Investigation of the Effects of Using Metacognitive Activities in Chemistry Laboratory on the Development of Conceptual Understanding

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Abstract

This study investigated the effects of using metacognitive activities in a chemistry laboratory, on the conceptual understanding of university students. A sample of freshman students was randomly assigned to either of two groups, the control group or the experimental group. Students in the control group conducted the experiments as they would do in conventional laboratory sessions. The students in the experimental group conducted the same experiments but also received a treatment including metacognitive prompts, feedback, reflection, and pre- and post- laboratory instruction discussions. The results revealed that the experimental group's scores for conceptual understanding in particular topics were significantly higher than those of the control group's, although both groups displayed some confusion about reaction rate and chemical equilibrium.

Key Words: Metacognition, executive functions, efforfull control, learning disabilities

Introduction

The main purpose of science education is to help students become scientifically literate and to appreciate the world around them (Hoang, 2007). There have been a consensus in the literature of science education that to become scientifically literate students have understand science concepts thoroughly (Andersen & Nersessian, 2000; Cobern, 1996; DeBacker & Nelson, 2005; Hewson, 1981; Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 2007). If they construct some misunderstandings and/or alternative conceptions, they need to pass through a process of conceptual change in order to correct those in desired direction. According to the theory of conceptual change, learners shift the way they perceive and conceptualize phenomena to a new way of thinking because their experiences have shown their original conceptualizations to be inadequate (Hewson, 1981). The conceptual change model assumes that learners are active participants in the process, activating prior conceptual knowledge, selecting and processing information, monitoring, evaluating, and modifying their conceptions (Pintrich, Marx, & Boyle, 1993).

The standard conceptual change model (cold model) suggests that learners behave in much the same way as scientists behave, that when they become dissatisfied with their existing ideas, they search out new ideas that seem intelligible, plausible, and fruitful. However, Pintrich, Marx, & Boyle (1993) advocate that academic learning is not cold and isolated, that there are interacting influences on learning, such as motivation, metacognition, and classroom contexts. They posit a dynamic and

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interactive relationship between the cognitive, motivational, and classroom factors and the conditions for conceptual change. In recent years, research has shown that such techniques as posing questions, reflections and group discussions contribute to conceptual change (Darmofal, 2002; Howe, Devine, & Tavares, 2011; Woodland & Hill, 2011). In order for conceptual change to occur, the learners must be active and generative and engage in various cognitive processes such as knowledge acquisition, cognitive learning strategies, problem-solving or thinking strategies, and metacognitive strategies (Pintrich, Marx, & Boyle, 1993). Metacognition is an important aspect for facilitating conceptual change. It refers to the learners' knowledge, awareness and control of their cognitive processes (Flavell, 1976). There are various definitions of metacognition in science education one of which is presented as follows:

> It is the process of thinking about one's own thinking, or the act of monitoring and controlling one's thoughts and cognitive processes while learning and knowing what strategies are personally useful to carry out any task more effectively (McComas, 2014, p. 63).

Metacognition, or thinking about thinking, refers to people's knowledge of their own cognition and monitoring and regulating their cognitive processes (Flavell, 1976). According to Boekarts and Simons (1993), Brown (1987) and Ku and Ho (2010), in order for metacognitive thinking to occur, first individuals must be aware of their own cognitions through self-monitoring or self-regulation, second, they must use appropriate cognitive processes to find and apply ways, such as critical thinking and reflective judgment for solving problems (cited in Hogan et al., 2015).

Despite the emphasis of self-awareness and self-management of metacognition definitions in literature, Hsu, Iannone, She, and Hadwin (2016) stress that the operational definitions of metacognition are somewhat unclear and confusing. For the purpose of clarifying our point of view of metacognition we specifically address the individuals' awareness of their thinking and feelings about the task as well as the process and the aim of the task in which they questioned what they would learn by these experiments before performing themand self-evaluation of they learned after the experiments as well as the course encompassing all these experiments is activated.

A number of research studies point out that metacognition is related significantly to improvements in learning science (Grotzer & Mittlefehldt, 2012; Schraw, Olafson, Weibel, & Sewing, 2012; van Den Hurk, 2006). Research also shows that metacognitive skill is a better predictor of learning performance than intelligence (van der Stel & Veenman, 2008; Veenman & Spaans, 2005). Implications for designing instruction that enable students develop their metacognitive skills are suggested in the literature about science education (Bektasli & Cakmakci, 2011; Cakmakci, Leach, & Donnelly, 2006). Metacognitive skills include planning learning activities, performing them in a systematic order, and monitoring, evaluating and reflecting one's own learning (van der Stel & Veenman, 2014).

As mentioned in the definitions of metacognition above, we regard metacognition in this study as students' awareness of the purpose and effectiveness of experiments and chemistry laboratory course, knowledge and skills that they would gain/gained before/after performing experiments and before entering/after completing the course as well as their capability to perform the experiments and the difficulties and obstacles that they would face/faced during performing the experiments and learning in the course.

Researchers utilized various instructional strategies to enhance metacognition (Schraw, 1998; Tien, 1998; Kipnis & Hofstein, 2008; Pulmones, 2010). One of the instructional strategies to support metacognition is the use of metacognitive prompts. “Metacognitive prompting is an externally generated stimulus that activates reflective cognition, or evokes strategy use with the objective of enhancing a learning or problem-solving outcome” (Hoffman & Spatariu, 2008, p. 878). In other words, metacognitive prompts ask students to analyze their own learning or evaluate their own progress (Linn, Clark, & Slotta, 2003). Questions for metacognitive prompting might include: “How did you think like a scientist in that lesson?”, “How can you think about your thinking?”, “Are there other ways of thinking?” (Peters & Kitsantas, 2010). Research has shown that the use of metacognitive prompts leads to improved academic performance (Hoffman & Spatariu, 2008; Nokes, Hausmann, VanLehn, & Gershman, 2011; Peters, 2008; Peters & Kitsantas, 2010; Pulmones, 2010).

In addition to metacognitive prompts, feedback can be a useful tool for enhancing metacognition, since it enhances students’ self-monitoring ability. Schraw, Crippen, and Hartley (2006) argued that detailed informational feedback enhances students’ self-regulatory skills and metacognition. Colbert et al. (2015) stressed the necessity of independent feedback from credible sources that learners receive. Hattie and Timperley (2007) conceptualized feedback as information provided by an agent (e.g., teacher, peer, book, parent, self, experience) in terms of an individual’s performance or understanding, thus a consequence of a performance. According to these researchers, in order for a feedback to be effective, it should provide information on correct rather than incorrect responses and should be based on the previous trails.

Lee, Lim, & Grabowski (2009) suggested giving metacognitive feedback, which is a strategy fostering learners’ awareness of what they do not know, what they need to know and what learning strategies work. For example, if a participant selected incorrect answer, they provided him/her the following feedback: "Incorrect! You need to go back and revise your highlighted sentence or summary." They found that students in a group that received metacognitive feedback attained higher comprehension and self-regulation measures than those in a group that did not receive the feedback. Roll et al. (2011) defined metacognitive feedback as the feedback that is triggered by students’ learning behavior rather than the accuracy of their responses and this kind of feedback also advises students toward a desired learning behavior rather than domain knowledge. In light of background information, in the present study we used metacognitive feedback, such as “You’re doing well!” or “You’ll do much better if you …”.

A number of other researchers have advocated instructional strategies for metacognitive development, including self-reporting and self-reflection (Smith, 2001; Zion, Michalsky & Mevarech, 2005). Reflection, as in diaries, journals, and progress worksheets, is an important technique for developing critical thinking and metacognitive skills (Schraw, Crippen, & Hartley, 2006; Smith, 2001; Zimmerman, 2001). Georghiades (2004) noted that self-reflection on the process of learning results in more durable science learning. Hewson et al. (1998) stressed the importance of explicit metacognitive discourse in order for conceptual change to occur. Hennessey (1999) also argued that there is a transparent link between metacognition and conceptual change in science by providing students' metacognitive statements as evidence of their conceptual change.

Georghiades (2006) studied the effects of integrating metacognitive activities, including classroom discussion and diary-like notes, into teaching procedures. The results of his study suggested that metacognitive activities had a positive impact on students' ability to apply science concepts in context, evidence that conceptualization in science can be developed by using metacognitive activities.

Literature on metacognition often makes a distinction between metacognitive knowledge and skills. Metacognitive knowledge refers to one's knowledge about himself/herself as a learner, task, and strategies while metacognitive skills relate to the ability of planning, monitoring, evaluating and controlling one's learning (Veenman, 2012). Recent literature also discusses the role of metacognitive skills from the perspective of how metacognitive skills relate to four types of learning processes, which are reading text, problem solving, inquiry learning, and writing (Zohar & Dori, 2012). For example, some researchers discusses these processes by asserting that the role of self-questioning serves as a monitoring process in reading; metacognitive knowledge is elicited during problem solving and inquiry activities (Herscovitz, et al., 2012); and a component of metacognitive skill, variable control in inquiry learning requires planning (Veenman, 2012).

In light of this theoretical background, it follows that laboratory instruction should be designed to use metacognitive activities in order to facilitate conceptual change. Metacognition can be developed when students are planning and performing experiments and discussing the results of experiments (Kipnis & Hofstein, 2008). However few studies in the literature examining the relationship between metacognition and conceptual understanding in a laboratory environment.

The literature about teaching and learning in science often points out the benefits of laboratory instruction (Hofstein & Lunetta, 1982; 2004; Ottander & Grelsson, 2006; Tobin, 1990). It is claimed that laboratory work provides students with opportunities for analytical and critical thinking and hands-on experience; increases their creativity and helps them to acquire conceptual and theoretical knowledge of science; leads to an understanding of the methods and nature of science by allowing students to work like scientists (Ottander & Grelsson, 2006); and increases manipulative, organizational and communication skills (Trowbridge & Bybee, 1990, cited in Greene, 2000). Laboratory experiences also enable students to increase scientific practical skills, problem-solving skills, scientific "habits of mind," interest, and motivation (Hofstein & Mamlok-Naaman, 2007). For these reasons, laboratory instruction is inseparable part of science teaching. For a better understanding of the effectiveness of various laboratory instruction styles, such as expository, inquiry, discovery, and problem-based, researchers should address specific learning outcomes including conceptual understanding and higher-order cognition, rather than looking solely at the general learning outcome of student achievement (Domin, 1999). The research presented in this paper addresses these learning outcomes.

Hofstein and Lunetta (2004) emphasized on the effectiveness of integrating laboratory activities with metacognitive experiences on learning science, however they mentioned "predict-explain-observe" as metacognitive experiences. In this study, we extend the metacognitive experiences from this limited understanding of inquiry to the students' reflection of their own thinking. Here we regard metacognitive activities in a broader perspective including not only inquiry experiences, but also students' reflections on their thoughts about the difficulties and obstacles they could encounter as well as the knowledge and skills that they would gain after the experiments and the course. Considering background information about metacognition, in this study we used metacognitive activities including reflections on the experiments and the course, feedback and discussion on the process and the concepts.

Chen, Huang, and Chou (2016) examined the influence of experimental goal setting and planning on low achievers' laboratory learning. The treatment group received scaffolds that guide them to set goals and plan the experiments while control group did not. The researchers found that each group improved their conceptual understanding. The researchers did not compare the conceptual development of the two groups. However, the comparison of metacognitive treatments and traditional laboratory teachings regarding conceptual understanding is needed. Furthermore, investigating the impact of metacognitive activities on students' conceptual understanding while both control and experimental groups planned their experiments may also bring new insights to literature on metacognition. The study presented here fulfills these requirements.

Zohar and Barzilai (2013) conducted a systematic analysis of 178 studies published in the years of 2000-2012, in peer-reviewed journals indexed in ERIC database and found that conceptual understanding of science was one of the central aims of current metacognitive research. They emphasized that the most prominent practice among a wide range of practices is the use of metacognitive use and prompts in the course of instruction to improve learners' metacognition. They also focused on several research gaps, one of which is the lack of controlled research designs that provide causal evidence to support the effectiveness of instruction for science learning.

This study fills this gap by using pre-test – post-test control group design and investigating the relationship between metacognition and conceptual understanding in a laboratory environment by not only setting goals and plan the experiments, but also discussing and reflecting their thoughts and feelings during their experiences of the experimental process and the course overall.

This study aims to contribute to the literature in two major ways. First, methodologically, the intervention presented here will bring new insight to laboratory instruction. Second, the research has theoretical significance. The literature review points out the beneficial effect of using metacognitive activities on conceptual understanding. However, few previous studies identify the extent of the development of conceptual understanding through metacognitive activities. We think that it is important to identify the extent of the effect of the use of metacognitive activities on conceptual understanding. Detailed discussions of chemistry conceptions the students develop throughout the instructional period are needed. This study investigates the extent to which using metacognitive activities in chemistry laboratory has an effect on students' conceptual understanding.

Method

Participants

Fifty-four freshmen students, who enrolled in General Chemistry Laboratory-I course in Primary Education, Science Education Program, at a public university in Turkey participated in this study. Sixteen of the participants were male and 38 were female.

Purpose and research question

The research study presented in this paper is part of a larger study, which investigated the effect of using metacognitive activities on pre-service science teachers' learning outcomes in a chemistry laboratory. The results previously published of this study showed the advantage of using metacognitive activities regarding some motivational outcomes, metacognitive learning strategies and science process skills; however, there was no significant gain in terms of attitudes towards chemistry (Author & Author, 2009a; 2009b). Another result previously published of this study revealed the increase in the affective learning outcomes, through the use of metacognitive activities (Author & Author, 2010). The participants in the present study were the same participants in the larger study. The current paper reports the effect of using metacognitive activities, comprised of metacognitive prompts, metacognitive feedback, reflection and discussion, on their conceptual understanding. The study addresses the following research question:
Do using metacognitive activities have an effect on pre-service science teachers' conceptual understanding when compared to pre-service science teachers who complete the same experiments and do not receive any metacognitive activities?

Research design and procedure

The treatment was implemented over 12 weeks. The sample was randomly assigned to either of two instructional treatment classes, the control group (n=27) and the experimental group (n=27). The students in the control group conducted the experiments in a laboratory by following procedures in their laboratory manual to verify concepts, principles, and laws that were taught in the lectures. The treatment implemented in experimental group included the use of metacognitive prompts and feedback.

To make the instructional method in the laboratory the only difference between the two groups and to eliminate other factors that might affect the students' learning outcomes, the instructors made the following provisions:

1. Both groups conducted the same eleven experiments on the topics of reaction rate, chemical equilibrium, precipitation reactions, acids and bases, buffer solutions, and hardness of water.
2. The duration of each laboratory session for both groups was two hours.
3. The same instructor (first author) taught both groups in the laboratory, and the same lecturer (second author) delivered all the lectures.
4. Students in both groups conducted the experiments in teams of three or four students per team.

The students in the control group conducted the experiments in the conventional way. They were given the topic, aim, and procedure of the experiments, which were designed to verify facts and concepts they had learned from the lectures and the textbook. No additional effort was made to elaborate the concepts.

In the experimental group's laboratory sessions, there were pre- and post-experiment discussions intended to raise the students' awareness of their understandings about experimental design and the scientific concepts elucidated by each experiment. Also, the students in the experimental group were asked to complete four kinds of semi-structured reflection forms prepared by the authors (See Apendix I, II, III, IV). Table-1 shows the schedule of the research.

Table 1. Schedule

Beginning of the study	Treatment	End of the study
CKT, CRF	11-week treatment	CKT, CRF

Pre- and post-course reflection forms (CRF) reflected students' knowledge and awareness about the course and about their feelings towards the course (Appendix-I and -IV). The items included in CRF aimed to prompt students' metacognition regarding the purpose of the course, knowledge and skills that they would gain/gained after the course, the difficulties that they would face/faced during performing the experiments and the obstacles they may encounter/encountered for learning in the course. Two additional items in post CRF required students' thoughts about the effectiveness of and whether they took pleasure from the experiments.

Pre- and post-instruction reflection forms (IRF) were given at the beginning and end of each laboratory lesson to stimulate students' thoughts about the experiments and develop their metacognitive awareness (Appendix-II and -III). The items included in IRF aimed to stimulate students' reflection regarding the reason of the experiments, knowledge and skills that they would gain/gained after the experiment, and use of the gained knowledge in daily life.

Expert opinion was sought during the development of these forms. According to the feedback an expert on educational sciences gave, the questions in the forms were revised. One professor of chemistry education and one professor of educational sciences evaluated the items for expert opinion.

Both of the groups conducted the same eleven experiments in small teams of 3 or 4 students. In the experimental group, but not in the control group, for the purpose of emphasizing the relevance of concepts, the instructor performed demonstration experiments with household materials in addition to the experiments prescribed by the curriculum and conducted by the students.

Each lesson in the experimental group began with the IRF to stimulate students' reflections on the process and aim of the experiment. The purpose of the pre-IRF was to make them aware of their feelings and thoughts about the experiment they would conduct. The lessons continued with additional questions that the instructor asked orally, such as "How would you understand the relationship between the concentration of substances and reaction rate by using the given equipment?” The aim of the questions was to stimulate discussion of the design of the experiment, first in the teams, then in the whole class. Each lesson in the control group began by giving students the aim of the experiment. No additional effort was made to raise their awareness of the process or planning of the task.

The second phase of the lesson was experimentation. The students in the experimental group conducted experiments they had designed collaboratively, while those in control group carried out the same experiments by following instructions in the lab manual.

In the third phase, the students in the experimental group were asked to think about and explain their thoughts and expectations related to the experiment (e.g., the dynamic nature of reactions or microscopic representations of chemical events). They were asked questions to help them evaluate their understandings of related topics, for example: How do you evaluate your work when you think about the formation of stalagmites and stalactites?; Would you be able to understand the data you gathered during the experiment by relating it to this natural event? If so, how? Or they were asked questions about the dynamic nature of reactions or microscopic representations of chemical events. The following examples represent general features of the questions: Which one of the following pictures do you think represents the strong/weak acid/base or salt you used in your experiment? How would these representations contribute to your understanding of the data you gathered during the experiment? They wrote answers to such questions and related reflections in their lab reports.

Lessons for the experimental group ended with responses to the post-IRF, which asked them to reflect on the experiment they had conducted and to evaluate the knowledge they had gained. The students in control group presented their data and results accrued from the experiments. No further discussion occurred in the lessons of the control group.

Students in both groups wrote reports about the experiments and answered the questions in their laboratory manual. However, the students in the experimental group were asked to expand on their answers to the questions in order to monitor and evaluate their own ideas. Except for grades, the students in the control group received corrective feedback about their reports, but the students in the experimental group received metacognitive feedback informing the students which errors they need to focus on and including supportive words appreciating their work. Feedback given to the students in the experimental group included supportive or suggestive statements such as “Well done!” or “You’ll be much better if you focus on ….” while the students in control group were only informed about their errors and received the correct response. All students submitted their reports one week after each experiment.

Table-2 shows the design of the research study and Table-3 reveals the details of the questions that were posed during the closure phase of the lessons carried in experimental group.

Table 2. Experimental Design

Phases of the lesson	Experimental Group	Control Group
Introduction	IRF Discussion through prompts	The aim of the experiment is given
Experimentation	Design decided collaboratively	Follow instructions in lab manual
Closure	Questions related to the topic IRF	No questions
Reports submitted after one week	Questions in the lab manual plus questions posed in the closure phase of the lesson Suggestive and supportive feedback	Only questions in the lab manual Corrective feedback

Table 3. Questions Posed During the Closure Phase of the Lessons in Experimental Group

Type of Question	Example
Self-evaluation	- Would you be able to understand the data you gathered during the experiment by relating it to this natural event? If so, how? - Do you think your drawings and/or representations explain the difference between the concepts of solubility and ionization of AgCl? Why/why not?
Daily life	- Why do you think we protect our food in the refrigerator? - Would you like to drink hard or soft water? What about your washing machines? What kind of water would you like to use in your washing machines?
Dynamic nature of reactions	- How do you evaluate your work when you think about the formation of stalagmites and stalactites? What is the relationship between the experiment you did in the lesson and the formation of stalagmites and stalactites? Justify your answer by writing the reactions of each. - Which ions would you expect to find in a beaker filled with water when you add vinegar (CH_3COOH)?
Microscopic representations of chemical events	- Which one of the following pictures do you think represents the strong/weak acid/base or salt you used in your experiment? How would these representations contribute to your understanding of the data you gathered during the experiment? - What do you think will happen when the salts AgCl and NaCl in water? Draw a model representing this event in particulate dimension.

Instrument

Conceptual Knowledge Test (CKT)

The CKT was prepared by the researchers to assess students’ conceptual understanding of reaction rates, chemical equilibrium and acid-base equilibria, salts, and chemical phenomena at microscopic levels. Literature pointing out students’ errors about kinetic and chemical equilibrium problems (Boujaoude, 1993), suggesting activities chemical equilibrium (Ellis et al., 2000), emphasizing students’ misconceptions of acids and bases (Orna, 1994), and discussing student understanding of solution chemistry through microscopic representations (Smith & Metz, 1996) were utilized during preparation of the test. The information given in these literatures was adapted to this study by turning them to questions. Expert judgment was taken during the preparation of the test. One professor of chemistry education and one professor of science education evaluated the items for validity. Complete agreement was reached between the experts on the appropriateness of the questions. The CKT is a two-tier test consisting of 11 items. The first tier of each item is a multiple-choice with two or three options. The second tier of each item asks why an option in the first tier was chosen. Responses to the first and second tier of each item were judged to be correct or incorrect. If both responses were judged to be correct, the item received a score of 2. If only the response of the first tier was judged to be correct and the second was incorrect, the item received a score of 1. If both tiers were judged to be incorrect, the item received a score of 0. The same professors analyzed the data. Percentage of agreement between these experts was 95%. The experts discussed their conflicts on the items they scored until they reach complete consensus.

Results and Discussion

T-tests and chi-square tests were used to evaluate the data obtained from this study. The hypotheses were tested in the 0.95 confidence interval. CKT was administered to students as pre- and post-test. Independent t-test results of the scores of pre-tests showed that there was no significant difference between the two groups in terms of their conceptual understanding ($t=0.941$; $df=52$; $p>0.05$), and metacognitive learning strategies (Saribas & Bayram, 2009a).

Research question

An independent samples t-test was used to compare the results of the post-test CKT for the two groups. Analysis shows that the students in the experimental group outperformed the students in the control group ($p<0.05$) (Table-4). This result indicates that the method used to develop metacognition in the experimental laboratory had a stronger positive effect on the experimental group’s conceptual understanding than the effect of more conventional methods on the conceptual understanding of the control group.

Table 4. Comparison of Conceptual Understanding of Each Group

	Group	N	Mean	SD	df	t	p
Conceptual understanding	Control	27	10.15	3.82	52	2.034	0.047*
	Experimental	27	12.07	3.10			

A chi-square analysis of each item produced a more detailed analysis of the students' conceptual understanding. The items were classified into four categories: reaction rates (items 1, 2, 3); chemical equilibrium and acid-base equilibria (items 3, 4, 10, 11); salts (items 5, 7); and chemical phenomena at the microscopic level (6, 8, 9). The microscopic representation of chemical events refers to the realm of unseen atoms, molecules, and ions in contrast to observable macroscopic phenomena. The entire conceptual framework of chemistry, according to Mammino and Cardellini (2005, p. 51) "is based on the interplay between the microscopic and the macroscopic levels of description. Chemistry models are rooted in the microscopic world of atoms and molecules and concerned with the way in which microscopic behaviors and events generate the macroscopic ones." This is why it was important to investigate the students' conceptions of chemical phenomena at the microscopic level.

Responses to each item were judged to be "correct" (score of 2), "partly correct" (score of 1), or "incorrect" (score of 0). The results of pre-test CKT scores showed that the responses of the students in the control and the experimental group were not significantly different for any categories in any item ($p>0.05$). The frequencies of each category for the response to each item in the pre-test CKT are shown in Table-5. Frequencies of each category in the post-test CKT are shown in Table-6.

Table 5. Chi-Square Analysis of the Items of Pre-Test of CKT

	2 (correct)	1 (partly correct)	0 (false)
1. The reaction is faster at the point which concentration is higher.			
Control	11	3	13
Experimental	13	3	11
$\chi^2 = 0.333$		$p>0.05$	
2. Reaction rate decreases while concentration decreases.			
Control	2	2	23
Experimental	1	3	23
$\chi^2 = 0.533$		$p>0.05$	
3. The increase of temperature raises the rate of all reactions, endothermic or exothermic.			
Control	0	2	25
Experimental	0	1	26
$X^2 = 0.353$		$p>0.05$	
4. Any effect made to a system in equilibrium causes the system behave to remove the effect.			
Control	6	8	13
Experimental	6	10	11
$\chi^2 = 0.389$		$p>0.05$	
5. If two different salt solutions are mixed and then water is evaporated 4 kinds of salts remain.			
Control	1	2	24
Experimental	1	2	24
$\chi^2 = 0.000$		$p>0.05$	
6. When dissolved in water, weak acids/bases ionize partly (symbolic representation).			
Control	11	6	10
Experimental	5	4	18
$\chi^2 = 4.936$		$p>0.05$	
7. Alkaline salts are composed of weak acids and strong bases.			
Control	1	1	25
Experimental	2	1	24
$\chi^2 = 0.354$		$p>0.05$	
8. When dissolved in water, weak acids/bases ionize partly (molecular representation).			
Control	9	4	14
Experimental	4	2	21
$\chi^2 = 3.990$		$p>0.05$	
9. No more precipitation occurs, because Na_2SO_4 solution is consumed.			
Control	8	1	18
Experimental	6	5	16
$\chi^2 = 3.070$		$p>0.05$	
10. $HI \leftrightarrows H^+ + I^{-2}$ if acid is added the reaction shifts to left (the solution is yellow), if base is added it shifts to right (the solution is red).			
Control	0	7	20
Experimental	0	10	17
$\chi^2 = 0.773$		$p>0.05$	
11. $K_{sp}= [Ag^+]^2[S^{-2}]$ if the value of K_{sp} is low it means that when solid Ag_2S is dissolved small amount of Ag^+ and S^{-2} ions form.			
Control	2	16	9
Experimental	4	12	11
$\chi^2 = 1.438$		$p>0.05$	

As shown in Table-6, students in the experimental group significantly outperformed students in the control group on the items 6 and 9, two of the three items related to the understanding of chemical phenomena at a microscopic level. This finding indicates that using metacognitive activities, which are metacognitive prompts, feedback, reflection and discussions in a chemistry laboratory may have helped students in the experimental group to a better understanding of chemical phenomena at a microscopic level. Even though more students in the experimental group gave a correct response to item 8 (the other item related to understanding of chemical phenomena at a microscopic level) and item 1 (which examines the knowledge of the effect of concentration on reaction rate) than students in the control group, the difference for these items is not significant at the 95 % confidence interval.

Table 6. Chi-Square Analysis of the Items of Post-Test of CKT

	2 (correct)	1 (partly correct)	0 (false)
1. The reaction is faster at the point which concentration is higher.			
Control	16	0	11
Experimental	21	2	4
$\chi^2 = 5.942$		$p>0.05$ ($p=0.051$)	
2. Reaction rate decreases while concentration decreases.			
Control	5	1	21
Experimental	9	1	17
$\chi^2 = 1.564$		$p>0.05$	
3. The increase of temperature raises the rate of all reactions, endothermic or exothermic.			
Control	3	0	24
Experimental	1	1	25
$\chi^2 = 2.020$		$p>0.05$	
4. Any effect made to a system in equilibrium causes the system behave to remove the effect.			
Control	13	6	8
Experimental	12	7	8
$\chi^2 = 0.117$		$p>0.05$	
5. If two different salt solutions are mixed and then water is evaporated 4 kinds of salts remain.			
Control	8	2	17
Experimental	7	1	19
$\chi^2 = 0.511$		$p>0.05$	
6. When dissolved in water, weak acids/bases ionize partly (symbolic representation).			
Control	16	5	6
Experimental	25	1	1
$\chi^2 = 8.214$		$p<0.05$	
7. Alkaline salts are composed of weak acids and strong bases.			
Control	11	2	14
Experimental	6	2	19
$\chi^2 = 2.228$		$p>0.05$	
8. When dissolved in water, weak acids/bases ionize partly (molecular representation).			
Control	17	2	8
Experimental	24	1	2
$\chi^2 = 5.128$		$p>0.05$	
9. No more precipitation occurs, because Na_2SO_4 solution is consumed.			
Control	12	4	11
Experimental	17	7	3
$\chi^2 = 6.252$		$p<0.05$	
10. $HI \leftrightarrows H^+ + I^{-2}$ if acid is added the reaction shifts to left (the solution is yellow), if base is added it shifts to right (the solution is red).			
Control	0	11	16
Experimental	1	12	14
$\chi^2 = 1.177$		$p>0.05$	
11. $K_{sp}= [Ag^+]^2[S^{-2}]$ if the value of K_{sp} is low it means that when solid Ag_2S is dissolved small amount of Ag^+ and S^{-2} ions form.			
Control	16	7	4
Experimental	20	5	2
$\chi^2 = 1.444$		$p>0.05$	

As shown in Table-6, students in the control group and the experimental group share the misconception, even after instruction, that “an increase in temperature raises the rate of reverse reaction” (item 3). Most of the students seemed confused about the concepts of reaction rate and chemical equilibrium. Similarly, most did not respond correctly to the item 5: “How many kinds of salts remain when two different salt solutions are mixed and then water is evaporated?” These findings are consistent with a study conducted by Cakmakci, Leach, & Donnelly (2006), which shows that students who understand clearly that reaction conditions influence reaction rates are nevertheless confused about the dynamic nature of the reaction system. The large number of incorrect responses to item 2, which asks about the reaction condition after 40 seconds, is further evidence of this confusion. Thus it is not surprising that only one student responded correctly to item 10, which asks about the color of the indicator in situations when a strong base is added to the solution, the solution turns red, and when a strong acid is added to the solution, the solution turns yellow. When the equation of the reaction was given, most of the students could identify the color of the solution (item 4) and the condition of a reaction in equilibrium (item 11). However, they could not write the equation of the reaction of an indicator. It seems that the students did not understand what happens to the indicator in a reaction that includes an indicator.

Conclusions

In this study, metacognitive knowledge and skills were activated through instruction reflection forms and prompts that enabled students monitor their learning by self-questioning; important metacognitive features of planning in inquiry and self-evaluation is activated through small group and classroom discussions; and feedback was used to enable students be aware of and evaluate their learning. Metacognitive prompts, feedback, reflection and discussion were identified as metacognitive activities in the present study. The findings of the study lead one to conclude that using these activities facilitates the development of conceptual understanding, especially at the microscopic level. As Bektasli & Cakmakci (2011) and Cakmakci, Leach, & Donnelly (2006) reported, designing instruction that provide students with the opportunities to develop metacognitive skills and reflection are needed to foster their conceptual understanding.

Using metacognitive activities in the chemistry laboratory seem to have had a positive effect on the students’ conceptual understanding. This result is consistent with Beeth’s (1998) findings in a study of elementary students’ science conceptions and their ability to reflect on their conceptions. In that study the students learned to speak metacognitively about their conceptions of force and motion. Subsequent learning outcomes showed considerable progress in their understanding of force and motion and their ability to examine their own conceptions.

Typical laboratory instruction in Turkey does not seem to be satisfactory. Most of the teachers do not have enough time or do not know how to employ methods, such as inquiry, that enable the students to be active participants in their own learning process. Instead, usual laboratory instruction in most of the schools in the country is teacher-dominated. Practical work is implemented in “cookbook” style. Students are passive learners who take notes and conduct experiments by following the “recipe” in their lab manual. The results of a study conducted by Erdoğan, Uşak, & Özel (2009) revealed the dissatisfaction of biology and chemistry students with the laboratories in which they performed their experiments. They were dissatisfied regarding the use of technology, working hours, and the diversity of available materials. Schools faced with these problems could use metacognitive activities such as metacognitive prompts, feedback, reflection, and discussion, with little effort or need for additional technology, material, or time.

Laboratory sessions that employ metacognitive activities seem to be more effective than conventional laboratory sessions for helping students to understand chemical phenomena at the microscopic level. Students in the experimental group were shown molecular representations of chemical phenomena and were asked questions about them. Nevertheless, their understanding of the dynamic nature of reactions seemed to be deficient, even in the experimental group. One possible reason for the deficiency may be the length of the period of instruction, which was relatively short. Such basic chemical issues should be emphasized frequently from the earliest years in school until graduate years in a university.

Discussion and Suggestions

Some other suggestions might contribute to a more thorough understanding. Firstly, computer simulations may be useful in this respect. Schraw, Crippen, and Hartley (2006) stress the importance of mental models in academic achievement and conceptual understanding in science. They argue that recent technology may create more and better opportunities for constructing mental models. Jong, Linn, and Zacharia (2013) stressed the advantage of using both physical and virtual laboratories to enhance learning in science. According to these researchers virtual laboratories increase the effectiveness of physical laboratories by enabling students explore unobservable phenomena.

Secondly, argumentation can stimulate exploration and lead to understanding. “Scientists continually work in an argumentation process of weighing empirical and theoretical evidence in light of warrants, backings and rebuttals to reach an understanding of how natural phenomena may be explained” (Hofstein, Kipnis & Kind, 2008, p. 74). If students use arguments to relate evidence to claims, as scientists do, they are likely to develop scientific knowledge in the laboratory and classroom. Kaya (2013) investigated the effect of argumentation practices on pre-service teachers’ understanding of chemical equilibrium and found that these practices are beneficial in conceptual understanding in science education.

Thirdly, more open-ended classroom activities that require challenging inquiry rather than the process of searching a text for ready-made answers would be more likely to promote cognitive activity and conceptual change (Pintrich, Marx, & Boyle, 1993). Katchevich, Hofstein, and Mamlook-Naaman (2013) found that inquiry experiments have the potential to increase the ability to formulate arguments. It can be concluded that this increase in turn may result in conceptual development.

Fourthly, it would be helpful to create authentic tasks or projects that extend over longer periods of time and result in reasoned proposals (Pintrich, Marx, & Boyle, 1993). It may then be possible to orient students towards inquiry that deepens understanding and facilitates conceptual change.

Concrete experience in the laboratory is an indispensable part of chemistry education, but students' understanding of chemical phenomena is gained through sub-microscopic and representational/symbolic levels. Laboratory instruction is often presented at the macro level; sub-microscopic level is invoked to explain observations at macro level; and representational/symbolic realms refer to the understanding of atomic and molecular formulas and symbols. Integrating the macro level with these two levels is significant for the development of thinking abilities in students, but a difficult task (Tsaparlis, 2009). The deficiency in students' understanding of the dynamic nature of reactions might be the lack of this integration. Tsaparlis (2009) points out the importance of history of science approaches in chemistry education for the connection of the macro level with sub-microscopic and symbolic levels. Further explorations of student understanding that incorporate history of science approaches in laboratory settings is needed.

A possible obstacle to understanding the dynamic nature of reactions may be the standard format of laboratory reports. The standard format for reporting experiments inhibits the level of the inquiry. "Level of inquiry" means "the degree to which the students are free to make choices before, during and after the laboratory experiment, as opposed to following prescribed directions" (Fay & Bretz, 2008: 38). The standard format for reporting experiments is a procedural format that makes the experimental process seem pre-determined, straightforward, and linear rather than creative. It also encourages dishonesty. Instead, students can write narrative reports describing the actual process of inquiry instead of following the pre-set template of the "lab report" (McComas, 2005). In this study, students conducted their experiments collaboratively and prepared their reports individually, but, as an alternative, reports could be collaborative. Peer editing and collaborative learning have been shown to be effective for learning communication skills as well as concepts (Kokkala & Gessell, 2003; Shull, 2005). A cooperative learning approach might be more effective than individually written reports.

Other avenues for exploration include authentic assessment and interviews. Authentic assessment would include the assessment of hands-on laboratory work in an experimental context. This may be more effective than paper-and-pencil tests for promoting an interest in scientific inquiry while also teaching students more about the nature of science (McComas, 2005). Interview techniques can also be used to elicit a fuller picture of each student's learning strategies and conceptual understanding.

Limitations

Metacognitive prompts, feedback, reflection and discussion were identified as metacognitive activities in the study presented here. The students in experimental group received prompts and were asked questions during experimental design and discussions of the concepts in the lesson while the students in the control group did not receive such prompts and questions except for the questions written in their lab manual. The students in experimental group also received suggestive and supportive feedback while those in the control group received corrective feedback in the reports of their experiments.

Another difference between the two groups were that the students in the experimental group reflected their thoughts and feelings about the course and the experiments while those in the control group did not write any kind of reflection. These differences between two groups does not allow us to conclude which one of these metacognitive activities had an impact on conceptual understanding. Overcoming this limitation of this study, further investigation examining the effect of merely reflection or one of other activities used here on conceptual understanding while others are kept the same may bring new light in research on metacognition in laboratory education.

In the present study, students' reflective forms were used solely as one of the metacognitive activities. They were not analyzed to probe the level of the students' metacognitive thinking. For a deeper analysis on the impact of metacognitive activities, students' products, such as reflections need to be analyzed. Further research made on the students' metacognitive thinking level may bring new light to this issue.

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Appendix-I: PRE-COURSE REFLECTIVE FORM

1. Why do you think you entered this course?
2. What kinds of knowledge and skills do you think should this lab course make you acquire?
3. Do you think you will easily be able to perform the experiments in this course or do you think you may have some difficulties? If you think that you may have some difficulties what kind of difficulties might they be
4. What kind of obstacles for learning do you think you may encounter in this course and what should you do to overcome these obstacles?

Appendix-II: PRE-INSTRUCTION REFLECTIVE FORM

1. Why do you think you should do this experiment?
2. What do you think you are going to learn by performing this experiment?
3. Do you think this experiment will contribute to your learning about other science topics or other aspects of chemistry? If yes which knowledge and skills will this experiment make you gain?
4. Do you think you will use knowledge you will acquire by performing this experiment in explaining daily phenomena? If yes where do you think you are going to use this knowledge?

Appendix-III: POST-INSTRUCTION REFLECTIVE FORM

1. Why do you think you were required to do this experiment?
2. What do you think you learned by performing this experiment?
3. Do you think this experiment contributed to your learning about other science topics or other aspects of chemistry? If yes which knowledge and skills did this experiment make you gain?

4. Do you think you will use knowledge you acquired by performing this experiment in explaining daily phenomena? If yes where do you think you are going to use this knowledge?

Appendix-IV: POST-COURSE REFLECTIVE FORM

1. Why do you think you entered this course?
2. What kinds of knowledge and skills do you think did this lab course make you acquire?
3. Do you think you were easily able to perform the experiments in this course or do you think you had some difficulties? If you had some difficulties what kind of difficulties were they?
4. What kind of obstacles for learning do you think you encountered in this course and what should have you done to overcome these obstacles?
5. Were the experiments you designed and performed instructive in this learning environment? If not how do you think should have you designed and performed them?
6. Were the experiments you designed and performed enjoyable in this learning environment? If not how do you think should have you designed and performed them?

Kimya Laboratuarında Bilişüstü Aktivitelerin Kullanılmasının Kavramsal Anlamanın Gelişimi Üzerindeki Etkisinin Araştırılması

Öz
Bu çalışmada, bir kimya laboratuarında bilişüstü aktivitelerin kullanımının, üniversite öğrencilerinin kavramsal anlamaları üzerindeki etkisi araştırılmıştır. Üniversite birinci sınıf öğrencilerinden oluşan bir örneklem, kontrol grubu ve deney grubu olmak üzere rasgele olarak iki gruba ayrılmıştır. Kontrol grubundaki öğrenciler deneyleri geleneksel bir şekilde gerçekleştirmiştir. Deney grubundaki öğrenciler aynı deneyleri gerçekleştirirken bilişüstü harekete geçiriciler, geribildirim, yansıtma ve laboratuar öncesi ve sonrası tartışmaları içeren bir uygulamaya tabi tutulmuşlardır. Her iki grupta da tepkime hızı ve kimyasal denge kavramlarında bazı yanılgılar görünmekle birlikte, sonuçlar, deney grubunun birkaç konuda kavramsal anlama düzeylerinin kontrol grubundakinden anlamlı olarak daha yüksek olduğunu göstermiştir.

Anahtar sözcükler: Bilişüstü aktiviteler, kavramsal anlama, kimya laboratu