the development and adaptation of that knowledge, their beliefs, their values and their thoughts mutually support one another (Erduran, 2004).

Science can be intrinsically defined as a social activity in which there are scientific discussions (Kuhn, 1991). Scientific discussion is defined as a process in which individuals with similar or different perspectives evaluate alternative perspectives in order to solve a problem, understand a phenomenon, make a decision or suggest, support, criticize, and evaluate opinions about a scientific subject (Kuhn, 1993). It consists of the body of proceedings within this process as well as the cognitive products that are formed as a result of this evaluation (van Eemeren, 1995). In this context, in addition to concepts and specific events, the ways in which the skill of thinking can be

developed should also be considered in the process of science education. Thus, it should be required that students participate in discussions more systematically (Zohar & Nemet, 2002). According to Driver et al. (2000), conducting scientific discussions in science classes develops students' epistemological knowledge. Considering that the epistemology of science is related to the beliefs and values held about the nature of the scientific knowledge, it can also be suggested that scientific discussion enables students to learn how to use evidence in the process of their decision-making. Students should have an idea about how scientists work in order to comprehend science. From this point of view, if students work with data, assertions, reasoning, and supportive and opposing arguments, as scientists do, then such scientific discussions will enable them to comprehend science better.

Jimenez-Aleixandre and Erduran (2007, pp.4-12) suggest that a reason for increasing argument-based teaching in science classes is that it can be seen as '(a) being critical for meaningful learning, (b) developing the communicational skills of students, (c) enabling students to develop critical reasoning skills, (d) supporting the scientific culture and applications of students, (e) encouraging science literacy.' The inclusion of students in the process of argumentation in science and technology lessons profits them greatly and makes them more scientifically literate, enabling them to practice this in life (Osborne et al., 2004). This approach is generally thought to be among the primary factors which play an important role in scientific thinking and reasoning in science education (Hand, 2008). Teaching argumentation methods by using relevant activities and teaching strategies will enable us to achieve objectives involving the skills required to structure arguments using evidence, as well as developing social skills (Simon & Johnson, 2008).

Grandy and Duschl (2007) state that it is important to arrange lessons as educational environments where opportunities to undertake research and systematic thinking are provided. They also suggest that the teacher, curriculum and the environment should provide support for the child to demonstrate her/his cognitive activities and develop her/his capacities. This is the point at which teachers have the greatest responsibility. In a study carried out to define the concepts of understanding and thinking, Felton and Kuhn (2007) stated that teachers should advance discussion, evaluation, analysis and research in line with the needs of students. If teachers think about how they should communicate with students in order to develop their argumentation skills and use more dialogical approaches, they will be able to involve students in discussions (Simon & Johnson, 2008). One of these dialogical approaches is the argumentation-based approach. Teachers can inculcate these skills in students. In addition to changes to programs for students (MNE, 2013), the primary group targeted for successful communication with students should be their teachers.

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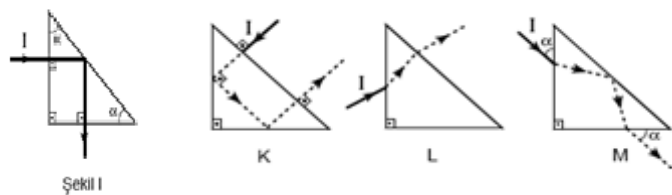
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#### **Attachment 1. Question samples.**

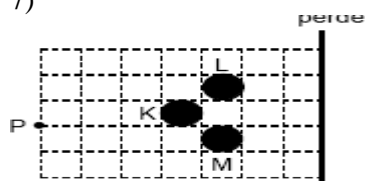
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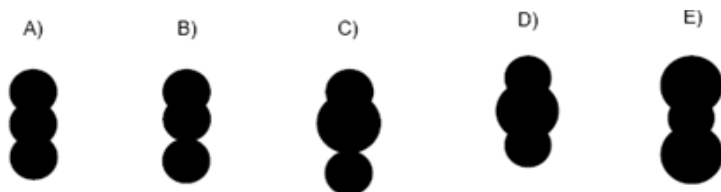
The light ray I reaching the rectangular prism follows the path shown in Figure I. If it reaches the same prism from the directions shown in figures K, L & M, in which of these directions will the light ray I **not** follow the path shown in the dotted lines?

- A) only K      B) only L      C) only M      D) K and L      E) L and M

7)



In a dark environment, the light source P and the balls K, L and M are placed in front of a curtain as in the diagram. Which of the following shows the shadow on the curtain?



C7. Does its wave length change as light moves from one environment to another? Does its frequency change? Does its speed change? Explain.

C2. You are asked to find the image of a candle using a concave lens. Show where you would locate the **object, observer, lens and the image** by drawing a diagram.

C9. You have just got out of class one evening. You are very hungry. As you pass by a restaurant, you can see both a delicious meal on a plate and yourself in the window of the restaurant. Explain this with the help of your in-depth knowledge of optics.

C10. Is it possible to make a magnifying glass using only two lenses? Explain.