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Developing critical thinking skills in the thinking-discussion-writing cycle: the argumentation-based inquiry approach

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Abstract

This study aimed to investigate the effects of the argumentation-based inquiry (ABI) approach on the critical thinking skills of fifth-grade students in a secondary school using a hybrid method. Using an experimental research model, the study had a semi-experimental design form with pre-test and post-test control groups. It was conducted in a middle school in Kastamonu with fifth-grade students from two classes during the fall semester of the 2016–2017 academic year. One of the groups was randomly assigned as the control group and the other as the experimental group. The science classes for the experimental group included activities fitting the ABI approach. In the control group, the lessons were carried out with frequently used teaching techniques such as lectures, question-and-answer and demonstrative experiments. The activities were implemented during the units “Measuring the Size of a Force” and “Matter and Change”. A Critical Thinking Test was used to measure the critical thinking skills of the groups at the beginning and the end of the study. *T*-test and ANCOVA analyses were applied to the quantitative data using the SPSS software. At the end of the study, semi-structured interviews were conducted with 12 students; six students from each group. The interviews were analysed using the Nvivo 11 software to obtain themes and codes. The evaluation of the quantitative and qualitative findings revealed that the ABI approach used in science lessons had improved the critical thinking skills of the experimental group students.

Keywords ABI · Argumentation · Critical thinking · Research inquiry · Twenty-first century skills

Introduction

In today’s world, science and technology are rapidly changing and knowledge is exponentially increasing. This makes it impossible to equip individuals with all the existing knowledge and information. Hence, it becomes more and more essential to educate individuals who know how to access accurate and reliable information and think critically about it. The Next Generation of Science Standards (2013) report on science education in the twenty-first century emphasized the need to develop critical thinking skills that students can apply throughout their lives, regardless of the subject matter. The most important educational mission should be to improve students’ thinking skills, enhance their democratic decision-making skills and prepare them for their lives as individual adults in the future by equipping them with business skills (Aydın and Yılmaz 2010). Interest in the development of thinking skills has increased alongside the changes in what is expected of students (MNE 2018). It has become more important for individuals to become good thinkers rather than developing conceptual understanding. “Good thinking” in education involves behaviours and skills such as formulating worthwhile questions, seeking answers through research and inquiry, being aware of the somewhat controversial nature of information and presenting evidence to support an argument (Pithers and Soden 2000). One of the twenty-first century cognitive skills is critical thinking (Ananiadou and Claro 2009; Geisinger 2016), and this is one of the thinking skills that education aims to develop (Fettahlıoğlu and Kaleci 2015).

To carry out reforms in science teaching changes are required in the role of the student, in the nature of the content, in the assessments and in the organization of the class (Walker and Sampson 2013). This change in educational goals has led to an increasing interest in critical thinking

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skills. It has also encouraged researchers and educators to search for learning processes and learning environments that will improve students' critical thinking. Learning environments that promote critical thinking are defined by Browne and Freeman (2000) as environments where more questions are asked and in which further discussions, unexpected results and active learning take place. The students also need to be encouraged to ask their own questions and to critically evaluate evidence or ideas to develop critical thinking (Osborne 2014).

Argument in science involves a collaborative structure with a common purpose in which two different, competing thoughts are discussed (Cavagnetto 2010). This structure embodies many processes, including introducing and evaluating different ideas, asking questions, persuading others and using evidence (Osborne et al. 2004; Sampson and Blanchard 2012). Cavagnetto (2010) identified three main types of interventions differentiated by the type of learning environment: (a) learning an argument through immersion, (b) teaching the structure of argument, and (c) emphasizing the interaction of science and society. Learning an argument through immersion means to utilize argument as an integrated component of students' investigations. How to structure an argument is taught separately from the investigations and the students are asked to apply it across various explanatory activities. The present study focused on the use of immersive argument-based inquiry (ABI) for students' scientific investigations. Working in groups, students identify questions and follow them up with activities including writing, making observations, posing questions and conducting experiments. After conducting their experiments, students share the results, compare claims and evidence through argumentation and negotiate statements in small or large groups.

Negotiating with others can be considered the main activity of argumentation, in which collaborative discussion is required in order to settle any uncertainties between different or controversial arguments (Chen et al. 2019). During this process, attention is drawn to the use of linguistic aspects, such as discussion and writing, in formulating arguments and scientific knowledge (Cavagnetto and Hand 2012; Chen et al. 2016a, b). It is stated that talk is important for the creation, explanation, and sharing, and distribution of scientific ideas, and that writing is important in developing and reinforcing new information related to the preliminary information (Rivard and Straw 2000). Chen et al. (2016a, b) study identified four patterns related of the use of discussion and writing: writing only, discussion only, discussion and writing in sequence, and discussion and writing at the same time. In our study discussion and writing were used simultaneously. Students used discussion and writing simultaneously in small and large group discussions to determine the claims being made, generate evidence from the experimental data and establish a relationship between them. It can be said that the main activity they engaged in during this whole process was thinking.

Critical thinking, considered as a process, involves going through certain processes such as analysing a problem, collecting data, evaluating the data and synthesizing the information obtained to reach a result (Bailin 2002). During the ABI process arguments are also put forward to convince others about the correctness of one's ideas. Critique likewise requires the ability to identify the elements of an argument as well as the ability to evaluate the validity of data and the usefulness of competing alternatives (Osborne et al. 2013). In addition, Zeidler et al. (1992) drew attention to the importance of reasoning and discussion skills in critical thinking, emphasizing that students engage in discussion activities so as to make better decisions about individual and social issues. As can be seen, it is possible to say that both the critical thinking and ABI approach involve similar processes. In fact, people with critical thinking skills are able to analyse and develop a structured argument, and understand the difference between proven and unproven claims. This study examined the effects of the ABI approach on critical thinking as well as considering the relationship between the two concepts.

Having scientific discussions during the learning process allow students to develop critical thinking skills and abilities (Kabataş Memiş 2016). As students engage with the scientific practices of argument, they also have the opportunity to develop their own critical thinking and reasoning skills (Hand et al. 2018). The ABI approach has been described as an approach that develops students' critical thinking (Stephenson and Sadler-McKnight 2016) and reasoning skills (Hand 2008). Stephenson and Sadler-McKnight (2016) stated that the ABI approach helped developed the critical thinking skills of undergraduate students in a chemistry department. In this study, critical thinking was associated with an ABI approach using writing, inquiry, collaboration and reflection. In addition, the ABI approach allows students with disabilities to actively engage in science instruction and scientific practices through the development of critical thinking skills (Taylor et al. 2012). Fostvedt et al. (2012) carried out ABI with fifth-grade students in 48 different schools, and found that these students showed more improvement than others in critical thinking measured using the Cornell Critical Thinking Test. In addition, they stated that the focus on the use of language in understanding of science during the inquiry lesson improved critical thinking and reasoning. On this basis, this study aimed to examine these effects in a different cultural context. This study thus investigated the effect of ABI approach on critical thinking skills. In the Turkish education system, science education is first seen as a separate subject in the fifth grade of secondary school. At this degree of maturity, students are able to carry out investigations (through argumentation) more intensively both individually and in groups. For this reason, fifth-grade students were selected as the study group. It takes time to acquire critical thinking, both in terms of the skills needed and the ability and desire to use them. To achieve the expected effect in a shorter time, the study was carried out over a period of two units.

Theoretical framework

Critical thinking

Critical thinking is the reflective and logical thinking that we employ when deciding what we want to do or what we want to believe (Ennis 1993). Pointing out that critical thinking is a skill as well as an attitude, Watson and Glaser (1964) stated that it has a comprehensive structure that includes research, inquiry and problem-solving. Critical thinking is a strength that allows an individual to personally control their development and learning process. The importance of critical thinking is emphasised in student-centred approaches and it is among the basic skills students are expected to have gained at the end of the learning process (Education Reform Initiative 2008). Because it encourages individuals to understand the information they encounter in a more complex way and to have better decision-making and problem-solving capacities in real-world circumstances, teaching critical thinking is extremely important (Butler et al. 2012). Critical thinking, which includes skills such as analysis, evaluation, inference and reflective judgment, is also important in adapting to the rapidly changing world of knowledge (Dwyer et al. 2014).

The differences in the definitions of critical thinking identify the different critical thinking skills. Facione (2015) classifies critical thinking skills into (a) interpretation, (b) analysis, (c) evaluation, (d) deduction, (e) explanation and (f) self-regulation. Critical thinking includes skills such as (1) the ability to see the difference between proven facts and asserted claims, (2) the ability to test the reliability of sources of information, (3) the ability to differentiate unrelated information from evidence, (4) the ability to be aware of prejudice and cognitive errors, (5) the ability to recognise inconsistent judgements, (6) effective questioning, (7) the effective use of verbal and written language, and (8) metacognition and similar skills that help the individual become aware of their own thoughts (Kökdemir 2000).

According to Seferoğlu and Akbıyık (2006), education built only on critical thinking, independent of the subject areas, is not sufficient to acquire critical thinking skills. Teachers need to establish learning environments that support the development of critical thinking skills in students and set appropriate goals for these skills (Kuhn 1999). Critical thinking in education involves high-level activities wherein teachers and students question information in a mutually effective manner, make decisions about what to do and what to believe, and evaluate claims and assumptions (Patrick 1986). In addition, learning environments where students can freely share their ideas and respect others' different ideas can also influence the development of their critical thinking skills. It is believed that guiding students towards research, discussing and questioning ideas in the classroom, and helping them gain self-confidence by participating in lessons and asking questions can boost their critical thinking skills (Semerci 2003). These activities can help students develop critical thinking skills and increase their likelihood of engaging in critical thinking. Furthermore, teachers should support the development of the students' critical thinking skills by becoming role models for them in the classroom. The ABI approach, which incorporates these activities with a research-based learning process, can be effective in the development of students' critical thinking skills.

ABI approach

Conceived by Keys et al. (1999), and based on the constructivist learning theory, the science writing heuristic approach was later referred to as argumentation-based inquiry due to its use of argument (Hand 2008). The ABI approach includes linguistic elements such as reading, writing and speaking, and helps to construct knowledge by integrating these elements into an environment based on making claims with regard to scientific activities, supporting assertions with evidence, and research and inquiry-based perspectives (Keys et al. 1999). ABI is a tool for both teachers and students to construct information through a process of detailed thinking and questioning (Günel et al. 2012). The ABI approach provides an outline of how students can perform research inquiries, write, think critically, develop conceptual understanding and conceive skills (Hand et al. 2004). There are two templates to help teachers and students effectively use the ABI approach (Hand and Keys 1999). These templates are included in Table 1.

The template for teachers is a tool that helps them plan the course objectives and activities based on the ABI approach (Hand 2008). In the ABI approach, the teacher is positioned as a learner alongside the students in the process rather than being at the centre and the sole presenter of information (Hand 2008). The teacher should design activities that can attract the students' attention and develop intellectual challenges for the students in the learning environment (Kabataş Memiş 2011). It is important for the ABI process that the teacher creates situations that encourage students to question. The teacher should encourage students to think by asking questions in different ways rather than directly providing answers to their questions.

Table 1 ABI teacher and student template (Hand and Keys 1999)

ABI part I: a template for teacher-designed activities to promote laboratory understanding	ABI part II: a template for students
1. Exploration of pre-instructional understanding through individual or group concept-mapping	1. Beginning ideas: what are my questions?
2. Pre-laboratory activities, including informal writing, making observations, brainstorming and posing questions	2. Tests: what did I do?
3. Participation in scientific activities	3. Observations: what did I see?
4. Negotiation phase I: writing personal accounts of scientific activity (e.g. writing journals)	4. Claims: what can I claim?
5. Negotiation phase II: sharing and comparing data interpretations in small groups (e.g. making a group chart)	5. Evidence: how do I know? Why am I making these claims?
6. Negotiation phase III: comparing scientific ideas to textbooks or other printed resources (e.g. writing group notes in response to focus questions)	6. Reading: how do I compare my ideas with those of others?
7. Negotiation phase IV: individual reflection and writing (e.g. a presentation to a larger audience)	7. Reflection: how have my ideas changed?
8. Exploration of post-instructional understanding through concept-mapping	

The ABI student template is a tool that guides students in planning their research activities (Günel et al. 2010; Kıngır et al. 2011). When students carefully answer the questions in the template, they construct their own knowledge by linking research questions, claims and evidence (Hand and Keys 1999). Students interpret scientific concepts in large and small group discussions on the basis of initial questions, explanations, tests, claims and the evidence that they have developed to support their own claims (Hand 2008; Kabataş Memiş 2014). Scientific debates that the students take part in during the ABI process involve evaluating alternative ideas, evaluating on the basis of evidence and assessing the validity of the outcome (Driver et al. 2000).

ABI is a research and inquiry-based approach that enables students to actively perform conceptual learning by conducting research (Kabataş Memiş 2014). In this process, the teacher elicits the students' existing knowledge by promoting brainstorming in large and small groups, helps students determine the activities, and initiates and maintains the negotiation process, which lies at the centre of the ABI approach (Akkuş et al. 2007; Evran 2015; Kabataş Memiş 2016). Students formulate concepts and ideas and build new knowledge on top of their existing knowledge by supporting their claims with the evidence they have gathered from experiments (Burke et al. 2005).

When the related literature is examined it is possible to say that the ABI approach involves a learning process that supports the various sub-skills (such as decision-making and problem-solving) of critical thinking. Considering these facts, this study aimed to investigate the effects of the ABI approach on the critical thinking skills of fifth-grade students. Within this framework, the following research questions were explored:

1. Are there any differences between the critical thinking skills of the fifth-grade students participating in ABI activities in science lessons and of those attending traditional science classes?
2. How does exposure to ABI activities and traditional activities affect the critical thinking skills of fifth-grade students?

Method

Research model

This study used a mixed method including both quantitative and qualitative approaches. In the semi-experimental method, randomly assigned groups are selected as experimental and control groups; both the groups are tested before the study and the desired activities are carried out with the experimental group while there is no intervention in the control group. In addition, the final tests are carried out with both groups (Çepni 2012). Thus, the quantitative aspect of this research was based on the semi-experimental design with pre-tested and post-tested control groups. The qualitative aspect of the study was based on semi-structured interviews conducted to learn the students' thoughts at the end of the process.

Study group

The study was conducted during the fall semester of 2016–2017 academic year in northwest Turkey. The study group in the research was identified with the purposeful sampling method using non-random sampling techniques. Two fifth-grade study groups being educated at the same school and with the same teacher were identified. One of the classes was impartially appointed the experimental group and the other was the control group. The purpose in the unbiased assignment was to create experimental and control groups that had equivalent features (Christensen et al. 2014). A total of 80 students participated in the study with 40 students (22 girls and 18 boys) in the experimental group and 40 students (22 girls and 18 boys) in the control group. To carry out the applications in the experimental group, the students created their own small groups of 5–6 person.

Implementation

Before the study, the experimental and control groups had science lessons in a traditional learning environment with lectures, questions and answers, and demonstrative experiments. The teacher shared visual elements using the smartboard as and when required during the lesson and reviewed the topics with the unit evaluation questions in the Science Book (MNE 2016–2017). Within the scope of the study, this learning environment was defined as being the traditional approach. Prior to implementing the research activities, the critical thinking skills of the experimental and control groups were pre-tested. In both experimental and control groups, lessons were conducted by the researcher. In the experimental group, the researcher has aimed to provide communication and collaboration among students in all small groups. As the activities began, the control group continued to attend science lessons that were given using the traditional approach, while the experimental group attended lessons that adopted the ABI approach. In the 1st week of the study, a preparatory activity was carried out in order to provide students with knowledge regarding the idea of "claims and evidence" which lies at the heart of argumentation. In the preparatory activity, students were asked to solve a "mysterious death" in groups of five or six; this death had no apparent cause. The students had to put forward a claim for the cause of death and support their claim with the evidence they had gathered from the text. Next, the students narrated their claims and evidence to their friends and tried to persuade each other. The students argued over the characteristics of the claim and evidence, and these were written on the board. They were then informed about the subtleties of inquiring and about how to ask good questions, which are at the core of the ABI approach. After this preparatory activity, students attended research and inquiry-based activities for 7 weeks, with 3 weeks on the "How to Measure the Size of a Force" unit and 4 weeks on the "Matter and Change" unit. Throughout the 7 weeks, the teacher primarily engaged the students in large group discussions, eliciting the students' existing knowledge on the topics. Further, the students designed experiments in the course of discussions in small groups. The teacher visited the small groups one by one and asked questions to make the students think and to guide them towards the learning objectives. These questions ensured that the students remained mentally engaged and focused on the learning objective. In addition, the students were asked questions that initiated and continued the discussions, attracted their attention and monitored their participation. During the small group discussions, students asked the teachers for help when they faced an obstacle. At this stage, the researcher asked more questions, encouraging the students to think more reflectively. At the end of these small group discussions, the researcher asked the students to come up with a claim, taking the experiments they had designed into account. Subsequently, the groups had the opportunity to share their claims and evidence, and the experimentations that had provided them with that evidence with students in other groups. At this stage, discussions (the persuasion process) took place between the group that presented the claim and the other groups. To persuade their friends, the groups that shared their claims showed the evidence they had obtained from the experiments they had designed; in some cases, they even showed experimental setups. As at every stage, the teacher guided the process, kept the discussion on course and directed the discussion with questions when needed. After all the groups had shared their claims and evidences, various points regarding the topic were emphasized. The students then completed the ABI test reports reflecting on the teaching method at the end of each course.

While the science courses of the experimental group involved activities appropriate to the ABI, those in the control group were taught by the researcher using the traditional approach. The topics were covered in the form of lectures and questions and answers, and demonstrative experiments appropriate for the topic were conducted in some weeks. These experiments were carried out by the researcher and some students participated in the experiments as assistants. After the lectures, the unit questions in the course book (MNE, 2016–2017) were answered by the students. At the end of the courses, both the experimental group and the control group took a Critical Thinking Test (CTT) as a final test. Finally, semi-structured interviews were conducted with a total of 12 students, comprising six students from different levels of success in each group (low, medium and high).

Data collection tools and data analysis

Cornell critical thinking test (CTT)

The CTT and semi-structured interview questions were used as data collection tools in the study. The Cornell Critical Thinking Test developed by Ennis and Millman was used as the CTT. The test was translated into Turkish by Mecit in 2006. It was designed for the purpose of evaluating inductive and deductive reasoning skills, judging the reliability of students' claims, and identifying assumptions in discussions. The test designers realized that the items were interdependent in the process of real critical thinking. Because of this interdependence, some of the items tested are assigned to more than one topic (Ennis et al. 1985; Daud and Husin 2004). The test gives a total score from items that measure inference, assessment, observation, judgment of the reliability of statements made by others, determination of assumptions, and clarifying their meaning (Mecit 2006). The test was used in this study because it objectively measures critical thinking and in essence overlaps with the processes of the ABI approach. It can be said that the questions in the test are mostly reasoning based questions. One of the questions in the test is given below as an example question. Example question:

Suppose you know that	
John is in the kitchen only if there is food in the kitchen	(A) Yes
There is no food in the kitchen	(B) No
Then would this be true?	(C) Maybe
John is in the kitchen	

The test aims to measure the critical thinking skills of individuals aged between 11 and 20 years, on a level of 4–14. The test contains 72 multiple-choice questions, each having three options, with one correct answer and two misleading answers. The test was used as a pre-test at the beginning of the study and as a post-test after the completion of the activities. Students were given a total of 50 min to finish this test. Students received 1 point for each correct answer and 0 points for unanswered questions or wrong answers. The Cronbach's alpha coefficient of the Turkish version of the test was found to be .75. In the current study, the Cronbach's alpha reliability value of the test was calculated as 0.90.

The effects of the science courses with the ABI approach on the students' critical thinking skills were studied. To measure the students' critical thinking skills, the students' pre- and post-test scores for critical thinking were taken into account. Their scores from the pre- and post-test were assessed using the statistical package software. Descriptive statistics and one-factor ANCOVA analyses were used to compare the scores of the students in the experimental and control groups.

Semi-structured interview

Semi-structured interview questions were formulated to evaluate how well the students could reflect on their own critical thinking skills. The questions were prepared by the researcher, taking into consideration the sub-dimensions of critical thinking, and were submitted for expert opinion. In preparing the questions, the definitions and categorizations of critical thinking found in the literature were taken into consideration. For example, Ennis (2011) states that a critical thinker is aware that it is risky to respect a source if the source is at fault, and that one needs to be able to "judge the credibility of a source". In the current study, the following questions were asked to determine how students evaluated a sources of information (peers, teachers, books etc.): "How did you evaluate your friend's ideas in the discussions? When did you accept their ideas, and when didn't you? How do you know if an idea is right or wrong?" After the expert's review, the necessary changes were made and the questions were finalised. Some examples of the final semi-structured interview questions are as follows:

> What do you think about having different ideas in a group? How did you decide that an idea was true or false? Did you clearly express your opinion in discussions? How did you convince your friends that your claim was correct? Why did you repeat your experiments a few times?

With the permission of the students, the interviews were recorded with a voice recorder. The interviews were carried out individually in the Science Laboratory of a vocational school.

At the end of the study, semi-structured interviews were conducted with 12 students, six students from each group. The students' names and identities were kept confidential. The experimental group students were coded 'S_{E1}, S_{E2}, S_{E3} etc.' and the control group students were coded 'S_{C1}, S_{C2}, S_{C3} etc.' The recordings were decrypted and transcribed after the interviews. The written data obtained were coded by one of the researchers using Nvivo11 software. However, an expert with experience in related studies and other researchers joined the researcher to discuss the validity and credibility of the coding. Thematic analysis was used for data analysis. The analytical process was completed from an inductive perspective. Inductive thematic analysis is an analytical process using data collected specifically for the research to create themes and codes and in which different themes are not taken into consideration (Braun and Clarck 2006, p. 12). Therefore, the data was read repeatedly and a new code was created for each of the different critical thinking skills encountered in the students' statements. Keeping the focus on the main theme of critical thinking skills, the coding was analysed to reveal how the students reflected on their critical thinking skills during the learning process. While the interviews were being coded, the sub-categories of critical thinking skills emphasised by the experimental and control group students were taken into account. The coding was displayed various using various analyses on the Nvivo11 software.

Findings

Quantitative findings

The pre-test CTT was used to determine whether there was a meaningful difference between the critical thinking skills of the two groups. The *t*-test and ANCOVA were applied since the data provided assumptions of normal distribution (Kolmogorov–Smirnov: $p > 0.05$), homogeneity (Levene's Test: $p > 0.05$), and linearity and homogeneity of regression trends ($p > 0.05$). An analysis of the *t*-test results for unrelated (independent) samples revealed that there was no statistically significant difference between the groups. The pre-test CTT results showed that there were small differences between the total test scores of the groups; however, these differences were not statistically significant. The pre-test CTT score was used as a covariate to reduce the error variance, to get a sounder statistical test and to statistically compensate for the primary differences between the experimental and control groups. The critical thinking post-test mean scores of the students in the experimental and control groups as corrected according to the critical thinking pre-test scores are shown in Table 2. The findings of the ANCOVA analysis on the post-test CTT are provided in Table 3.

The findings of the ANCOVA analysis of post-CTT in Table 4 showed a significant difference between the critical thinking post-test scores corrected according to the groups' pre-test CTT scores ($F_{(1,78)} = 5.975$, $p = 0.017$). Eta squared measure of effect size is slightly biased because it is based purely on sums of squares from the sample and no adjustment is made for the fact that we're trying to estimate the effect size in the population (Field 2005, 2009). For this reason, often it is recommended to use a slightly more complex measure called omega squared (ω^2). The following equation is used to calculate the omega-square value. The $\omega^2 = SS_M - (df_M)MS_R/SS_T + MS_R$ equation is used to calculate the omega-square value. As a result of the calculation, the omega-square value was calculated as .025. Compared with the literature, this value was found to have a small effect.

Table 2 Post-CTT findings

Test	Group	Average	Corrected average
Post-CT	Control	31.487	32.804
	Experimental	37.821	36.504

Table 3 Findings of post-CTT ANCOVA analysis

Source of variance	Sum of squares	sd	Average of squares	*F*	PA
Pre-CT	4385.930	1	4385.930	101.165	0.000
Group	259.059	1	259.059	5.975	0.017
Error	3251.557	76	43.354		
Total	8419.654	78			

Qualitative findings

Experimental group's qualitative findings

The semi-structured interviews conducted with the students were analysed and codes were created under the theme of "Critical Thinking". Codes and frequencies related to the theme of critical thinking, which included "using evidence", "open-mindedness", "evaluation", "decision-making", "search for truth", "staying on topic", "systematicity", "testing variables" and "self-assessment", are presented in Table 4.

During the interviews with experimental group, the students discussed many skills that display critical thinking and that are sub-skills of critical thinking. All the students stated that they take different opinions seriously; they thought that having differences of opinion and openly sharing their ideas with others were important. The students' answers also demonstrated that the ABI approach involves many processes that help students to be open-minded and supports the development of this skill. S_{E4}stated the students' willingness to consider different ideas in the following way:

> Of course, there were some discussions. For example, a friend of mine said, "Let's do it the other way". And I told them that it would make more sense if we did it another way. There were such discussions…We all had our own ideas.

Table 4 Critical thinking themes, codes and frequencies for the experimental group

Theme	Code	Frequency
ABI approach	Using evidence	23
	Open-mindedness	21
	Evaluation	13
	Decision-making	12
	Search for truth	9
	Staying on topic	8
	Systematicity	8
	Testing variables	6
	Self-assessment	5

S_{E6} stated that, "*A friend of mine said that it would be like that and another friend suggested something totally different. Everyone in the group had different ideas*." While emphasising the importance of having different ideas in the group, the students also wanted to make sure that these ideas were correct. S_{E2} explained this situation by stating the following:

> One of our friends would tell us that this was the way it should be done. Then, we would explain our idea to him and someone else examined the idea in its tiniest details, and then we'd choose his idea... Our friend told us his idea, and we agreed on it, but also made our own adjustments. We did brainstorming like that.

Individuals with critical thinking skills should be able to tell the difference between a claim and a proven fact. They seek evidence before believing in an idea or a thought and compare the two. In their interviews, students often stated that they looked for evidence when a friend of them had an idea.S_{E5} pointed out this situation saying, "*There were different ideas. Then, we wanted to work out which were the right ones…We decided to test both of them by experimenting with both and gathering evidence*."

An individual with critical thinking skills takes into account different claims about a topic and uses reasoning to go through an evaluation process. The students stated that when they had different ideas in hand, they analysed and evaluated them. S_{E4} explained this situation as follows: "*I carefully thought about this twice to avoid any errors… We also compared the two ideas to figure out which was more appropriate*". Some students tried to find the reasons for these differences. For example, S_{E3} said, "*Some of our friends came up with different results, because they did the experiment using wedge and we did it with a car.*" Determining the variables which influence a desired outcome and investigating the extent of their effects are two very important critical thinking activities. These activities allow students to test variables and move towards their objectives with greater confidence. The students stressed that they tested the variables in their interviews. S_{E3} discussed the importance of one variable during an experiment saying, "*We moved the beaker slightly closer to the furnace, and then we measured the temperature. Then, we moved it farther away and measured the melting temperature again.*"S_{E6} also drew attention to the fact that they tested the effects of different surfaces on friction in the following statement:

> Some of them had a surface like a rug and others were flat. Some had sand, pebbles and stones on the surface. We used the wedge and the car on them. We tried to find out if the car's speed was affected by the surfaces...Sometimes we tilted the board upwards. When we put the wedge there, the wedge started moving on its own. The car went really fast on the flat surface, but had some difficulty moving on the stone surface.

Decision-making that reflects critical thinking is a logical process. The individual makes a deliberate choice between multiple options. Throughout the activities involving the ABI approach, the students often employed a decision-making process and they discussed this in the interviews. Moreover, they emphasised the importance of mutual decision-making by drawing attention to the group decisions. For example, students S_{E1} and S_{E3} pointed this out, saying, "*There were different ideas, but we finally reached a common result*" and "*We all made a collective decision by hearing out everyone's ideas…I learnt how to get to a shared result through discussions with my friends…*" In fact, S_{E3} clarified that they learnt it through ABI activities.

An ABI approach contributes to students' questioning and evaluating themselves, as seen in their statements. The students took account their own deficiencies through evaluating their own performances. For example, S_{E5} assessed themselves, stating that they had made a mistake during the experiment: "*We saved some of them for last because of the mistakes we made during the experiments. For example, we built a dynamometer, but some of the writing on the dynamometer was erased*." The statements of S_{E2} draw attention to self-evaluation and peer evaluation: "*For example, I put forward an idea but I had not thought about the details. But my friend made the final decision by thinking through all the details"*.

The students stated that throughout the process they did not lose their focus on the main topic and conducted the experiments without drifting off the main subject. S_{E1} emphasised that they were careful to stay on the topic and mentioned that "*We wanted to find out whether different surfaces and weights affected friction. We had discussions on this subject.*" Some dialogue between the researcher and S_{E4} during the interview is provided below. In this dialogue, the student stated that they considered different ideas in the group but were also careful to stay on the topic while doing so.

Researcher:	For example, you mentioned that there were different ideas while you tried to come up with a claim
S_{E4}:	Yes
Researcher:	How did you evaluate these ideas?
S_{E4}:	I tried to figure out if the different ideas would be more suitable
Researcher:	And how did you decide which idea would fit better?

S_{E4}:	Based on the experiment, depending on whether they would be appropriate for the purpose of our experiment

Systematicity refers to specific stages that go together to create a complete system. Individuals with critical thinking skills pay attention to systematic thinking. During the interviews, the students stated that they tried to follow a specific sequence throughout the ABI activities, that they tried to make sure that each consecutive step was in harmony with the one before, and that they were paying heed to this issue both in their experiments and while preparing their reports. S_{E5} stressed the importance of systematicity and thinking systematically as follows:

> First, we talked and took notes, then we tried out the things we had talked about, and then, we came up with our claim...We conducted the experiments step by step. If we had not done everything in order, the experiment would have been messy and we would have got incorrect results.

Qualitative findings of the control group

We analysed the students' responses in the semi-structured interviews within the theme of critical thinking and the codes for self-awareness, open-mindedness, seeking truth and self-evaluation and their frequencies are given in Table 5 below.

The control group discussed the skills of open-mindedness, seeking truth and self-evaluation in the interviews, all of which reflected critical thinking. Students stated that they were aware of the fact that having different ideas is a positive thing. They emphasised that diversity is important to achieve better results and added that they wanted their ideas, as well as those of their friends, to be heard. For example, student S_{C6} stressed the importance of this issue by saying, "*When everyone shares a different idea, you can create something more beautiful by bringing them together*." Students indicated that they did not immediately accept new ideas and that they needed make efforts to seek the truth. One dialogue between the researcher and S_{C5} reflecting this situation went as follows:

Table 5 The critical thinking theme and codes and frequencies of the control group

Theme	Code	Frequency
Traditional approach	Open-mindedness	3
	Seeking truth	2
	Self-evaluation	1

Researcher:	Would you like to discuss the subject with your friends?
S_{C5}:	Yes, I would
Researcher:	Why?
S_{C5}:	Because some of them say that this is not the correct answer to the question. Discussing it with them helps me talk about the subject more easily
Researcher:	How would this help?
S_{C5}:	It's the best way to learn. It makes it more memorable, so you don't forget it after a while
Researcher:	There are five or six people in the group and all of them have different ideas
S_{C5}:	That's why we need to have discussions
Researcher:	So, what happens when there are different ideas?
S_{C5}:	We talk and that's how we get to the correct idea

In the interviews, students made various statements reflecting their awareness of their own deficiencies and competencies. S_{C2} stated that he was aware of his own abilities and he thought about those abilities when he evaluated himself. He said:

> I can't answer some questions easily because I don't know much about the subject, I raise my hand if I know the answer... It's easier when you're just listening to the subject, you think that you've learnt it, but you get confused when you are explaining it yourself.

A critical thinker takes other opinions into account before choosing to believe or reject an idea, evaluates different opinions through discussion and ultimately decides which idea is to be believed. When we analysed the interviews, we saw that the statements of some students did not reflect critical thinking. The dialogue between the researcher and SC1 the following statement was made:

Researcher	Can you tell an idea that comes to your mind to others?
S_{C1}	I ask a friend and if they tell me that I should say it, then I say it
Researcher	Can't you decide for yourself?
S_{C1}	I can't decide for myself
Researcher	Well, do you like arguing a topic with friends?
S_{C1}	I like a little
Researcher	Why do you like a little?
S_{C1}	I don't like arguing with my friends
Researcher	So, do you get your friends' opinion on a subject you are unstable?
S_{C1}	Yes, I take their thoughts
Researcher	Do you have discussions on these different ideas?
S_{C1}	I argue, but I do not do it in a very crowded. Because when I get very crowded, I get confused

This student thinks that a discussion is equivalent to arguing with their friends and they prefer not to participate in the discussion. They stated that they had reservations about expressing their ideas and were not competent to make their own decisions. It is important to think and discuss in critical thinking on the various ideas and reasons why these ideas are put forward. S_{C6} also stated that they would accept an idea presented by the teacher without questioning and evaluating it, as seen in the following words: "*I accept whatever my teacher says. What our teacher tells us sounds more interesting and smarter than what anyone else has to say. I would not accept anyone else's ideas that easily*". Although this statement showed that the student was evaluating the information, it can be said that the critical thinking demonstrated did not fulfil various criteria. Assessing why a teacher (as an authority) is a credible resource is an important skill in critical thinking. S_{C4} also stated his hesitation in sharing his ideas and inability to express them to the full group, saying, "*Sometimes I know the answer to the questions, but I'm hesitant. I'm afraid they will laugh at me. Sometimes my friends laugh a lot*". Such statements do not reflect critical thinking because critical thinking requires that different ideas be discussed to reach a shared view of a subject. This type of process can be promoted by creating a classroom environment that is democratic. In this case, the student's response showed that the current classroom environment was an obstacle in the development of critical thinking.

Discussion and results

This study aimed to investigate whether the ABI approach has an impact on students' critical thinking skills. We found that there was a difference between the ability of fifth-grade students trained with the ABI approach to think critically and those who were not. This difference between the students was detected using the CTT and semi-structured interviews. These findings show that the ABI approach is effective in the development of critical thinking skills.

There were no significant differences between the critical thinking skills of the experimental and control groups in the critical thinking pre-test findings. When we examined the post-test CTT data, we found that there was a significant difference in favour of the experimental group in terms of critical thinking. The quantitative findings indicated that the experimental group had better critical thinking skills. In this regard, we can claim that the use of the ABI approach in science lessons is effective in developing students' critical thinking skills. Stephenson and Sadler-McKnight (2016) linked the development of critical thinking to the four core elements of the ABI approach: (a) writing, (b) inquiry, (c) cooperation, and (d) reflection. It is not clear which of these four elements is most effective in the development of critical thinking skills. However, on the basis of the semi-structured interview findings of our study, we can conclude that inquiry, cooperation and reflection are more effective in improving critical thinking skills because the experimental group emphasised that the learning process and the activities conducted using the ABI approach helped them improve their critical thinking skills. In addition, some previous studies have revealed that inquiry, cooperation and reflection promote the development of critical thinking skills (Hofstein and Lunetta 2004; Osborne et al. 2009; Hein 2012; Sönmez et al. 2019).

Language plays a central role in scientific practice (Cavagnetto 2010) and in expressing scientific insights (Fostvedt et al. 2012). The importance of understanding the critical thinking and reasoning that underpin any argument is related to understanding that using language is a complex cognitive process that requires the use of different activities to be successful (Hand et al. 2018). Science is not possible without spoken and written language (Norris and Philips 2003). Students need to not only engage in cognitive activities such as creating arguments, but express their results in written and verbal language (Hand et al. 2018). Kuhn (1999) stated that as an individual's ability to think develops it can be affected by factors related to their family, their immediate environment and their education. This article focuses on the factors related to education. It is important to provide opportunities for students to use language in learning environments. In addition, it is thought that the behavior, language and perceptions of teachers may have important effects on student's learning and critical thinking (Bee and Boyd 2004).

ABI activities help develop problem-solving, decision-making and critical thinking skills and promote high-level thinking (Hand 2008). The ABI process consists of many activities including constructing claims, designing experiments to support the claims, producing evidence as a result of the experiments, explaining the relationship between the claim and the evidence, holding discussions and refuting counterarguments with evidence. It is important that the claim produced are evaluated by other people than their advocates (Walton 2016, p. 223). Participating in these activities which encourage high-level thinking can help students gain critical thinking skills and improve their existing skills. In addition to constructing an argument during the process of argumentation, it is also important to review and evaluate the argument in terms of its deficiencies (Ford 2008; Mercier and Sperber 2011). Group discussion and written activities, and evaluating arguments developed by others and reaching an agreement contribute to individuals' cognitive development (Chen et al. 2016a, b). The discursive skills that students gain in dialogues with their peers are valuable in terms of writing effective arguments as well as in extending the thinking that underlie the arguments they are defending (Shi et al. 2019). Participating in scientific discussions provides external support for anticipating many different perspectives, achieving common results from different ideas using evidence, and developing critical thinking skills (Felton and

Kuhn 2001). This is also evident from the findings of the interviews. We can argue that the students emphasised the importance of (1) designing and implementing experiments with their peers, (2) evaluating variables, (3) generating evidence for their ideas, (4) formulating explanations using the evidence and (5) convincing each other of their arguments. Moreover, it was apparent that the students valued hearing different ideas, the decision-making process, and working in small groups in cooperation with their friends during the process. At the same time, students also pointed out that they shared their ideas with each other and, if necessary, changed their misconceptions. However, we observed that the control group students made more superficial assessments about their critical thinking skills during the interviews and even used phrases that did not reflect critical thinking. This suggests that the ABI approach creates effective learning environments for the development of critical thinking skills such as using evidence, making decisions, testing variables, evaluation and self-evaluation. We observed that the experimental group students were more able to express themselves and the control group students used more simple and superficial expressions. This may also be an indication of the effectiveness of the ABI approach. Because the experimental group students communicated with their teachers and peers throughout the courses, they constantly exchanged ideas and justified these ideas using evidence. In fact, the students in the experimental group often tried to justify their opinions using the word "because". With regard to Kökdemir's (2000) statement about a critically thinking individual's ability to tell the difference between proven facts and assumptions, we can say that providing a justification for their ideas was an important indicator that the students were becoming individuals with critical thinking skills.

Given that one of the primary aims of science education is to inculcate critical thinking skills (MNE 2013, 2018), the importance of the current study becomes evident. Synder and Synder (2008) stress that learning environments that promote critical thinking skills should be established in classrooms and provide three basic recommendations to teachers who want to develop their students' critical thinking skills. They state that the teachers should (a) be examples of critical thinking themselves, (b) set tasks that help develop critical thinking through activities and (c) ask open-ended questions to make students think freely, rather than providing definite answers. Conducting investigations as well as engaging in deeper thinking and creating conceptual information strengthens reflection and encourages critical thinking (Osborne 2014). Teachers should ask questions that will promote critical thinking skills in students and encourage them to think more profoundly. In the ABI approach, the teacher is not the provider of readily available information but a guiding figure who helps students achieve knowledge. It was stated that the moments of uncertainty during the discussion were necessary because they offered constructive opportunities for evaluating, discussing and deepening students' reasoning and led to productive learning (Chen et al. 2019). As stated above, the aim was for students to experience more moments of uncertainty as a result of the teacher's questions. This was taken into account in the current study and argumentation activities to develop critical thinking skills were adopted. To this end, the students were asked questions to promote higher-level thinking, to initiate and continue the "negotiation" stage and to help them engage in dialogue with their peers and teachers during the study. All the students were actively involved in the lessons at every stage. In addition, when a student asked the teacher a question, the teacher asked guiding questions to allow the student to reflect and make their own comments. We believe that the continual promotion of high-level thinking is effective in developing critical thinking skills.

Critical thinking is a logical and reflective mode of thinking used while deciding what to believe or what to do (Ennis 1993). An individual seeks appropriate evidence to evaluate their options while making a decision and this evaluation reflects a logical process (Siegel 1992). Ford (2008, 2012) drew attention to the importance of the discussion process and stated that when claims and evidence for the development of scientific knowledge were developed, these claims and evidence should be criticized. Recognizing the relationship between the evidence and the argument counts as a key achievement and creating an evidence-based claim is seen as the main and key element of a controversial article (Hemberger et al. 2017). Having to seek suitable evidence in order to assess claims and evaluate the evidence for them may have contributed to the development of students' critical thinking throughout the ABI activities. In addition to seeking evidence, the students also pointed out that they shared their ideas with their friends, evaluated different ideas, became aware of the misconceptions or flaws in their own thinking and changed their opinions. Thus, we can argue that the ABI approach critical was effective in developing critical thinking and its many sub-skills, including evaluation, analysis, use of evidence, problem-solving and decision-making.

Suggestions

This study examined the impact of the ABI approach on critical thinking skills. However, critical thinking comprises both skills and attitudes. The study could have examined not only critical thinking skills but also attitudes towards critical thinking. High-level thinking skills such as analytical thinking, reflective thinking and creative thinking, and the effects of the ABI approach on these skills could also have been examined. The study determined that the students frequently drew attention to the ABI process while engaged in it. The ABI process could thus also be examined through observation, and its relationship with critical thinking or other high-level thinking skills could be further elaborated. Since the importance of language is emphasized in scientific discussions and critical thinking, it is important to reveal the relationship between these concepts.

In the ABI approach, the teacher needs to guide the learning process and help the students to access information. In this respect, unlike in the traditional approach, the emphasis falls on the teacher's knowledge of the subject area and pedagogical knowledge, because managing the ABI process well is only possible by asking the kind of good questions which require this knowledge. From this perspective, the importance of equipping teachers and future teachers with the necessary skills is very evident. To this end, we suggest that similar studies be carried out with students currently in higher education.

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