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The Effects of Scientific Argumentation on High School Students' Critical Thinking Skills*

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Abstract

One needs higher order thinking skills in positioning perspectives for any kinds of problems that affect one's view of life in order to develop a fundamental scientific understanding. For this reason, science teaching requires thinking skills instruction to be included in classes. This study aimed observing the effects of student-centered activities, which were formed through scientific argument centered teaching method, on the critical thinking development of students, comparing it with those of traditional approach in chemistry classes. The research was conducted in two 11th grade classes of a high school in the city of Çankırı in Turkey. Classes were carried out with the teaching approach based on scientific argumentation in the experiment group with 17 students and with the conventional teaching approach in the control group with 17 students. The study lasted for 29 weeks with 11th grade students in two groups. In the experimental group, argumentation-centered instruction activities, which were based on Toulmin's argument model, were conducted. Data were obtained through Watson Glasser Critical Thinking Scale and achievement tests named Achievement Test 1: Reaction Rate, Achievement Test2: Chemical Equilibrium, Achievement Test 3: Solubility Product, Achievement Test 4: Equilibrium in Acid-Base Solutions were applied at the beginning and end of the intstructions as pre-test and post-test. Wilcoxon test and Mann Whitney U test were used to analyze the data quantitaviely. With regard to the results, critical thinking skills of experimental group and control group students made progress but there was a statistically significant difference between the two groups. Also, when students' answers in achievement tests are analyzed qualitatively in terms of critical thinking subskills, it can be seen that all critical thinking sub skills of the experimental group students have developed more than the control group.

Keywords: Scientific Argumentation; Critical Thinking; Science Education; High School.

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INTRODUCTION

Thinking acts as an important instrument in preparing the required environment, and ensuring the continuity of it, in order for individuals and communities to attain secure and constant life styles. In parallel with this, one's effective thinking and decision making in the face of incidents or situations reflects his/her critical thinking aspect (Porter, 2002). In Bloom's taxonomy; more often, there are higher order thinking categories that focus on abilities such as analysis, synthesis and evaluation instead of lower order thinking categories that focus on critical thinking skills, knowledge, comprehension and practice skills (ten Dam & Volman, 2004). Critical thinking often plays a role in recognizing problems, finding viable tools for the solving of these problems, enumerating relevant information, recognizing unexpressed assumptions and values, interpreting data with accuracy, clarity and discrimination in understanding and using language, evaluating evidence and arguments, accepting the existence or absence of logical relationships between propositions, testing conclusions and generalizations and also conclusions and generalizations reached by individuals (Brown, S., 2009; Gábor, 2007).

There are many different ways to improve critical thinking. According to specialists, an individual can inspect and evaluate their own thinking process critically. They can question how to think more objectively and logically and understand the thinking processes and standarts used by other individuals coming from a different field. Also, experience is of utmost importance for the acquisition of these skills (Güven & Kürüm, 2004). Critical thinking requires an active process and the instruction provided on higher order cognitive processes such as understanding, inference, analysis, synthesis, reflection and decision making which are intellectual skills of critical thinking, requires a complicated cognitive activity, as well (Meral, Şahin & Akbaş, 2021; Özdemir, 2005).

Learning to think critically is learning about the act of thinking itself. Vieira, Tenreiro and Matins (2011) present two main aspects of critical thinking in their study. One is the logical aspect of thinking, and the other is the cognitive aspect of thinking. The first is to teach the principles of logic, rhetoric and argumentation; and the other is to teach *teaching thinking* or *thinking skills* in a broader and more general way. Thinking critically encourages questioning, problem solving, decision making, discussing, criticizing, assessing, active learning techniques and similar critical thinking and it improves science education. According to National Science Education Standards, a relation between scientific thinking and a more comprehensive thinking in students' minds should be built in science teaching. So as to strengthen this relation, thinking environments that students participate in educational contexts should be situated in a more comprehensive content and conveyed beyond conventional science (Council of National Science Education, 1996 cited in Van Zee et al., 2001). Social interaction and group work are important class activities in teaching methods which have been suggested after considering all the theories that constructivist approach is based upon in a way to eliminate the drawbacks of the teaching methods prepared according to cognitive theories. Therefore, during classes, activities focus students‘ attention on studies. Small group argumentations ensure conceptual understanding, attitude, motivation, group membership and leadership skills (Cho & Jonassen, 2002; Hasnunidah, Susilo, Irawati & Suwono, 2020; Zohar, Weinberger & Tamir, 1994). At this very point, argumentation-based teaching method comes to the forefront.

When the constituents making up the argumentation are examined, it is observed that characteristics such as high-level cognitive skills, scientific acculturation, critical thinking, and scientific literacy are significantly affected by argumentation (Figure 1). Scientific argument method is very essential in terms of the interaction between students, bringing their mental models forward, using backing and evidence to defend their own models, rebutting and providing the development of students' cognitive skills as well as reasoning and inquiry skills. (Duschl & Osborne, 2002; Erduran, Ardaç & 2006; Lee & Ertmer; 2006; Osborne, 2002; Osborne, Erduran & Simon, 2004; Özdemir, 2005; Öztürk & Doğanay, 2019; Sampson & Walker, 2012; Simon, Erduran & Osborne, 2006; Ural & Gençoğlan, 2020; Von Aufschnaiter, Erduran, Osborne & Simon, 2008; Yerrick, 2000; Zohar & Nemet, 2002).

Psychologists are of the opinion that argumentation with valid justifications and rebuttals involve higher-level thinking skills (Iordanou, 2013; Nussbaum & Sinatra, 2003). Scientific argumentation builds a framework that develops students' scientific thinking skills critically, for instance being able to distinguish between theory and data, organizing data, and coordinating theory and data (Driver, Newton & Osborne, 2000). Likewise, students stating their thoughts and opinions in written form become cognitively active. Written statements give students the opportunity for defining the problem, reasoning, making inferences, and expressing themselves better (Doğanay & Ünal, 2006). Moreover, considering the strong relationship between language and thinking and that the first stage of critical thinking education should be language education (Lee & Ertmer, 2006), it can be said that critical thinking skills develop more effectively in learning environments where scientific argumentation-oriented teaching approach is used. Using language skills in activities enables students to improve their thinking skills. Critical thinking, as one of the thinking skills, evolves correspondingly with the language efficiency that is used during discussion.

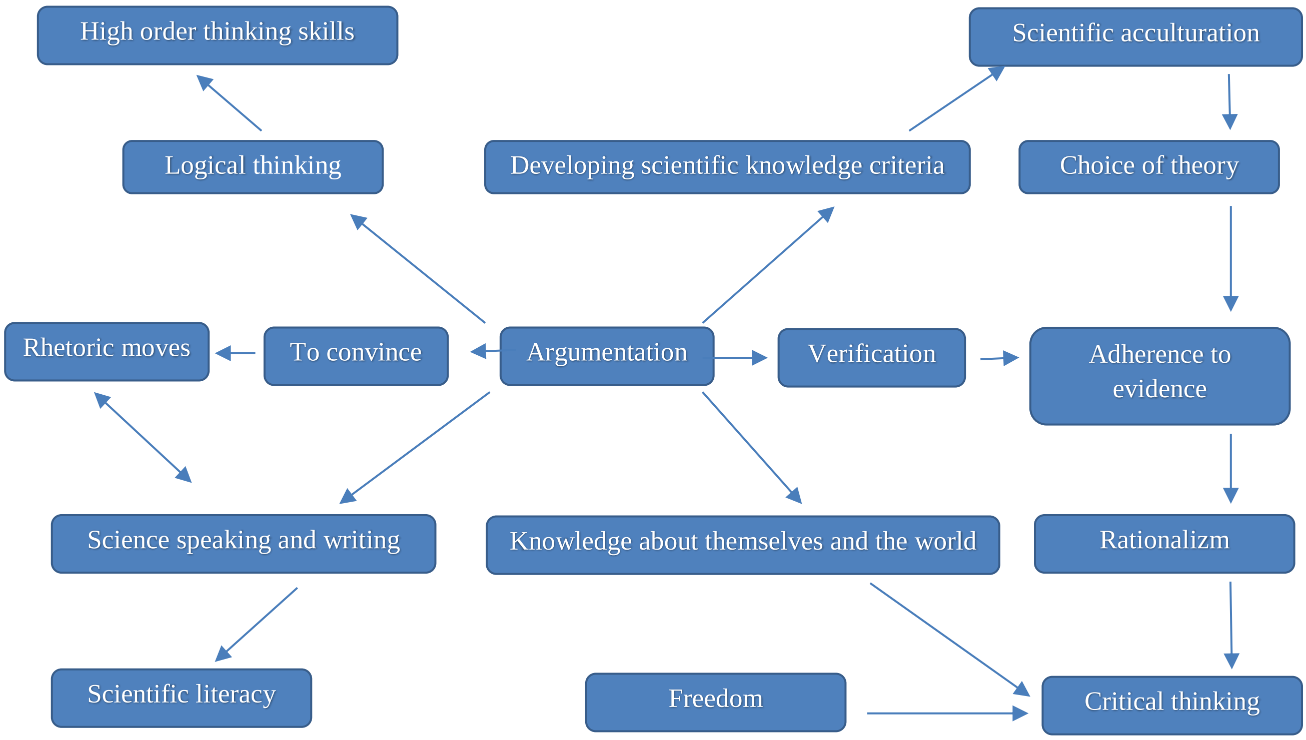


Figure 1. Argumentation Concept Map (Erduran & Aleixandre, 2007)

Expression of ideas in the classroom environment allows the student to move from the inner psychological field (mind) and rhetorical discussions to the outer psychological field (class) and dialogic discussions. Students develop both themselves and their friends by having quality discussions as a result of being of the same opinion for the benefit of the discussion. Students' interactions in personal and social areas enable them to develop their shared knowledge, values and beliefs. Students need to have a say, to be listened, to be taken seriously, to be able to make their own choices, to express those choices and to defend their rights in the learning process. These needs of students can be granted in an environment where scientific discussion takes place (Aslan, 2010). Discussions make students curious and active. Creating explanations to ensure in-depth understanding encourages them and provides students with the opportunity of examining the mistakes thoroughly and resolve them (Kaya, 2005).

The learning environment should support students’ acquisition of critical-thinking skills as a tool that students use to construct their understanding (Grabinger & Dunlap 1995). In classes where scientific discussions take place, the student approaches the subject in the way a scientist thinks, instead of memorizing it, and tries to correctly configure concepts in his mind (Ardaç, D. & Yakmacı-Güzel 2006; Simon, Erduran & Osborne, 2006). In addition, students' critical thinking also develops, since understanding the relationship between the claim and the evidence in discussions is an understanding of the claim and the reasoning. Jacob (2012) stated a significant relationship between critical-thinking skills and conceptual understanding. Students who are skilled in critical thinking have higher cognitive learning outcomes than those who are not, and critical thinking has a significant influence on academic success (Beaumont Walters & Soyibo, 2001; Wiles, Allen & Butler 2016). Researches show that there is a significant relationship between concept structuring and students' development levels and higher level thinking skills. Accordingly, students who score higher than their peers in terms of scientific reasoning achieve higher scores compared to students who score low on structuring theoretical concepts (Cavallo, 1996, Kwon & Lawson, 2000) Skills that are learnt and developed in class can be used in similar subject areas and in similar situations outside the class (Seferoğlu & Akbıyık, 2006). The subject knowledge that a person has affects his or her reasoning about the events that he/she encounters. When the same event is interpreted using different subject knowledge, different inferences are reached. For instance, in the first observations that were done with magnetism, the inference of the objects with magnetic properties carrying mystical powers was an inaccurate reasoning made in subject knowledge (Ateş, 2004).

During the argumentation, the students submit their claims and support these claims using evidence. Students know that they are right if they can support their claims with scientific evidence but if they can't, then they need to change their claims. Throughout this process students learn both the scientific concepts and apply scientific methods (Driver, Newton & Osborne, 2000). The goal is to enable science students to think critically about scientific concepts, to support their evidence-based claims, and to take on the role of an individual who explains and researches, questions and discusses their ideas rather than just conveying only a number of known phenomena (Taasoobshirazi & Hickey 2005). In this way, students in science education can develop their critical thoughts throughout argumentation (Rayner & Papakonstantinou 2018).

According to Schafersman (1991) critical thinking" is the *scientific method or scientific thinking* utilized in everyday life. Critical thinking matches with the skills used in obtaining scientific knowledge. Both critical thinking skills and scientific thinking processes include hypothesizing, testing and evaluation, experiment planning (including the control of variables) and coming to valid and reliable conclusions. Critical thinking is closely related with skills of choosing the right option among alternatives and constantly considering various alternatives. Students are ensured to think critically in science classes at the stage of determining variables when designing experiments and producing new experiments through changing those variables and developing hypotheses, when using new instruments in every new experiment or finding new ways of using those instruments, at the stage of presenting and assessing data (Koray, Koksal, Özdemir & Presley, 2007). Laboratory practices conducted with this purpose resulted in a significant effect on students' critical thinking in the development of skills. The literature indicates that argumentation – based laboratory practices had positive effects on students' critical thinking skills (Hasnunidah et al., 2020; Sönmez, Memiş, Yerlikaya, 2021; Stephenson & Sadler-McKnight 2016).

Argumentation involves evaluating claims, citation evidence to justify claims, and using decision-making strategies with opposing positions. Students need to learn the reasons and ponder the evidence. In other words, they need to develop their skills by engaging in discussion (Maloney & Simon, 2006). It is now a common view that scientific practices such as discussion help young people learn scientific theory and concepts and enable them to engage in scientific discourse, learn the functionings of scientific initiatives, and embed scientific concepts and practices in decision-making processes in daily life. Discussion has a *competing theories* activity in which students have to evaluate how to decide between competing claims (Bricker & Bell; 2008; Erduran, Ardaç & Yakmacı-Güzel, 2006). In the process of structuring the scientific knowledge, the skills of decision making about the strenght and validity of evidence, thinking scientifically and reasoning are required. In order for these skills to develop in students and for them to be appreciative about the importance of evidence, it is a necesssity to expect them to use the evidence to justify their own judgments and decisions. For this, students need to engage in activities in which they can explore and examine different points of view that will enable them to understand how evidence is used to convince someone to change a specific point of view (Maloney & Simon, 2006). These activities, on the other hand, can be carried out in an environment where there is scientific argumentaiton. Discussion in learning environments should be created for students by directing students to criticize or question the already framed information, with critically comparing evidence by making predictions and observations (Longino, 1990), and this will naturally challenge students' thoughts by inviting critical questions (Osborne, Erduran & Simon, 2004).

Haynes and Bailey (2003) emphasized that it is important to ask accurate questions in order to improve students' critical thinking skills. Hemming (2000) stated that learning environments should be supported in order for students to demonstrate and practice their critical thinking skills, and this will be done by integrating classroom discussion and questioning techniques. Critical thinking skills of students can be developed with these questions: "*What do you think about it?*, *Why do you think like that, and what is your knowledge based on*?, *What explains it, what leads to it, what are its links*? *Is it possible to view it with different perspectives*?". By questioning whether students think about all the other alternatives, whether they are aware of the reason of them thinking that way or in short, by questioning their thinking process, students can be made to think about their own thinkings (Snyder & Snyder, 2008). In the convention of critical discussion, both trying to refute and criticism have a dominant role. The qualification of criticism is probably that it deosn't leave knowledge to personal opinions, but to method, discussion and exchange of ideas (Kökdemir, 2003).

At this point, Cohen (1993) highlights the importance of having students do argumentation practices that they can think upon and see what other viewpoints are, instead of just one specific viewpoint of the teacher. This way, students learn as they discuss and question subjects (cited in Kökdemir & Demirutku, 2000). In consideration of these data, the research questions investigated in the study were: Is there a significant difference between the experimental group students and control group students in terms of critical thinking? This study aimed at investigating the effects of student-centered activities based upon scientific argumentation in chemistry classes on the critical thinking skill development of students.

METHODOLOGY

Implementation

In this experimental study, semi-experimental design with unequated control group was employed in pre-test and post-test. It was assumed that the experimental and control group students had similar backgrounds and were of the same age and experienced similar changes in their behaviors through which they achieved similar levels of cognitive and psychological maturation. Participants did not differ significantly from each other in terms of their ages and cognitive levels, experiences and socioeconomic characteristics. There were four classes in the 11th grade in the school where the study was conducted. While choosing the groups to be included in the study, it was assumed that similar experiences were going to be acquired, and also whether the same branch teachers attended the classes and volunteering were taken into consideration. Students in both classes were eager to get involved in the study. The researcher randomly selected one of the two groups of students of the same age group with similar academic characteristics as the control and the other as the experimental group. The study was carried out with the participation of an experimental group of 17 students who were taught through instruction based upon argumentation and a control group of 17 students who were taught through conventional instruction. The study was conducted with 11^{th} grade students and continued for the two successive terms within the same educational year. The sample of the study was selected with an exam that was held in the last year of primary education, and among the students who had high-level thinking skills; who were curious, studying, questioning, interested in environment and social issues, interested in different areas such as history of countries and religions, literature, technology, space sciences and who had a high intellectual level as of their age. As the researcher conducted the implementation process in control and experimental groups, he spent a good time with participants in the research environment. The researcher met with the students in both groups before the implementation process and interacted with them until the end of the implementation.

To ensure the validity of the qualitative leg of the research, procedures such as making long-term observations in natural environments proposed by Creswell and Miller (2000) and monitoring the research process by an outside science researcher were adopted. The courses in both the control and experimental group were monitored by a researcher, who had a doctoral dissertation on argumentation, for one day in monthly periods. At each stage of the study, the researcher constantly interacted with two experts in chemistry education, and took their evaluations and opinions into account.

Argumentation activities were prepared that enabled the interaction of students individually or in small groups, explained the concepts and relations between concepts of the 11th Grade Chemistry Curriculum content, included critical thinking skills appropriate for the nature of educational targets for the experimental group students. Thirteen activity applications for reaction rate unit, eight activity applications for chemical equilibrium unit, five activity applications for solubility equilibrium unit, ten activity applications for acids and bases unit were carried out. In the experimental group, the courses were conducted in accordance with the philosophy of the constructivist approach in accordance with argumentation-based activities.

Students studied individually in the first 1-2 minutes of each activity. After this, each student formed a duo with another student in their group. These two students were encouraged to discuss their individual work with each other, sharing and comparing it, especially when they had different thoughts. The purpose of this activity was to enable students to reach a common decision as a result of their discussions based on the reasons of their thoughts. However, they were not necessarily required to make a joint decision. They were asked to share their decisions with the other duo, who had reached a common decision in their group within the same process, and how and why they reached this decision, and ultimately discuss and make another small group decision. In each activity where individual differences were tried to be determined, the required environment was prepared for small groups to make a decision within themselves, and the researcher did not interfere in small group discussions unless necessary. But the researcher made some attempts to get students involved in the discussion where necessary. The researcher asked encouraging questions like "*Why do you think that?*, *What is your reasoning?*, *What is your proof?*, *How do you refute that claim?*, and *What is your argument?"* Discussions conducted by small groups within themselves allowed to reveal and analyze new ideas, reveal the inaccuracy or accuracy of ideas through promoters and rebuttals, evaluate the weaknesses and strengths of ideas and allowed students to think and detail knowledge in depth. Below are two examples of the way activities are processed.

a. *Theories that compete with ideas and proof:* In an activity called *Rusty Pipes*, whether there was a difference with the thickness of the rust in the hot water and cold water pipes in the plumb system of a house was asked and there were different statements regarding the claims' reasonings. Students were asked to support their claims by making appropriate choices from the statements of evidence. Students evaluated each evidence statement through small group discussion and identified evidence statements that supported their chosen theory. Decision made in small groups was moved to larger group discussion and a joint decision was reached.

b. *Experimental design:* After the *Rusty Pipes* activity, the students were asked to design an experiment regarding the effect of temperature on reaction rate. Students designed the experiment in groups of four. Blackboard of the classroom was divided into sections by the number of groups. A spokesperson for each group wrote important elements like the hypothesis to be tested, dependent/independent/controlled variables, and design of the experiment onto the section given to them on the board. Each group's spokesmen discussed the appropriateness of the experiments they designed in front of the classroom. Other students were able to have a say when they wanted. Experimental designs that contained appropriate, inappropriate or missing elements were identified. The completion of experimental designs with missing elements was determined by a large group discussion.

In the control group, an approach was adopted in which the teachers played an active role with their teaching position and the students were passive with their listening position. Before coming to the classes, the teacher determined how to explain the subject, how much time it would take and what examples to give. Students were informed about which topic to discuss in the next class, and they were allowed to come prepared for the class. At the beginning of each class, the teacher started by giving examples from current issues related to the subject in order to draw student's attention to the subject. After the subject was covered, the teacher asked the students if there was any point they didn't understand. The points that were not clearly understood by the students were explained again by the teacher. Afterwards the students were asked various questions to find the accurate answers. The course-book and worksheets containing open-ended and multiple-choice questions at all levels of Bloom's taxonomy were used as sources. At the end of the class, the connection between subjects was built by making a general review. Experiments with the same content as the experimental group were conducted according to the chemistry textbook. For the experiment, students were divided into groups of three and four, and all the necessary materials, procedures, templates of tables and graphs that they were required to draw were prepared and given to each group. In the control group, though rarely, the class spontaneously turned into a discussion class and continued in this way.

Measuring Tools

Critical Thinking Skills Measuring Test (CTSMT):

Watson Glaser Critical Thinking Skill Scale (WGCTSS) was used as data collection tool. Instead of the complete Watson-Glaser Critical Thinking Skill Scale (WGCTSS), an adaptation scale, which was developed through alterations that would not change the question content, was applied. Two educators' opinions were received in terms of language and research suitability. As a result of a study conducted with 120 students for the reliability of the test, the reliability of the test was found to be α=0.65.

The five subsets are as follows (Watson & Glaser, 1964): Test 1: Inference (CTS1, 10 items), samples ability to discriminate among degrees of truth or falsity of inferences drawn from given data. Test 2: Recognition of Assumptions (CTS2, 6 items), samples ability to recognize unstated assumptions or presuppositions which are taken for granted in given statements or assertions. Test 3: Deduction (CTS3, 7 items), samples ability to reason deductively from given statements or premises, to recognize the relation of implication between propositions, to achieve necessary inference from given premises. Test 4: Interpretation (CTS4, 6 items), samples ability to focus on evidence and to distinguish between (a) generalizations from given data that are not warranted beyond a reasonable doubt, and (b) generalizations which, although not absolutely certain or necessary, do seem to be warranted beyond a reasonable doubt. Test 5: Evaluation of Argument (CTS5, 6 items), samples ability to distinguish between arguments which are strong and relevant and those which are weak or irrelevant to a particular question at issue. The highest score that can be obtained from the WGCTSS is 40. The application time of the test is set to be 45 minutes.

Achievement Tests (Reaction Rate Achievement Test RRAT, Chemistry Equilibrium Achievement Test CEAT, Solubility Equilibrium Achievement Test SEAT, Acid/Base Equilibrium Achievement Test, ABEAT)

Determining the effect of a scientific discussion-based teaching approach on students' critical thinking skills step by step was also covered by the study. Restricted and unrestricted open ended questions, multiple choice questions, paper and pencil performance assessment questions were included in the tests. Achievement tests were prepared in a multi-format structure to measure critical thinking skills. The test questions were developed by the researcher by examining the basic achievements predicted by *2008 Secondary School Chemistry Course Curriculum*, 11th grade chemistry textbooks and especially the misconceptions of the same age group students in literature

(Çakmakçı, Donnelly & Leach, 2005; Petrucci, Harwood & Herring, 2002, Trans: Uyar & Aksoy). RRAT and ABEAT tests consisted of six questions, CEAT test seven questions and SEAT test five questions. The time limit for each test was set to be 45 minutes. The content and structure validity of each achievement test was evaluated by three chemistry teachers and two science education specialists and the research was decided to be suitable for its goal.

To determine the reliability of results from achievement tests the intracoder and intercoder reliability were examined. Intracoder reliability is whether the encoder can achieve the same result when the encoding process is repeated (Stemler 2000). Intercoder reliability is expressed as the ability to encode the same text in the same way as different people (Weber 1990). The researcher developed encodings of the critical thinking sub-skills of each unit's achievement test. Evaluation of the tests in terms of the use of critical thinking sub-skills was carried out by two science education researchers. In the first encodings, Inter-encoder reliability was about 60% for RRAT, 60% for CEAT, 70% for SEAT, and 80% for ABEAT. For situations in which there was no match between the researchers' codes, the opinion of the other researcher who was involved in certain stages of the study was consulted. The final version of the assessment was reached after at least two researchers' joint decision. In order to evaluate the reliability of the intra-coder, this process was repeated by the researcher to evaluate the post-tests at the end of each unit and the pre-tests of the next unit. Intra-evaluator reliability was achieved at about 70% for RRAT, 80% for CEAT, 80% for SEAT, and 80% for ABEAT. And this rate can be said to be sufficient (O'Connor & Joffe, 2020, p.9). Students' responses are encoded in the following way: CTS1 for each valid inference skill not explicitly stated based on evidence and logic, CTS2 for each unstructured correct assumption that can be deduced from a given situation, CTS3 for any valid conclusion, a given implication, or any necessary inference that can be drawn within the entire set of advanced propositions / successive logical propositions by referring to a formula, law, or a premise, CTS4 for every unsuspecting correct description of information components leading to a conclusion, CTS5 for each correct evaluation of the strength of an argument.

Prior to a course to determine knowledge baseline, a pre-test was administered in order to determine the students' pre conceptions about the subject and the skills they previously had about scientific and critical thinking processes. A post-test was administered to determine both the conceptual change and the acquisition of critical thinking skills in students at the end of the learning process. The study dealt with data on changes in students' critical thinking skills and interpretations of data. The content of the achievement tests is summarized in Table 1.

Table1. Evaluation of Achievement Tests in terms of Critical Thinking Skills

Unit	Questions	Subjects	Critical Thinking Subskills
RRAT	1	Enthalpy of Reaction- Activation Energy	CTS1, CTS3, CTS4
	2	Factors Affecting Reaction Rate	CTS1, CTS4
	3	Factors Affecting Reaction Rate	CTS1, CTS3, CTS4
	4	Factors Affecting Reaction Rate	CTS1, CTS2, CTS3, CTS4, CTS5
	5	Factors Affecting Reaction Rate	CTS1, CTS2, CTS3, CTS4
	6	Factors Affecting Reaction Rate	CTS2, CTS3, CTS4
CEAT	1(1-8)	Le Chatalier Principle	CTS1, CTS2, CTS3, CTS4, CTS5
	2	Interpretation of Equlibrium Constant	CTS2, CTS3, CTS4
	3	Le Chatalier Principle	CTS2, CTS3, CTS4
	4	Le Chatalier Principle	CTS2, CTS3, CTS4
	5	Le Chatalier Principle	CTS1, CTS2, CTS3, CTS4
	6	Le Chatalier Principle	CTS2, CTS3, CTS4
	7	Le Chatalier Principle	CTS2, CTS3, CTS4
SEAT	1	Solubility Equilibrium, Dissolution Rate	CTS2, CTS3
	2	Common Ion Effect on Solubility Equilibrium	CTS2, CTS3, CTS4
	3	Temperature Effect on Solubility Equilibrium	CTS3, CTS4
	4	Relation Between Dissolution and Solubility	CTS1, CTS2, CTS3, CTS4
	5	Selective Precipitation of Ions	CTS1, CTS2, CTS3, CTS4

ABEAT	1	Neutralization reactions	CTS1, CTS2, CTS3, CTS4
	2	Properties of Acidic Substances	CTS1, CTS2, CTS4
	3	Properties of Acidic Substances	CTS1, CTS3, CTS4
	4	Acid Base Strength	CTS1, CTS2, CTS4
	5	Acid Base Strength	CTS1, CTS2, CTS3, CTS4
	6	pH of Extremely Dilute Acid Solutions	CTS1, CTS2, CTS3, CTS4

RESULTS

Quantitative Analysis

Repeated t-test was applied to the WGCTSS pre-test score averages of the experimental and control groups and there was no significant difference between the score averages of the two groups ($\overline{X}$ =22.59 for the experimental group, $\overline{X}$ =22.41 for the control group, SD=32, t=0.15, p>0.01). Although the WGCTSS pre-test scores of experimental and control group students showed normal distribution, Wilcoxon test analysis was applied to the $WGCTSS_{pre}$ and $WGCTSS_{post}$ test scores in both groups, since the $WGCTSS_{pre}$ test scores did not show normal distribution. A statistically significant difference was found between the groups' WGCTSS score averages before and at the end of practice (for the experimental group, $WGCTSS_{pre}$ test score average=5.00, $WGCTSS_{post}$ test score average= 8.73, Z=-3.26, p < 0.01, for the control group, $WGCTSS_{pre}$ test score mean average=2.57, $WGCTSS_{post}$ test score average= 9.87, Z=-396, p<0.01). According to these results, critical thinking skills of experimental and control group students developed all research round.

Since the $WGCTSS_{post}$ test scores of the experimental and control group did not show normal distribution, the Mann Whitney U test analysis was applied to the $WGCTSS_{post}$ test score averages. It was observed that there was a statistically significant difference between the average critical thinking skill scores of experimental and control group following the research. When the score averages of the experimental and control group are taken into account, this difference appears to be in favor of the experimental group. The results are given in Table 2 below.

Table2. U-Test Results of WGCTSS Post Test Mean Scores

Scale	Group	n	Score Averages	Sequence Sum	U	p
$WGCTSS_{post}$	Experiment	17	23.11	398.00	44.00	0.000
	Control	17	11.59	197.00		

In other words, the score average of 23.11 of the experiment group students is higher than the score average of 11.59 of the control group students, and the difference is statistically significant (p<0.01). According to these results, the teaching approach based on scientific argumentation is more effective in developing students' critical thinking skills than the teaching approach in which the teacher's narrative is at the center.

Qualitative analysis

Critical thinking can be developed depending on the subject area. Trainings focused only on critical thinking, independent of the subject area, are insufficient to acquire critical thinking skills (Seferoğlu & Akbıyık, 2006). In this research on the experimental group, with the said situation taken into account, the development of critical thinking skills was carried out together with the content of the course.

In Table 3, the total critical thinking skills of the students in the experimental and control groups were determined in the pre and post achievement tests applied in each unit.

Table 3. Total critical thinking skills in pre and post achievement tests of experiment and control groups

Achievement Tests	Experimental Group	Control Group
$RRAT_{pre}$	29	34
$RRAT_{post}$	*261*	213
$CEAT_{pre}$	62	54
$CEAT_{post}$	332	308
$SEAT_{pre}$	8	15
$SEAT_{post}$	141	97
$ABEAT_{pre}$	24	23
$ABEAT_{post}$	335	287

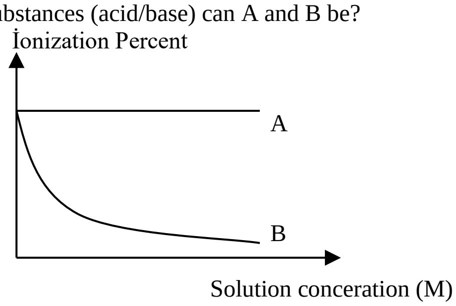
The total critical thinking skills in the pre and post achievement tests of the critical thinking skills of the experimental and control group students during the practice are as shown below.

Experiment Group: Pre - test-N: 123 CTS; post - test-N: 1072 CTS

Control Group: Pre - test-N: 126 CTS; post test-N: 905 CTS

A sample of the two questions applied in the test and an example of how the evaluation was performed are given in Table 4. As a result of the implementation, the reason why the critical thinking skills of the students in the experimental group developed more than the students in the control group is because the courses in the experimental group are processed with a scientific discussion oriented teaching approach. Critical thinking, a complex and comprehensive process that requires high-level cognitive skills, can be better developed in discussion environments where frequent questions, growing tension, unexpected results, and active learning are present.

Table4. Sample questions from achievement tests and sample coding for evaluation

Questions	Students' Answer and Measured Skills	
	Student 1C (Control Group)	Student 1E(Experimental Group)
ABEAT 5. The graph below shows the change of the ionization percentage of A and B in water depending on the concentration. What kind of substances (acid/base) can A and B be?  A: ....Because, B: ....Because, How does the pH value of A and B change? Explain the reasoning according to your answer to Section A of the question. A: decreases () increases () does not change () because; A: decreases () increases () does not change () because;	Water is evaporated (CTS1) or acid or base is added (CTS1, CTS2). Strong acids ionize 100%. A is a strong acid (CTS3), A is already completely ionized (CTS1). In strong acids, the percentage of ionization does not change depending on concentration. Because they are already completely ionized. They are strong, anyway. The reason of them being strong is because the percentage of ionization does not change (CTS4), pH does not change (CTS3, this answer was not accepted accurate). As there is no fully ionization, B is either a weak acid or base (CTS2, CTS3). There is equilibrium in solution B (CTS1) which shifted to those which entered the equilibrium so that the percentage of ionization decreased. B is either weak acid or base (CTS1). As the ionization percentage of B decreases, the equilibrium shifts to the reactants, the concentration of hydrogen ions decreases (CTS4 was not evaluated because the associations were not established correctly), the pH increases (CTS3).	Temperature is constant. More concentrated acid or base solution was added (CTS1). Strong acids ionize 100% in water, so a strong (acid or base) (CTS2, CTS3) is a one-way reaction (CTS1). The percentage of A did not change. It became more concentrated (CTS4), while the acid decreased in pH, and the base increased in pH (CTS2). Ionization of weak acids is not 100%. B can be weak acid or base (CTS2, CTS3). As the concentration of the acid increased, the percentage of ionization decreased, the ionization of weak B (acid or base) (CTS4), is an equilibrium reaction (CTS1). Temperature is constant (CTS2). $HB + H_2O \rightleftarrows H_3O^+_{(aq)} + B^-_{(aq)}$ when the equilibrium shifts to the left, the reduced hydrogen must be less than the added amount (CTS1) so that the ionization constant does not change (CTS2). If $Ka=x^2/A = y^2/B$ (CTS2), y is y>x, since $y/x = \sqrt{B/A}$ is B>A. Hydrogen concentration increases (CTS3). pH decreases. If it's acid, the pH decreases because its acidity is increased. If it's base, the pH increases (CTS3).

SEAT1: There are the solubility constants (K_{sp}) values of some salts below. What kind of information can be obtained from this data? AgCN $AgIO_3$ AgI Ag_2SO_4 Ag_2CO_3 AgCN Ksp= $1,2x10^{-6}$ $AgIO_3$ Ksp= $3,0x10^{-8}$ AgI Ksp= $8,5x10^{-17}$ Ag_2SO_4 Ksp= $1,4x10^{-5}$ Ag_2CO_3 Ksp= $8,5x10^{-12}$	The solubility at the same temperature (CTS2) can be found (CTS3). The ions concentration at equilibrium can be calculated (CTS2, CTS3). Data about ionization percentages can be reached (CTS3). (This judgment was not accepted because there is no data about the concentration of solutions.).	In saturated solutions (CTS2) at the same temperature (CTS2), ion concentrations can be calculated (CTS3). The solubility of these can be compared (CTS3). The boiling point of Ag2SO4 solution, which contains the most ion concentration, is the highest, and the boiling point of AgI solution is the lowest (CTS3).

Discussion activities implemented on the experimental group were conducted based on writing and speaking about science. This may have contributed to the development of students' critical thinking skills. Likewise, being able to write their thoughts and opinions makes students cognitively active (Doğanay & Ünal, 2006). Written statements give students the opportunity for defining the problem, reclaiming, reasoning, making inferences, and expressing themselves better. There is a strong relation between language and thinking. Also the first stage of critical thinking education should be language education (Levy, 1997 cited in Kökdemir, 2003). Therefore, it can be said that critical thinking skills develop more effectively in educational environments where scientific argumentation approach is used.

DISCUSSION

One of the most important skills that scientifically literate individuals are expected to possess is critical thinking skills. In order to find a way to the problems experienced today and make sound judgement, it is necessary to have individuals with critical thinking skills. Science education has an important responsibility for students to acquire and develop critical thinking skills because critical thinking is an important power that supports the gaining of knowledge. In this regards, the teaching approach to be used in science education should be carefully selected to acquire thinking critically. Critical thinking is a complex and comprehensive process that requires high level cognitive skills. It can be developed better in an environment of frequent questions, growing stress, unexpected results and active learning.

Critical thinking can be improved depending on the subject. Skills that are learnt and improved can also be used with other similar subject and situations in/outside the class. Trainings focused only on critical thinking, independent of the subject, are insufficient to acquire critical thinking skills (Seferoğlu & Akbıyık, 2006). In the implementation of this study on the experimental group, with the said circumstance taken into consideration, the development of critical thinking skills was carried out together with the content of the course.

Experience that individuals obtain through their lives is very important with regard to education. And this experience gives rise to certain changes in topics such as getting information about facts and skill improvement. Studies on the acquisition and development of critical thinking skills have indicated that the school type affects the results of the study (Beaumont Walters & Soyibo, 2001). The students in this study consist of students with overachievement. Both traditional and argumentation teaching that have been suggested have contributed to students' critical thinking skill improvement. The students in both groups participated actively. In the control group, especially in the courses where chemical equilibrium and acids and bases units were taught, students took an active role in their own learning rather than being passive learners. Courses in which teaching was conducted with a traditional approach were mostly learning environments in which students asked high-level questions about problems they faced during or after the course, and other students thought about and commented on these questions as well. Students in both groups had extensive information webs for each class during research period and hence their cognitive development increased and their learning and life experiences enriched. That open-ended questions were asked in written exams and in-class activities, computer animations and experimental activities, designing suitable class environments in which students could ask questions and express themselves freely, following thinking processes and class activities in which knowledge patterns were created, students' questioning their own concepts and constructing their concepts correctly and meaningfully instead of providing them with facts to memorize supported critical thinking in both groups. However, in the argumentation activities based on causal hypothesis, students' defending their claims with reasoning, supporting their claims with strong evidence, building patterns between concepts, listening to different claims and defenses critically, rebutting opposite views made greater contributions to experimental group students' skills of determining variables, interpreting data scientifically using reason-result relation more than those of control group.

As scientific argumentation is a process of using evidence and presenting necessary argumentations, it is related with problem solving skills and problem solving includes argumentation. During problem solving activity, more than one viewpoint and idea should be identified, a logical solution should be found and that solution should be supported with data and evidence. Argumentation has positive effects on students' problem solving processes and skills (Cho and Jonassen, 2002). The written exam question content for both groups, achievement tests applied at the beginning and end of each unit, students' solving high level problems after class hours and solving the unsolved questions during class hours may have supported the critical thinking skills of both group students. Besides, the sample of the study was constituted by students who were chosen by an exam in their senior years of elementary school, mainly had higher level thinking skills, had high capacities in science and mathematics, were curious, read a lot, questioned a lot, took interest in issues related with their neighborhood and society, had different interests, had high intellectual levels compared to their ages. It was difficult at times to conduct argumentation-based activities with students at these levels; in that, as students reached conclusions in a short time and hence arguments came to an end before long, the role of the activities on the development of students' higher order thinking skills was very little. Moreover, the students experienced more anxiety for university entrance examination as they viewed that their knowledge attainments were not sufficient at the end of these activities. Besides, control group students' attendance to certain classes was high. In these classes, they played an active role in their own learning instead of being a passive receiver of knowledge. The students asked high level questions for the questions and problems they encountered during or after classes and searched for answers with their classmates. This may have been the reason for significant difference in terms of critical thinking sub skills of control group between pre and post tests.

The key of understanding a subject is understanding the language of that subject, and almost everything we habitually call knowledge is language. A doctrine (discipline) is a way of knowing, and everything known cannot be separated from the symbols (mostly words) in which knowledge is codified. For example, what is biology but words? If all the words used by biologists were removed from the language, there would be no biology (Osborne, 2002). Students may be asked to explain the concepts, terms, models and phenomena that scientists have come up with in a social context by reaching a common view. For this, students should be introduced to the ways in which scientists perceive the world and to the scientific tools of that culture. Learning and using the language of science allows students to define, depict and portray the world in completely new forms. Recent studies have emphasized that courses conducted with scientific discussion are useful in developing a better understanding of scientific ideas for students (Aslan, 2010).

Discussion activities implemented on the experimental group were conducted based on writing and speaking about science. This may have contributed to the development of students' critical thinking skills. Students in the experimental group explained the reasons for their responses to achievement tests in detail, either using mathematical links or at the molecular level. There is a strong relation between language and thinking (Levy, 1997 cited in Kökdemir, 2003). Therefore, it can be said that critical thinking skills develop more effectively in educational environments where scientific argumentation approach is used. Experimental group students' critical thinking skills improved more than those of control group students because they defended their claims with reasoning in argumentation activities based on causal hypothesis, supported their claims with strong evidence building patterns between concepts, listened to various claims and reasoning critically, rebutted opposite views. This result corresponds to the results of other studies in literature (Lee & Ertmer;

2006; Özdemir, 2005; Simon, Erduran, Osborne, 2006; Yerrick, 2000). The discussion level was high in the activities where students commented and made inferences about a graph or a chemical event (Reaction Mechanism, Le Chatalier's Principle, Percentage of Ionization), and where the students had solution suggestions for a given problem (precipitation conditions). Students' activeness and interest in such discussions were really high, as the activities containing table of statements summarized the concept and the relationships between the concepts in the activity and also required students to support their decision regarding the accuracy of the statement with strong evidence. As a matter of fact, according to Zohar, Weinberger and Tamir (1994), critical thinking matches with the skills applied in obtaining scientific knowledge. Methods, tools and materials were not given to the student directly in the laboratory activities, but a problem situation was given to the students, and the students were asked to formulate a hypothesis for the solution of this problem or the students were given a hypothesis, and they were asked to design an experiment to determine the accuracy of this hypothesis, record the obtained data, evaluate and interpret the findings. In the activities where teaching was continued with this approach, students became more active in evaluating their existing scientific models, observing, interpreting data, and creating new scientific models. Similarly, during the activities, students were not given some of the necessary data directly, and they were asked to determine the information they would need to solve the problem and find it from sources. For example, in the *reaction of metals with acids and bases* activity, students were not given the atomic numbers of the metals used directly and were expected to use the existing periodic table in the laboratory. They were in a laboratory setting in which students, through argumentation activities, can pass on their own ideas and their friends' ideas through lenses of reliability, accuracy, validity, and competence, as well as practice to this end (Sönmez, Memiş &Yerlikaya, 2021). Meanwhile, the students identified variables, developed a hypothesis and determined a method. It can be stated explicitly that students' writing down their claims on activity papers with reasoning made great contributions to their skills of expressing their experiments and hypotheses written and orally during argumentation activities. According to Schafersman (1991), writing activities promote organizing thinking and thinking critically. Scientific process skills and problem solving skills that students employed in these stages may have contributed to the development of critical thinking skills.

Critical thinking skills of each person improve gradually but continually when used successfully. Sudden improvement of critical thinking skills without effort is unexpectable. Therefore, from the first school years, students should be directed towards dealing with problems that they can employ their rational skills at their levels and be successful at these levels (Kuhn, 1986 cited in Zohar & Nemet, 2002).

The concepts of equilibrium were explained with analogies. Thinking scientifically, of course, can be taught through analogies. Scientists often use analogies to discover new laws and explain natural phenomena. Huygens used water wave model (motion) to understand the phenomenon of light; Kepler developed the concepts of Earth motion by looking at the way a clock works. By transferring these mind habits of scientists to students at all levels, students' descriptions of the mind can be embodied. If the student gets a clear idea of the basic and target concepts, then the knowledge qualities will come in more systematic and meaningful models (Ganguly, 1995).

Engaging students in argumentation is not a target of curriculum in science classes. Therefore, teachers scarcely hearten their students to discuss. In their study in which they tried to identify how 12 elementary school teachers employ argumentation in their classes, Simon, Erduran and Osborne (2006) stated that before employing this method the teachers were not sure about explaining alternative concepts to students as they might strengthen concepts inconsistent with scientific truth or feel puzzled but they became comfortable after employing argumentation method. Actually it signifies the fact that teachers do not know about argumentation. As a matter of fact, it is no surprise as very few newly-graduates have studied argumentation. More and more studies are mentioning the advantages of argumentation in science education. Therefore, argumentation classes should be taught at universities for future teachers. Yet, the number of studies which will lead the way for teachers and educators are not many. As such studies increase, educational literature will attain favorable contributions.

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