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The effect of the inquiry-based learning approach on student's critical-thinking skills[1]

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The purpose of this study is to determine the effect of an activity set developed according to the inquiry-based learning (IBL) approach in the unit "Particulate Structure of Matter" on students' critical-thinking skills in science and technology courses. The study was conducted with 90 students from the 6th grade attending four, 6th grade secondary school classes. Within the framework of the study, in order to evaluate the effects of IBL approach on the students' critical-thinking skills in science and technology courses, the guided activity set was developed by the researchers in line with the IBL approach. In this study, pretest and posttest control group experimental designs were applied. The findings of the study revealed that science and technology learning supported with the guided activities developed in line with the IBL approach have significant effects on students' critical-thinking skills in science and technology courses.

Keywords: critical thinking skills, guiding activity set, inquiry-based learning approach, the particulate structure of matter

INTRODUCTION

Contemporary science reform movements emphasize the fact that inquiries in science teaching are of great importance and that science should be taught to students by means of inquiry (American Association for the Advancement of Science, 1990; National Research Council, 1996). Science and technology courses are primarily based on observation in elementary school. Thus, many senses can be involved in the learning process, and students are enabled to actively participate in classes and gain concrete experiences (Nas, 2000). The vision of science and

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technology courses in Turkey is to educate all students to be science literature, no matter what their individual differences. Science and technology literacy consists of science-related skills, attitudes, values, and information required for individuals to improve their research-inquiry, critical thinking, problem solving, and decision-making skills, to be lifelong learners, and to sustain their feelings of curiosity about their environment and the world (MONE, 2005). In order to develop science and technology literacy, many different activities are used to encourage students to take part in inquiry, problem solving, and decision-making processes which can be included in the science and education curriculum (Milli Eğitim Bakanlığı (MONE), 2005). In Turkey, for the 2005-2006 school year, the Science and Technology teaching program was renewed in line with the methods and tools of the constructivist approach. In this connection, the Ministry of National Education declared that the student-centered approaches were making students active in the learning environment. One of these approaches is IBL.

State of the literature

- Numerous research investigating the effects of inquiry models developed in line with the IBL approach (5-E, 7-E teaching models etc.) on the levels of conceptual understanding and some learning outcomes.
- Very few applied studies in Turkey show how to use the inquiry-based approach in elementary schools.
- A clear need for studies to design learning and teaching activities that comply with IBL settings, and to investigate the effects of such activities on some learning outcomes.

Contribution of this paper to the literature

- The study was designed to determine the effect of using guiding materials constructed in line with the guided-inquiry method, based on Llewellyn's (2002) inquiry circle on students' critical-thinking skills.
- Learning materials developed in this study are believed to contribute to more effective science instruction.
- It is considered very important to demonstrate how to use IBL activities in elementary school science and technology classes, and to reveal how these activities affect students' critical-thinking skills.

IBL is a way of asking questions, seeking information, and finding new ideas related to an event. That is, in IBL, students learn by using cause and effect, relational and critical thinking, and combining both scientific knowledge and operations (Parim, 2009).

IBL also requires students to conduct scientific reasoning and use critical thinking when combining scientific knowledge and processes to generate a perception of science (Bianchini & Colburn, 2000). In IBL, students should learn scientific concepts and improve critical-thinking skills while conducting activities (NSES: 1-2; 2000). IBL is an instructive approach in which students can acquire information and improve their critical-thinking skills by means of discovery and investigation in authentic settings (Hwang & Chang, 2011).

IBL engages students' analytic and critical-thinking skills. While analytic thinking enables students to define the similarities and differences in variables and tendencies in data, critical thinking helps them to define the cause of a change in a variable and the effect of one variable on other variables. Through critical thinking, students can draw upon many different resources in order to explain events and predict outcomes (DiPasquale, Mason, & Kolkhorst, 2003). According to Branch and Solowan (2003), IBL, which is a student-centered approach focusing on the asking of questions, critical thinking, and problem solving, enables students to develop skills needed throughout their whole lives. As such, it helps students to cope with their problems. Moreover, it puts great emphasis on understanding and exploring scientific phenomena, expressing the meanings of these phenomena, enhancement of problem solving, scientific discussion, critical-thinking skills, construction of cognitive structures and cooperation with peers (Tseng, Tuan, & Chin, 2012; Anderson, 2007). Through discussions conducted in an IBL environment, students feel like a junior scientist and can learn how to approach issues critically (DeBoer, 2000). In a similar manner, based on a great amount of research findings, Lawson

(2010) argues that the IBL approach improves students' creativity, academic achievement, critical thinking and problem-solving skills. Thus, the IBL approach can be defined as a learning approach making students active throughout their learning lives, enhancing their scientific process using skills, and improving their critical-thinking skills through discussions and activities. In addition, in the 2013 science program, it was suggested that devices and equipment that are easy to obtain, low cost, easy to use, and do not pose any security threat, should be employed in research-inquiry activities. Although these activities should be designed for classroom environments, informal learning settings and laboratories can also be utilized (MONE, 2013).

Aiming to enhance critical thinking and problem-solving skills, the IBL approach can be implemented at different levels. These are constructed inquiry, guided inquiry, and free inquiry (Colburn, 2000). In the current study, using the guided-inquiry method, in which the teacher provides guidance for the construction of questions, students plan their own questions and processes and they generate new concepts by creating connections between prior knowledge and new information (Colburn, 2000). Similarly, in the 2013 science teaching programs, particularly in the 5th and 6th grades, the main focus was on a guided research–inquiry activity.

However, when compared with the traditional teacher-centered method of teaching, the inquiry-based teaching method is seen as more effective in increasing overall achievement and improving scientific process skills by encouraging students to discover new information and fostering their critical-thinking skills (Köksal, 2008; Blanchard et al., 2010). Moreover, based on the fact that some inquiry-based learning environments differ from traditional learning environments, Llewellyn (2002) defined inquiry-based learning environments as primarily student-centered and interactive. Table 1 shows a comparison of inquiry-based teaching with traditional teacher-centered teaching.

It is seen that there are some studies in the literature that look at the effect of the guided-inquiry method implemented at different grade levels (Köksal, 2008; Yıldırım, 2012; Bağcı-Kılıç, Yardımcı, & Metin, 2011; Karakuyu, Bilgin, & Sürücü, 2013; Bilgin & Eyvazoğlu, 2010). However, few studies investigate the effect of the inquiry-based approach on critical-thinking skills (Evren, 2012; Mecit, 2006; Wu & Hsieh, 2006; McDonald, 2004); hence, there is a need to support these studies from different points of view. Though the importance of inquiry is greatly emphasized in efforts invested to improve science education, it is observed that inquiry-based teaching is not actually conducted in class to the desired extent (Capps, Crawford, & Epstein, 2010). When reviewing research conducted in Turkey, very few applied studies were found that showed how to use the inquiry-based approach in elementary schooling. It is obvious that there is a great need for studies to design learning and teaching activities that comply with the IBL model and to investigate the effects of such activities on some learning outcomes. In this regard, it is of great importance to demonstrate how to use IBL activities in elementary school science and technology classes and to reveal how these activities affect students' critical-thinking skills. A great deal of research found in the literature investigates the effects of inquiry models developed in line with the IBL approach (5-E, 7-E teaching models etc.) on the levels of conceptual understanding and some learning outcomes. In the current study, an activity set was developed based on the stages of Llewellyn's inquiry circle (2002) that complies with the guided-inquiry model in order to render the guided-inquiry model more effective.

As a result, the current study was designed in order to determine the effect of using guiding materials constructed in line with the guided-inquiry method, based on Llewellyn's (2002) inquiry circle on the students' critical-thinking skills. The learning materials to be developed in the current study are believed to contribute to more

Table 1. Comparison of traditional teacher-centered teaching with inquiry-based teaching

	Traditional teacher-centered teaching	Inquiry-based teaching
Teacher	Provides information, presents principles, concepts and generalizations.	Guide, counselor and leader.
Student	Passive receiver of information.	Person who solves problems by following scientific stages.
Area of interest	Related to teaching of phenomena, skills and concepts. Focuses on what to teach.	Related to selection of the method suitable for solving the problem. Focuses on what and how to teach.
Learning environment	Class, teacher and standard classroom tools, fixed class hour.	Learning is a creative process that is independent of any specific person, time and place.
Method-Technique	Lecturing, reciting, repeating and dictating.	Problem solving, project, experiment.
Communication	Competition-based communication.	Cooperation-based communication.
Creativity	Performance of activities expected from children as modeled by the teacher is important.	Children have opportunities to try original ways of accomplishing behaviors and skills expected of them.
Expectation - motivation	All children are expected to be successful in the subject studied. Perfection is promoted.	Children's attempts to solve problems through their own ways are supported. Every type of effort is supported.
Purpose	Something must be learned as it must be learned.	Students learn by solving problems. The purpose of learning is understanding.
Measurement-evaluation	One-dimensional, product-oriented evaluation through standard tests.	Multi-dimensional, process-oriented evaluation through performance tests, portfolio etc.

effective instruction in science. In the current study, the purpose is to determine the effect of an activity set developed according to the IBL approach on 6th graders' critical-thinking skills of the unit "Particulate Structure of Matter" in elementary school science and technology courses.

METHODOLOGY

Research Model

The current study used a semi-experimental pretest and posttest control group design. In the pretest–posttest control group model, there were two groups formed through unbiased assignments. One of them was used as the control group, while the other was employed as the experimental group. In both groups, pretest and posttest applications were conducted (Karasar, 2004). In the study, the lessons in the experimental group were taught by the guided-inquiry method, whereas in the control group, they were only taught through the traditional lecture method, which was strictly affiliated with the science and technology textbook of the Ministry of National Education.

Sample

The population of the study consists of 6th grade students attending a secondary school in the provincial city of Muğla, Turkey, during the 2012-2013 academic school year. The sampling of the study is made up of four randomly selected classes according to a set of criteria. The basic criteria taken into consideration during sample selection included two factors: 1) the students must be 6th graders, and 2) they must attend a school that includes at least five 6th grade classes (two for the experimental group, two for the control group, and one for the pilot study). These classes are Experimental 1 (n=25), Experimental 2 (n=20), Control 1 (n=22), and Control 2 (n=23), making a total of 90 participants of the study. Piloting was conducted with the selected 6th graders for a period of four weeks, with a total of 24 course hours and 23 students. Students who participated in the pilot study were not involved in the actual research study.

Instrumentation

In line with the purpose of the current study, the 'critical thinking skills scale', developed by Demir (2006), was used to elicit the extent to which critical thinking levels were affected by various variables. The scale having analysis, evaluation, inference, interpretation, explanation, and self-organization sections consisted of a total of 56 items. The students were given 40 minutes to respond to the scale.

Within the framework of the current study, the critical thinking questionnaire was administered to 305 students as a pilot exercise, and the Cronbach Alpha coefficient of the scale was calculated to be .93. This indicated a high degree of reliability.

Development of Instructional Guidance Material in line with Guided Inquiry

Guidance material is a written material with activities based on the 6th grade unit known as 'Particulate Structure of the Matter'. While developing the material, great importance was placed on the material so as to include all the lesson objectives and to comply with all stages of inquiry-based teaching.

The guidance material was developed on the basis of the stages of Llewellyn's (2002) inquiry-based circle. Yet, different from Llewellyn's model, in the current study, the final two stages (interpretation, presentation of outcomes) were combined into a single stage. The stages of the inquiry circle laying the basis for the current study are as follows: questioning, elicitation of existing knowledge, prediction, planning and implementation of the application, commenting and presenting outcomes. Activities examples are given within Appendix 1.

Before piloting, guidance activities developed in line with the stages of the inquiry circle were scrutinized by an expert in the field of chemistry, four experts specializing in the field of inquiry-based approaches, a program development expert, and three science and technology teachers. They each scrutinized the guidance activities in terms of its suitability for the grade level, unit objectives, and the stages of guided inquiry-based teaching. In addition, the guidance materials were reviewed by a Turkish language teacher for the purposes of grammar checking. Piloting was conducted in the selected 6th graders school for a period of four weeks, with a total of 24 course hours with 23 students. Students who participated in the pilot study were not involved in the actual research study.

Application Process in the Experimental and Control Groups

The application was conducted in the same school where piloting had been carried out with the participation of 90 students from the 6th grade during the 2012-2013 academic school year. The experimental groups (Experimental 1, Experimental 2) consisted of a total of 45 students, and likewise, the control groups (Control 1, Control 2) also consisted of 45 students. The application process was conducted by the researcher in the experimental groups and by the science and technology teacher in the control groups. The teacher of the control group (in which the researcher was an observer) applied the traditional lecture method as a means of instruction and required the students to take notes. Since the teacher did not employ the inquiry-based learning approach during the teaching process, the validity of the research was established.

The experimental group students were informed about the application that would be performed. Then, each student was handed the application material designed as a book to be followed throughout the process. The students were informed about the content of the book and how it should be used.

The researcher paid special attention to the students so that they would feel comfortable asking and responding to questions. The main purpose of the activities was to make the students actively participate in the process; hence, the learning environment was maintained as suitable for the students to ask questions, to work in cooperation with their peers, and to discuss scientific topics. The researcher adopted the role of guide, showing the students ways to access information rather than providing the information for them.

In the experimental groups, the application process was completed within eight weeks. After the completion of the application process, the posttest was then administered to the students.

DATA ANALYSIS

In analysis of the quantitative data, the SPSS 15.0 statistical program package was used. ANCOVA was planned to be used after the completion of the application in order to determine whether or not there were differences between the learning products of the experimental group students, who were taught by means of inquiry-based teaching, and those of the control group students taught through the traditional learning method and who strictly followed the course book. For the determination of the difference between the posttest scores of the experimental group students and those of the control group students, ANCOVA was applied considering the significance level (p) in the pretest. By keeping the critical thinking scale pretest scores under the control, equalization was realized and based on the adjusted scores taken from the posttest, evaluations were made. By keeping the critical thinking scale pretest mean scores under the control, ANCOVA was run for the six dimensions of the scale and for each of the sub-dimensions.

RESULTS

Findings related to Experimental and Control Groups' Pretest Scores

Table 2 shows a significant difference between the critical-thinking skills of the experimental and control group students ($p<.05$) before the application. That is, the experimental and control group students were not equal before the application according to the pretest scores. As the pretest scores of the experimental and control group students vary depending on the grade level, posttest mean scores were analyzed through the ANCOVA data analysis technique.

Table 3 shows a significant difference between the experimental group students and the control group students in terms of the measured analysis, evaluation, inference, interpretation, explanation, and self-organization sub-dimensions ($p<.05$). That is, it can be argued that the experimental group students and the control group students were not equal at the beginning of the study in terms of their pretest scores. As the pretest scores of the experimental and control group students vary depending on the grade level, posttest mean scores were analyzed through the ANCOVA data analysis technique.

Table 2. CTS Pretest Analysis Results for the Experimental and Control Groups

Before Application	Class	N	$\overline{X}$	Std. Deviation	F	p
Pre-CTS	Experimental 1	25	48.44	11.25	8.63	.000*
	Experimental 2	20	32.45	15.32		

Before Application	Class	N	$\bar{X}$	Std. Deviation	F
	Control 1	22	44.95	9.08	
	Control 2	23	40.48	7.04	

Table 3. Critical Thinking Skills Test Sub-Dimensions Pretest Analysis Results

Before Application	Class	N	$\bar{X}$	Std. Deviation	F	p
Analysis	Experimental 1	25	5.96	1.65	12.50	.000*
	Experimental 2	20	3.95	2.24		
	Control 1	22	6.90	1.11		
	Control 2	23	6.13	1.36		
Evaluation	Experimental 1	25	6.76	2.37	10.20	.000*
	Experimental 2	20	3.55	2.37		
	Control 1	22	6.41	1.99		
	Control 2	23	5.04	1.72		
Inference	Experimental 1	25	6.16	1.80	8.94	.000*
	Experimental 2	20	3.35	2.52		
	Control 1	22	5.36	1.76		
	Control 2	23	5.52	1.34		
Interpretation	Experimental 1	25	6.00	1.83	7.76	.000*
	Experimental 2	20	3.30	2.20		
	Control 1	22	5.45	2.30		
	Control 2	23	4.39	1.70		
Explanation	Experimental 1	25	5.00	2.38	3.89	.012*
	Experimental 2	20	3.65	2.62		
	Control 1	22	4.77	1.95		
	Control 2	23	3.09	1.88		
Self-organization	Experimental 1	25	18.56	4.20	3.133	.030*
	Experimental 2	20	14.65	5.00		
	Control 1	22	16.05	4.47		
	Control 2	23	16.30	3.85		

Findings and Discussions related to Critical-Thinking Skills

When Table 4 is analyzed, it is seen that the posttest critical thinking mean score of the experimental group students [Experimental 1 ($\bar{X}$= 55.08) and Experimental 2 ($\bar{X}$= 46.00)] is higher than that of the control group students [Control 1 ($\bar{X}$= 40.27) and Control 2 ($\bar{X}$= 35.91)]. Whether or not the difference between the mean scores of the experimental and control groups is deemed significant was tested with ANCOVA.

Table 4. Results Concerning CTS Mean Scores

Class	N	Pretest Mean	$\bar{X}$	Adjusted Mean
Experimental 1	25	48.44	55.08	52.79
Experimental 2	20	32.45	46.00	49.99

22	44.95	40.27	39.53
23	40.48	35.91	36.48

Table 5. CTS Adjusted Posttest Scores ANCOVA Analysis Results

Variance Source	Sum of Squares	Sd	Mean Squares	F	p
Pretest	1256.05	1	1256.05	25.05	.000*
Class	4244.10	3	1414.70	28.21	.000*
Error	4061.54	81	50.14		
Total	189637.00	90			

*p< .05

When Table 5 is examined, a significant difference is seen between the critical-thinking skills adjusted mean scores of the experimental and control group students (F(3-81) = 28.21, p<.05). This difference is between the critical-thinking skills of the experimental group students measured after the application and those of the control group students. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

While no significant within-groups difference is observed, it is seen that there is a significant difference between the experimental and control groups. Therefore, it can be argued that the IBL used in the experimental group improved the students' critical-thinking skills.

Findings and Discussions Related to Critical-Thinking Skills-Analysis Sub-Dimension

When Table 7 is examined, it is seen that the analysis sub-dimension posttest mean score of the experimental group students [Experimental 1 ($\bar{X}$= 7.12) and Experimental 2 ($\bar{X}$= 6.80)] is higher than that of the control group students [Control 1 ($\bar{X}$= 6.00) and Control 2 ($\bar{X}$= 5.83)].

Table 6. Comparison of CTS-related Grade Levels

(I)CLASS	(J)CLASS	Mean Difference (I-J)	Std. Error	p	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Experimental 1	Experimental 2	2.79	2.42	1.000	-3.75	9.34
	Control 1	13.26	2.10	.000*	7.58	18.94
	Control 2	16.31	2.13	.000*	10.54	22.08
Experimental 2	Experimental 1	-2.79	2.42	1.000	-9.34	3.75
	Control 1	10.46	2.41	.000*	3.94	6.98
	Control 2	13.52	2.27	.000*	7.39	9.65
Control 1	Experimental 1	-13.26	2.10	.000*	-18.94	-7.58
	Experimental 2	-10.46	2.41	.000*	16.98	-3.94
	Control 2	3.06	2.17	.974	-2.80	8.92

Control 2	Experimental 1	-16.31	2.13	.000*	-22.08
	Experimental 2	-13.52	2.27	.000*	-19.65
	Control 1	-3.06	2.17	.974	-8.92

*p< .05

Table 7. CTS Analysis Sub-Dimension Mean Scores

Class	N	Pretest Mean	.$\bar{X}$	Adjusted Mean
Experimental 1	25	5.96	7.12	7.09
Experimental 2	20	3.95	6.80	7.08
Control 1	22	6.90	6.00	5.86
Control 2	23	6.13	5.83	5.74

Table 8. CTS Analysis Sub-Dimension Adjusted Posttest Scores ANCOVA Analysis Results

Variance Source	Sum of Squares	SD	Mean Squares	F	p
Pretest	8.66	1	8.66	5.18	.026*
Class	31.96	3	10.65	6.36	.001*
Error	135.59	81	1.67		
Total	3922.00	90			

*p< .05

When Table 8 is examined, it is seen that there is a significant difference between the critical-thinking skills analysis sub-dimension adjusted posttest mean scores of the experimental and control group students ($F(3-81) = 6.36$, $p<.05$). This difference is between the experimental group students' critical thinking analysis skills and those of the control group. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

Findings and Discussions Related to Critical-Thinking Skills-Evaluation Sub-Dimension

When Table 9 is examined, it is seen that the evaluation sub-dimension posttest mean score of experimental group students [Experimental 1 ($\bar{X}$= 7.72) and Experimental 2 ($\bar{X}$= 5.70)] is higher than that of the control group students [Control 1 ($\bar{X}$= 5.86) and Control 2 ($\bar{X}$= 5.22)].

Table 9. CTS Evaluation Sub-Dimension Mean Scores

Class	N	Pretest Mean	$\bar{X}$	Adjusted Mean
Experimental 1	25	6.76	7.72	7.17
Experimental 2	20	3.55	5.70	6.61
Control 1	22	6.41	5.86	5.52
Control 2	23	5.04	5.22	5.43

Table 10. Evaluation Sub-Dimension Adjusted Posttest Scores ANCOVA Analysis Results

Variance Source	Sum of Squares	SD	Mean Squares	F	p
Pretest	63.63	1	63.63	27.46	.000*

49.47	3	16.49	7.12	.000*
187.67	81	2.32		
3796.00	90			

When Table 10 is examined, it is seen that there is a significant difference between the critical-thinking skills evaluation sub-dimension adjusted posttest mean scores of the experimental and control group students ($F(3\text{-}81) = 7.12$, $p<.05$). This difference is between the experimental group students' critical thinking evaluation skills and those of the control group. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

Findings and Discussions Related to Critical-Thinking Skills-Inference Sub-Dimension

When Table 11 is examined, it is seen that the inference sub-dimension posttest mean score of the experimental group students [Experimental 1 ($\bar{X}$ = 7.00) and Experimental 2 ($\bar{X}$ = 5.55)] is higher than that of the control group students [Control 1 ($\bar{X}$ = 4.86) and Control 2 ($\bar{X}$= 4.52)].

When Table 12 is examined, it is seen that there is a significant difference between the critical-thinking skills inference sub-dimension adjusted posttest mean scores of the experimental and control group students ($F(3\text{-}81) = 11.55$, $p<.05$). This difference is between the experimental group students' critical-thinking inference skills and those of the control group. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

Findings and Discussions related to Critical-Thinking Skills-Inference Sub-Dimension

When Table 13 is examined, it is seen that inference sub-dimension posttest mean score of the experimental group students [Experimental 1 ($\bar{X}$= 7.20) and Experimental 2 ($\bar{X}$= 4.85)] is higher than that of the control group students [Control 1 ($\bar{X}$= 4.23) and Control 2 ($\bar{X}$= 2.96)].

Table 11. Results Related to CTS Inference Sub-Dimension Mean Scores

Class	N	Pretest Mean	$\bar{X}$	Adjusted Mean
Experimental 1	25	6.16	7.00	6.83
Experimental 2	20	3.35	5.55	6.00
Control 1	22	5.36	4.86	4.87
Control 2	23	5.52	4.52	4.44

Table 12. Inference Sub-Dimension Adjusted Posttest Scores ANCOVA Analysis Results

Variance Source	Sum of Squares	SD	Mean Squares	F	p
Pretest	9.40	1	9.40	3.95	.050
Class	82.45	3	27.48	11.55	.000*
Error	192.74	81	2.38		
Total	3047.00	90			

*p< .05

Table 13. Results related to CTS Inference Sub-Dimension Mean Scores

Class	N	Pretest Mean	$\bar{X}$	Adjusted Mean

Experimental 1	25	6.00	7.20
Experimental 2	20	3.30	4.85
Control 1	22	5.45	4.23
Control 2	23	4.39	2.96

Table 14. CTS Inference Sub-Dimension Adjusted Posttest Scores ANCOVA Analysis Results

Variance Source	Sum of Squares	SD	Mean Squares	F	p
Pretest	30.18	1	30.18	6.80	.011*
Class	175.27	3	58.42	13.16	.000*
Error	359.54	81	4.44		
Total	2770.00	90			

*p< .05

When Table 14 is examined, it is seen that there is a significant difference between the critical-thinking skills inference sub-dimension adjusted posttest mean scores of the experimental and control group students ($F(3\text{-}81) = 13.16, p<.05$). This difference is between the experimental group students' critical-thinking inference skills and those of the control group. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

Findings and Discussions related to Critical-Thinking Skills-Explanation Sub-Dimension:

When Table 15 is examined, it is seen that the explanation sub-dimension posttest mean score of the experimental group students [Experimental 1 ($\bar{X}$= 6.36) and Experimental 2 ($\bar{X}$= 5.20)] is higher than that of the control group students [Control 1 ($\bar{X}$= 4.00) and Control 2 ($\bar{X}$= 2.48)].

When Table 15 is examined, it is seen that there is a significant difference between the critical-thinking skills explanation sub-dimension adjusted posttest mean scores of the experimental and control group students ($F(3\text{-}81) = 10.58, p<.05$). This difference is between the experimental group students' critical thinking explanation skills and those of the control group. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

Table 15. CTS Explanation Sub-Dimension Mean Scores

Class	N	Pretest Mean	$\bar{X}$	Adjusted Mean
Experimental 1	25	5.00	6.36	6.12
Experimental 2	20	3.65	5.20	5.60
Control 1	22	4.77	4.00	3.81
Control 2	23	3.09	2.48	2.86

Table 16. CTS Explanation Sub-Dimension Adjusted Posttest Scores ANCOVA Analysis Results

Variance Source	Sum of Squares	SD	Mean Squares	F	p
Pretest	43.66	1	43.66	9.19	.003*

150.82	3	50.27	10.58	.000*
384.75	81	4.75		
2538.00	90			

Findings and Discussions related to Critical-Thinking Skills-Self-Organization Sub-Dimension

Table 17. CTS Self-Organization Sub-Dimension Mean Scores

Class	N	Pretest Mean	$\bar{X}$	Adjusted Mean
Experimental 1	25	18.56	19.68	19.17
Experimental 2	20	14.65	17.90	18.61
Control 1	22	16.05	15.32	15.56
Control 2	23	16.30	14.91	14.95

When Table 17 is examined, it is seen that the self-organization sub-dimension posttest mean score of the experimental group students [Experimental 1 ($\bar{X}$= 19.68) and Experimental 2 ($\bar{X}$= 17.90)] is higher than that of the control group students [Control 1 ($\bar{X}$= 15.32) and Control 2 ($\bar{X}$= 14.91)].

When Table 18 is examined, it is seen that there is a significant difference between the critical-thinking skills self-organization sub-dimension adjusted posttest mean scores of the experimental and control group students ($F(3\text{-}81) = 9.12$, $p<.05$). This difference is between the experimental group students' critical thinking Self-organization skills and those of the control group. When the adjusted arithmetic means of the groups are examined, it is seen that this difference favors the experimental group.

DISCUSSION AND CONCLUSION

1. At the end of the application, covariance analysis was conducted on the students' scores of the experimental and control group, and this analysis revealed a significant difference between the critical thinking levels of the experimental and control group students. The critical thinking level of the experimental group students taught with the IBL approach was found to be higher than that of the control group students who were instructed through the traditional lecturing method. In this regard, the IBL approach is more effective in improving students' critical thinking level.

As a result, it can be argued that science and technology classes taught with IBL approach have a more positive effect on students' critical thinking level, and that science and technology lessons taught within the constraints of the course book do not result in a significant improvement in students' critical thinking levels.

In light of the researcher's observations, it is believed that students' active participation in lessons by taking part in activities and answering the questions asked by the researcher within and between group discussions made positive contributions to the development of their critical thinking levels. Discussions enhance the critical thinking levels of participants, helping students to improve their ability to make connections between claims and evidence, and as such, improve critical-thinking skills[p1]

Table 18. [p2]CTS Self-organization Sub-Dimension Adjusted Posttest Scores ANCOVA Analysis

Variance Source	Sum of Squares	SD	Mean Squares	F
Pretest	116.01	1	116.01	10.53
Class	301.31	3	100.44	9.12
Error	892.17	81	11.01	
Total	27462.00	90		

*p< .05

(Çelik & Kılıç, 2007). [p3]The research proved that when discussion opportunities are provided for students, their comprehension level of experimental details increases (Niaz, Aguilera, & Maza, 2002). Therefore, learning through "scientific inquiry" should include "scientific discussion" (Clark & Sampson, 2007).

The finding of the current study, showing that IBL makes positive contributions to students' critical thinking levels, concurs with the findings of other studies (Mecit, 2006; Wu & Hsieh, 2006; McDonald, 2004).

Evren (2012) conducted a study to investigate the effect of the IBL approach in science and technology courses on the critical-thinking skills of 6^{th}, 7^{th}, and 8^{th} graders and found there to be a correlation between the students' inquiry skills and critical-thinking skills and also between the students' critical thinking skills and their attitudes towards science and technology courses. It was also reported that the students' critical-thinking skills significantly vary depending on gender.

In Parkinson and Ekachai's (2002) work, it was found that IBL strategies provide more opportunities for students to enhance and use their critical thinking and problem-solving skills (as cited by Tabak & Karakoç, 2004).

Apedoe, Walker, and Reeves (2006) informed university students about inquiry-based learning and its integration. IBL is of great importance in improving critical-thinking skills, nurturing scientific problem-solving skills, and developing scientific information.

DiPasquale et al. (2003) used the IBL approach in the experimental group and traditional laboratory learning in which instructions are given by the teacher throughout the laboratory work of a physiology course. At the end of the study, they found that the experimental group students acquired some critical-thinking skills, improvement was observed in their skill of integrating information, and they could combine the information learned in other classes, make interpretations, and take on more responsibility.

Akbıyık (2002) stated that students who have critical-thinking dispositions are more successful. Jackson (2000) researched the effectiveness of the development of critical-thinking skills to develop problem-solving skills in mathematics, and revealed that some students' critical-thinking skills developed when faced with a problem of self-confidence and that thinking skills are developed more than others during problem analysis. Akınoğlu (2001) stated that in the field of basic science teaching, critical-thinking skills are more effective than traditional approaches on student achievement.

Batı (2014) researched the effects of critical thinking on other methods and techniques, focusing on the effect of model-based science education programs based on skills of constructing, testing and revising mental, expressed and consensus models in middle school science education, students' views about the nature of science and critical-thinking abilities were tested, and students' and teachers' views in terms of effectiveness of this process were analyzed. Results showed statistical differences were found between experimental group students' pretest and posttest scores for critical-thinking skills. Additionally, no statistical difference was found between critical-thinking skills posttest mean scores of the experimental and control groups. If we look to another study, Çetinbaş-Gazeteci (2014) researched the effect of game-based learning on students' academic achievement and critical-thinking skills in 8th grade science and technology lessons. According to results of her quantitative analysis, science education supported by game activities had a significant positive effect on students' academic achievement and critical-thinking abilities. In a different study, Kılıç (2015) studied the impact of activities prepared through the integration of science and mathematics on critical thinking and science process skills of gifted 6th grade secondary school students. According to the findings, Kılıç noted a significant difference between pretest and posttest scores of students' critical-thinking levels. In Yağmur's (2010) study, creative drama studies in science instruction positively affected critical-thinking skills, one of the basic purposes of science instruction. It is therefore suggested to generalize this method within science instruction.

A study by Kutlu-Kalender (2015) investigated 6th grade students' manners on science and their relationship with critical thinking levels according to various variables, and to determine if and how they differ. According to the findings of this study, there is an overall positive and medium level significant relationship between students' manner scores to science and critical thinking levels in 6th grade students. Furthermore, the students' manners to science differed significantly in terms of all demographic variables, except for mother's education level and bulletin subscription.

In another study, Kokmaz [p4]and Yeşil (2009) examined students' critical-thinking levels and dispositions at the end of primary, secondary, and higher education. As a result; Critical-thinking level and dispositions of students was found to be medium. It was also determined that high school courses negatively affect students' critical-thinking level and disposition. On the other hand, faculty courses are positively affected, although not to a sufficient extent. According to findings by Saysal-Araz (2013), there is a positive and medium level meaningful relationship between science and technology literacy levels and critical-thinking levels of 4th and 5th grade students.

2. When sub-dimensions of critical thinking are examined, it is seen that differences between the experimental and control groups in terms of these sub-dimensions favor the experimental group. In short, critical-thinking levels of the experimental group students showed a positive increase across all dimensions.

All of the critical-thinking skills (analysis, evaluation, inference, interpretation, explanation, self-regulation), according to the variable of science and technology course achievement, have a significant difference in favor of students with higher levels of science and technology course achievement (Yıldız, 2011).

In a study by Demir (2006) of a social studies program in 2005, 4th grade students in four of the six areas of critical-thinking skills (analysis, evaluation, inference, explanation) showed a significant difference for the variable of 'school type', in favor of private schools, yet in two of the six areas of critical-thinking skills (interpretation, self-regulation), no significant difference was found. However, the in the 2005 social studies curriculum for the 5th grade, in one of the six areas of critical-thinking skills (interpretation), the 'school type' variable showed a significant difference in favor of public schools. In five of the six critical-thinking skills areas (analysis, evaluation, inference, explanation, self-regulation), the variable of 'school type' showed no significant difference.

In conclusion, this application can be argued to have contributed to students' use and development of their critical-thinking skills.

SUGGESTIONS

1- When the fact that the IBL approach is conducive to students' critical-thinking skills is considered, the guided-teaching materials developed within the inquiry circle in the current study can be utilized by teachers and students.

2- It was observed that the students gave similar or limited examples from their daily lives during most of the activities. Hence, incorporation of out-of-school activities such as field trips and observations into the activities can be useful for students to provide more actual examples from daily life.

3- In the current study, within- and between-group discussions were conducted. Great importance was attached to ensure the groups were homogenous during the discussions. Moreover, classes including group works were seen to have positive effects on student motivation, mutual respect, and tolerance to others' opinions. Students should be provided with settings suitable for small group works so that they can construct the information better through their inquiries and discussions. This may nurture social interaction among the students.

4- In the current study, it was seen that when students are given enough time and encouragement, most students ask questions and try to answer questions asked of them. Hence, teachers should encourage their students to ask questions and allow sufficient time for them to think about questions posed. What is important in IBL is that all students should be able to think about the question and express their opinions, rather than some students giving correct answers quickly. Students' opinions should be respected, even if they are false or incomplete.

5- All these issues should be considered within in-service training, which should focus on the provision of practice and application rather than information. Moreover, teachers should be followed to see how they apply in class what they have learned from their in-service training, and the findings should be evaluated together.

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◈◇◈

Appendix 1.

4. SECTION

HOURS	RECOVERY
4	Students, about in relation to creating connections between the characteristics of the matter and its porous structure ; 2.1. The students conclude that atoms might be different, based on the fact that matters are different from each other (BSB-9). 2.2. They can name the matters made up of the same sort of atoms as "elements". 2.3. They can distinguish different element atoms on compound models (BSB-30). 2.4. They name the pure substances including different atoms as "compound".

1. STEP: "INQUIRY"

ACTIVITY: Salty Cake☺

As Selin wanted, her mother decided to make a fruit cake. However, her mother put salt instead of sugar into the cake by accident. Selin had to eat a salty cake instead of a fruitcake.

What can be the factor making two substances having the same appearance have different tastes?

What do you think leads to this difference? Why do you think so?

What are the characteristics of water, paper, table, iron and soil?
Why do you think difference substances have different characteristics?

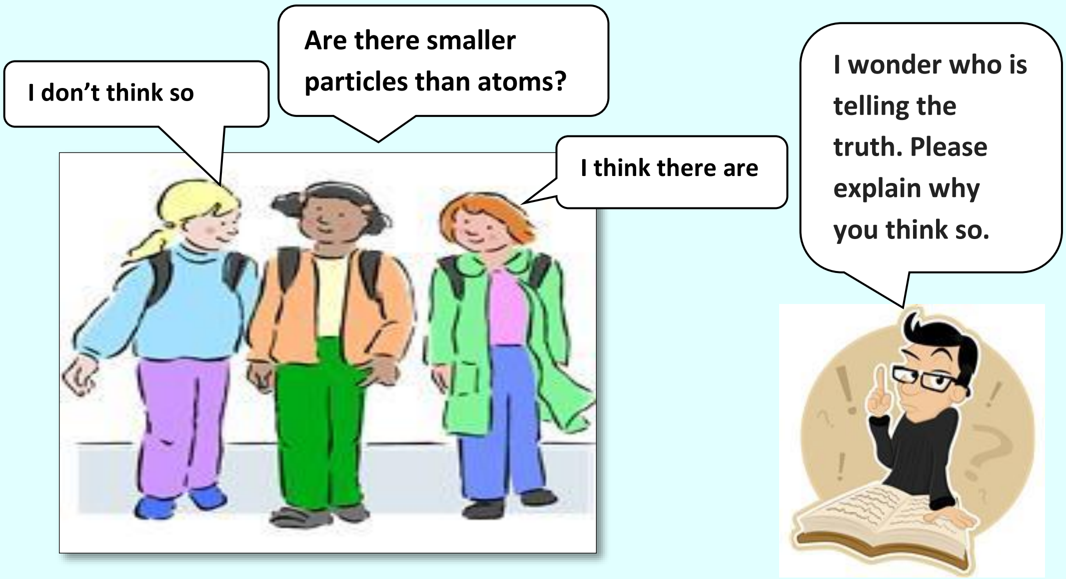
What about the appearances of water and ice, are they different?
If their appearances are different, can we claim that their particles are also different?

3. SECTION

HOURS	RECOVERY
4	1.6. They name the basic unit of a matter as atom. 1.7. They realize that their opinions about the concept of atom change over time. (FTTÇ-1, 2, 3, 4, 14). 1.8. They state that atoms are made up of smaller particles (TD-3).

2. STEP: “UNCOVER EXISTING KNOWLEDGE”

ACTIVITY: Who is telling the truth?



Berrin Sinem Ayla

Whose answer do you think is correct?
Put an “X” next to the statement of the person whose answer you consider to be correct.

☐ BERRİN

☐ AYLA

Explain why you think so.

....

Group Name:

Whose answer do you think is correct?
Put an “X” next to the statement of the person whose answer you consider to be correct.

☐ BERRİN

☐ AYLA

Explain why you think so.

……………………………………………………………………………………………………

1. SECTION

HOURS	RECOVERY
4	**1. In relation to atoms, basic units of the matter;** 1.1. The students compare the compression-expansion properties of solids, liquids and gases. (BSB-1, 2, 4, 5, 6). 1.2. On the basis of the compression-expansion properties of gases, they conclude that there are some gaps in gases (BSB-1, 2, 8).

3. STEP: "MAKING PREDICTIONS"

ACTIVITY: Let's inflate a balloon ☺

A balloon is placed on the top of glass bottle including some water. When the bottle is heated, what may happen? Write about your expectations. Observe the bottle while you are heating it and compare your observations with your expectations. Write explanations for your observations.

Expectations:

Observations:

Explanations:

Discuss with your group members and write the conclusion you have reached.

……………………………………………………………………………………………………
……………………………………………………………………………………………………
………………………………………………………………………………

3. SECTION

HOURS	RECOVERY
4	1.6. They name the basic unit of the matter resembling a sphere as atom. 1.7. They recognize that their opinions about the concept of atom change over time. (FTTÇ-1, 2, 3, 4, 14). 1.8. They state that atoms are made up of smaller particles (TD-3).

4. STEP: "IMPLEMENTATION PLANNING AND MAKING"

ACTIVITY: Let's ask the scientists ☺

Scientists who have conducted research on ATOMS throughout the history inform us about their studies. Then, these scientists ask you some questions about their studies on atom. You can make some notes below about each of the scientists' studies. You can ask more questions to get more detailed information about those you wonder about.

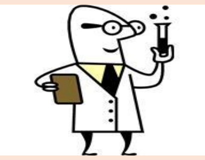
Mr. Dalton's studies;

Mr. Thomson's studies;

Mr. Marie Curie's studies;

Mr. Becquerel's studies;

Mr. Einstein's studies;



The things I have learned from the scientists;
....

7. SECTION

HOURS	RECOVERY
4	3.5. They can distinguish physical and chemical events in changes represented by atom-molecule models. 3.6. By looking at the matters including multiple atoms and molecules, they can recognize the concepts of "pure substance" and "mixture" at atomic and molecular levels.

5. STEP: MAKING COMMENTS AND RESULTS PRESENTATION

ACTIVITY: Let's review the newspapers ☺

Which of the following newspaper news items might be related to physical and chemical transformations? On the basis of this news, make some comments. Let's create a journal about chemical and physical transformations.