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Using the Science Writing Heuristic Approach to Enhance Student Understanding in Chemical Change and Mixture

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Abstract This study investigated the effect of the Science Writing Heuristic (SWH) approach on grade 9 students' understanding of chemical change and mixture concepts. Four intact classes taught by two chemistry teachers from a Turkish public high school were selected for the study; one class was assigned as the treatment group, and the other class was assigned as the comparison group. Students in the treatment group were instructed by the SWH approach, while those in the comparison group were instructed with traditionally designed chemistry instruction. Tests measuring students' conceptual understanding in the units of chemical change and mixture were administered as pre- and posttest for both groups. At the end of the instruction, semistructured interviews were conducted with 13 students from the treatment group and eight students from the comparison group. ANCOVA results revealed that the SWH approach was superior to the traditional approach on students' understanding of chemical change and mixture concepts. Interview results indicated that students in the treatment group demonstrated better scientific understanding of chemical change and mixture concepts compared to those in the comparison group.

Keywords Chemistry education · Conceptual change · Grade 9 students · Science writing heuristic approach

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Introduction

Constructivism is increasingly influential in guiding student learning around the world. However, as knowledge is constructed in the minds of students, some of their commonsense ideas are personal, stable, and not congruent with the scientifically accepted conceptions (Driver et al. 1985). These kinds of ideas held by students are often referred to as misconceptions (Nakhleh 1992). Students' misconceptions and learning difficulties constitute a major barrier for their learning in various chemistry topics (Garnett et al. 1995). Some studies have shown that students struggled with learning various chemistry conceptions (Ayas et al. 2010; Bilgin and Geban 2006; Coştu et al. 2010; Pınarbaşı et al. 2006). Chemical change and mixture are two important chemistry topics in the grade 9 chemistry curriculum in Turkey. The concepts of chemical property, chemical change, and types of chemical reactions from a unit on chemical change, and classification of mixtures and separation of mixtures from a unit on mixtures, are covered in the Turkish high school chemistry curriculum. Several international and national studies have probed students' thinking about chemical changes (Ahtee and Varjola 1998; Ardac and Akaygun 2004; Johnson 2000; Solsona et al. 2003) and mixtures and solutions (Çalık et al. 2007; Coştu et al. 2007; Stains and Talanquer 2007).

Several studies found that students had difficulty in distinguishing the chemical change from the physical change (Ahtee and Varjola 1998; Eilks et al. 2007; Stavridou and Solomonidou 1998); these students' understanding of the term *chemical change* was not as a transformation of one or two substances into other substances, but rather as events with some observable indicators (e.g., color change, gas release, explosion, etc.). However, those changes could be in both physical and chemical changes. Additionally, some students' personal criteria for the identification of chemical changes were not scientifically satisfactory. For example, some students identified a phenomenon as chemical when there were two products at the initial state. Some of them thought that a chemical reaction resulted in a new product, but their understanding of the new product was not scientifically correct; they interpreted the new product as a thing different from the initial product. For example, when salt was dissolved in water, those students interpreted the salty water as a new product so the change was chemical. Some students believed that two starting substances form one product (Ahtee and Varjola 1998; Eilks et al. 2007). Another misunderstanding—that chemical reactions are not reversible—was demonstrated in the studies by Gabel (1999) and Johnson (2000).

Students also held classification errors about the mixtures; for example, a higher number of students had difficulty in classifying the substances as an element, a compound, or a mixture (Ayas and Demirbas 1997). Students classified the pure compounds as mixtures because they contain two or more different atoms, and they classified all the mixtures as heterogeneous because there were two different chemicals in the drawing (Sanger 2000). A common misconception among students was the confusion between dissolving and melting (Abraham et al. 1994; Çalık et al. 2007).

Since prior learning is an active agent for student learning, science educators have been focused on changing these misconceptions with scientifically acceptable ideas. In traditional science teaching, it is difficult for the learners to change their misconceptions (Jones and Beeth 1995). The strategies based on the conceptual change approach are widely used to remediate students' misconceptions (Davis 2001). According to the conceptual change approach (Posner et al. 1982), learning is the interaction between prior knowledge and new information. The process of learning depends on the degree of the integration of prior knowledge with the new information. If individuals know little about the subject matter, new information is easily embedded in their cognitive structure (assimilation). In contrast, if a person has stronger beliefs and knowledge, there are two possibilities. If these stronger ideas are consistent with the new information, then new conceptions are easily integrated with existing knowledge; but if these stronger ideas are conflicting with the subject matter, then a set of conceptual change conditions are required for the acquisition of new knowledge (accommodation). Posner et al. (1982) focused on the more radical change, accommodation and suggested four conditions that must be met for this type of change to occur: (a) there must be dissatisfaction with the currently held concept, (b) the new concept must be intelligible, (c) the new concept must be plausible, and (d) the new concept must be fruitful.

The Science Writing Heuristic (SWH) approach can be used to promote students' acquisition of scientific concepts (Keys et al. 1999). The SWH approach is grounded on the constructivist philosophy because it encourages students to use guided inquiry laboratory activities and collaborative group work to actively negotiate and construct knowledge. The SWH approach successfully integrates inquiry activities, collaborative group work, meaning making via argumentation, and writing-to-learn strategies. SWH consists of a teacher template and a student template (Table 1).

The teacher template includes a series of activities that can be used for the design of the learning environment. The negotiation activities are the central part of the SWH because learning occurs through the negotiation of ideas. Students negotiate meaning from experimental data and observations through collaboration within and between groups. Moreover, the student template involves the structure of argumentation known as question, claim, and evidence. Students can use this template in both writing their laboratory reports or participating in classroom and laboratory activities. Reflective writing scaffolds the integration of new ideas with prior learning. Students focus on how their ideas changed through negotiation and reflective writing, which helps them confront their misconceptions and construct scientifically accepted conceptions (Burke et al. 2005; Hand et al. 2009).

There are many international studies investigating the effectiveness of the SWH approach over the traditional approach (Akkus et al. 2007; Keys et al. 1999; Nam et al. 2010; Rudd et al. 2007; Schroeder and Greenbowe 2008). Keys et al. (1999) investigated the effect of the SWH approach on grade 8 students' meaning making, conceptual change, and reasoning. They found that student-written reports had evidence of their science learning, metacognitive thinking, and self-reflection. Students

Table 1 SWH template for teacher and student

Teacher template	Student template
Preinstructional activities (e.g., questioning, brainstorming)	What are my questions?
Participation in investigations	What did I do?
Negotiation I: interpretation of the data individually	What did I see?
Negotiation II: sharing individual data interpretations in small groups and developing group interpretation of data	What can I claim?
Negotiation III: comparing science ideas to other printed or electronic sources	How do I know?
Negotiation IV: personal reflection or writing	How do my ideas compare to others?
Exploration of students' postunderstandings	How have my ideas changed?

presented reasons and arguments in the meaning-making process, and students' self-reflections illustrated the presence of conceptual change about the science concepts. Similarly, Rudd et al. (2007) asserted that using the SWH laboratory report format in lieu of a traditional laboratory report format was effective on acquisition of scientific conceptions, elimination of misconceptions, and learning difficulties in chemical equilibrium.

Several national studies examined the impact of the SWH approach over a traditional approach on students' science learning and found parallel results with the international studies (Erkol et al. 2008; Günel et al. 2010; Kabatas et al. 2008). Günel et al. (2010) found that SWH activities led to greater understanding of grade 6 science concepts when compared to traditional activities. The studies conducted at the postsecondary level showed similar results as studies conducted at the elementary level.

Chemical change and mixture are two chemistry concepts that have many applications in everyday context. One of the important aims of chemistry education is to improve students' understanding of the everyday life phenomena and make them apply and use scientific concepts to describe the events occurring in daily life. Therefore, confronting students with their scientifically incorrect explanations and making them acquire scientific conceptions is an important issue that needs to be taken into consideration. Students' scientific acquisition of chemical change and mixture conceptions can facilitate understanding of further chemistry concepts, like "chemical reactions and energy" and "solutions" (Stavridou and Solomonidou 1998). There are few studies regarding the implementation of the SWH approach at the secondary school chemistry level, and the number of national studies is limited when compared to international studies. Students have difficulty in understanding the chemical change and mixture concepts. It was demonstrated that the SWH approach can be effective on students' acquisition of chemistry concepts (Rudd et al. 2007; Schroeder and Greenbowe 2008). SWH facilitates conceptual change through a set of argument-based inquiry activities. Students negotiate meaning and construct knowledge, reflect on their own understandings through writing, and share and compare their personal meanings with others in a social context (Keys et al. 1999). Therefore, the present study aimed to investigate the effect of the SWH approach compared to traditional chemistry instruction on grade 9 students' understanding of chemical change and mixture concepts. Additionally, these students' conceptions about chemical change and mixture were examined through in-depth interviews.

Method

This section describes in detail how the study was conducted, including sample characteristics and data collection tools.

Participants

The participants in this study were 122 grade 9 students from four intact classes of two teachers in a Turkish public high school. In selecting these four classes, we paid attention to work with teachers having two classes at the ninth grade level to minimize the teacher effect on this quasi-experimental design. There were 62 students (33 male and 29 female) in the treatment group (one section from each teacher) and 60 students (30 male and 30 female) in the comparison group (the other section from each teacher). In this study, groups were selected, and the individuals were not assigned to the group randomly, which limits the control of subject characteristics threat. To control this, the students' chemistry mean scores in the previous semester, and the data about their socio-economic status (SES), age, and gender were obtained and assessed. The treatment and comparison group students were not differing with respect to previous chemistry mean scores (X_{TG}=2.05; X_{CG}=2.33), SES (X_{TG}=7.93; X_{CG}=7.88), age (X_{TG}=15.27; X_{CG}=15.23), and gender (X_{TG}=1.52; X_{CG}=1.50) prior to the study. For interviews, students were categorized as high achievers, middle achievers, and low achievers based on their chemistry mean scores in the previous semester. Then, volunteers from each achievement level were selected for each group. Semistructured interviews were conducted with 13 students from the treatment group and 8 students from the comparison group for further exploration of the concepts.

Data Collection

Data were collected using a pretest and a posttest and interviews of some students, which are described more fully below.

The Chemical Change and Mixture Concept Test

This instrument was used to identify students' misconceptions of chemical changes and mixtures. The chemical change and mixture concept test (CCMCT) is a two-tier test that was developed by the researchers in this study. The questions considered the related literature (e.g., BouJaoude 1992; Çalık 2005; Çalık et al. 2007; Coştu et al. 2007; Eilks et al. 2007; Papageorgiou and Sakka 2000) and the objectives related to the chemical change and mixture units determined by the national chemistry curriculum (MNE 2007). In the first tier, a multiple-choice question was asked; in the second tier, the reason for preferring that choice was asked. In the development of the first tier, possible misconceptions were included in the alternative answers of each item. In total, there were 20 items in the CCMCT: 10 questions about chemical changes and 10 questions about mixtures. Table 2 demonstrates misconceptions related to chemical change and mixture concepts addressed in CCMCT.

Cronbach's alpha reliability of the test's pilot scores was computed as 0.80. To ensure validity, three experts in chemistry education examined the test and evaluated whether the items identified students' misconceptions. Because this test was developed in Turkish, a Turkish language teacher examined the test with respect to its grammatical aspects and understandability, and a chemistry teacher examined it for understandability. The CCMCT was administered in a regular class hour to all students both before and after the treatment. See Fig. 1 for sample CCMCT items.

Semistructured Interviews

Semistructured interviews were conducted after the instruction to elicit information about the students' ideas on chemical change and mixture. The interview protocol was constructed by the researchers and revised with the recommendations from experts. Interview protocol was administered to the students in both treatment (n=13) and comparison groups (n=8). It included eight conceptual questions about chemical change (e.g., What is the type of change when a silver ring tarnishes? Why?) and mixture (e.g., What is a solution? Are all the mixtures solutions? In which form, solid–liquid–gas, can a solution be found? Give examples.). The interviews lasted about 30 min. One of the researchers interviewed the students individually at school and audio-recorded all sessions.

Table 2 Common misconceptions probed by CCMCT

Misconceptions	Items
Physical changes are reversible while chemical changes are not	1, 5, 7
Change of state is a chemical change	2, 4
A candle burning is the same as wax melting	1, 6
When a candle burns, only the wick burns	1,
Melting and dissolving is the same thing	3, 18, 19
Rusting of an iron nail is a physical change	7
A nail's weight does not change after rusting	8
A nail's weight decreases after rusting	8
A nail's weight increases after rusting due to adding something like water, rust, oxygen, oxygen and water, without a reaction	8
Coldness causes a nail to rust	9
Iron turns into other elements after rusting	9
Rust eats away the material	8
Iron and rust are the same	8
All mixtures are heterogeneous	11
Mixtures always consist of two substances	12
Things dissolve by mixing them in water or solutions are in a liquid state	20
Weight decreases in dissolving	14
Confusion between pure substances and mixtures	15
Failure to discriminate between elements, compounds and mixtures	13, 15
The identities of the components in a mixture are not retained	3

Procedure

This study was carried out during regular classroom hours over a 10-week period. The classroom instruction for both groups included two 45-min periods per week. A quasi-

Item 1: What is the type of change when a candle burns?

a) Physical
b) Chemical

Explain the reason for your choice in the previous item.

………
………
……………………

Item 14: What is the mass of the solution when 1 g salt is added to 20 g water?

a) less than 21 g
b) 21 g
c) more than 21 g

Explain the reason for your choice in the previous item.

………
………
……………………

Fig. 1 Sample items from the chemical change and mixture concept test experimental design was used because it is unlikely to obtain administrative approval to randomly select and remove a selected few students from different classrooms for any study in a Turkish high school. During the study, the topics related to chemical change and mixture were covered as part of the regular chemistry curriculum. Equal amount of instructional time was devoted for both groups. The language of the instruction and the data collection tools used in both groups was Turkish. The comparison group was instructed using a traditional approach, while the treatment group was instructed using the SWH approach. Prior to the instruction, the CCMCT was administered to both groups to determine whether there was a significant group difference with respect to measures of this instrument before the treatment. The treatment period started after the pretest was given. To examine the effect of the treatment, the same CCMCT was given to both groups as a posttest.

In order to facilitate the proper instruction of the SWH approach in the treatment group, the teachers were given training sessions about its implementation prior to the study. The teachers were familiar with the traditional instruction. One of the teachers was teaching chemistry for 20 years, while the other was teaching chemistry for 22 years at a high school. The researcher also asked the teachers to teach the comparison group students in the same way they taught before and not to do things specified for the treatment group. One of the researchers participated in all class sessions with the teachers and observed the class by taking field notes in both groups in order to control for the teacher effect and bias. It was observed that the teachers fulfilled the requirements for each instruction and were not biased in their implementations.

In the first week, students in both groups were taken to the laboratory and were told that the chemistry classes would be conducted in the laboratory for most of the weeks. Since it was the first time for these students in the laboratory, they did not have much information about laboratory safety rules and the basic materials used in a chemistry laboratory. For this reason, in the first laboratory class hour, the students were informed about safety rules and basic materials (e.g., beaker, tube, etc.). Because the students' safety is very important in the chemistry laboratory, they were especially cautioned about acids, bases, and toxic materials. In order to prevent the occurrence of negative attitudes in the comparison group students, the teacher also used the laboratory in the comparison group, although it was not a part of their regular instruction. However, the laboratory was used for the experiments suggested in their textbook in a traditional format for this group.

Instruction in Treatment Group

The teacher asked students to form their own small groups ($n=5$) and introduced to them the SWH approach via the mystery death activity (Burke et al. 2005). Each group was given a short story including details of a potential crime scene with possible outcomes. The students were asked to read it individually and play the role of a detective investigating the scene. Then, they were asked to suggest a beginning question about the death, write a claim, and support that claim with evidence. Upon completion, they shared their questions, claims, and evidence in order to construct a group question, claim, and evidence. A student from each group wrote their group's question, claim, and evidence on the board, and each group, in turn, explained their written arguments to the entire class. After each group presented the rest of the class asked them questions or refuted something they claimed or argued. After all these processes were completed, the teacher summarized what was done in the classroom from the beginning to the end. The teacher engaged students in a discussion about questions, claims, and evidence in order to make students aware of the meaning of those words. The appropriateness of students' evidence for their claims, and the relations among questions, claims, and evidence were also discussed in the classroom. This activity was not related to chemistry; for this reason, it attracted students' attention very much. The aim of this activity was to make students understand the SWH approach and conceptualize the process of argumentation, which is a structure of question, claim, and evidence.

The teacher then engaged students in a discussion about the following week's chemistry topic: chemical change. First, the teacher attempted to elicit students' prior understanding about chemical change through questioning; for example, What is physical change? What is chemical change? What is the difference between a physical and chemical change? Could you give daily life examples of physical and chemical change? The teacher asked students to write down what they wanted to learn about chemical change, to share those items within their group, and to prepare an investigation question with a possible test and procedure for the next class. While students constructed their own questions and planned their testing procedure, the teacher circulated through the groups and facilitated students' thinking through questioning as follows, "What is your question?," "What are you going to do to test your question?," "What are your variables?," and "How would you measure/control those variables?"

In that class, students wrote their beginning questions on the board. Each group presented their questions to the class. The teacher and the rest of the class evaluated the quality of the question in relation to the big idea (e.g., chemical identity of a substance changes in a chemical change) and appropriateness for the laboratory investigation. During the group presentation, each group mentioned the procedure they were going to follow. The groups' procedures were discussed and revised prior to the actual laboratory investigation. After the appropriateness of each group's questions and procedures were assessed via classroom discussion, each group tested their own questions experimentally. Almost all of the students in each group actively engaged in an experimental process; they recorded the data and observations during the experimentation. Students were generally eager to contribute to the whole process because they were investigating their own questions. Throughout the experimentation, the teacher circulated through the groups, warned a few students that were not actively engaging in group work, and asked questions as follows, "What did you observe/find?" and "Could you organize and summarize your data in a visual way?" The teacher asked each student to write a claim about what they thought happened, and support that claim with the evidence. The teacher circulated through the classroom, served as a resource person, and asked the following questions, "How do you interpret your data?," "Do you see any pattern/relationship in your data?," and "Do you think that your question, claim, and evidence are related to each other?" Immediately afterwards, students negotiated their individual claims and evidence within their groups, and constructed group claims and evidence. Upon completion of these processes, each group wrote their questions, claims, and evidence on the board and presented them to the rest of the class.

For example, one group's question was, "What are the physical and chemical properties of granulated sugar (sucrose)?" To test their question, they stated, "We are going to take two test tubes. Then we are going to add granulated sugar to the water in the first test tube, and add granulated sugar to the second tube and heat it." The students recorded their observations during the experimentation. Based on their data, they claimed, "Dissolving sugar in water is a physical change but burning sugar is a chemical change." They justified their claim by stating, "Sugar dissolved in water, and we can taste sugar again. When we evaporated the water in a sugar-water solution, we obtained sugar easily. However, sugar burned when we heated it, and the burned sugar is a completely different substance; it does not show sugar properties, and we could not obtain sugar from burned sugar."

During the presentation, the teacher and the rest of the class asked questions, which started a discussion in the class. The teacher had the students assess the presenter group and discuss the quality of their arguments. During the discussion, one student from the presenter group used *melting* for dissolving. He stated, “Sugar melted in water.” The teacher has been alerted to possible student misunderstandings and misuse of the conceptions. The teacher asked the rest of the class whether they would agree with their classmate. There were some students agreeing with that student. Then, the teacher asked the following questions to clarify the distinction between dissolving and melting, “What is melting?,” “Could you melt sugar?,” “How does sugar melt?,” “How do you represent the melted sugar in your drawing?,” “What is dissolving?,” “How does sugar dissolve?,” and “How do you represent sugar–water solution in your drawing?” Classroom discussion guided by these questions helped to clarify students’ conceptions about melting and dissolving and thereby facilitated students’ acquisition of scientific conceptions. The teacher also asked, “What is the equation for burning sugar?” The students tried to write it with the help of the teacher. The other four groups presented their arguments in the same way. At the end of the class session, the teacher and students summarized what they did in the class. The teacher asked students to write a laboratory report based on the SWH student template given in Table 1 and bring it the next week. In the SWH laboratory report format, the subheadings were beginning questions, test, data and observations, claims, evidence, reading, and reflections. The teacher explained how to approach writing each aspect of the report. When explaining the questions, claims, and evidence parts of the SWH report, the teacher mostly referred to the mystery death activity because the aim of that activity was to make students familiar with those concepts. Students were encouraged to use relevant sources for their writing, including readings from various sources, expert views, notes, and classroom discussions. Students’ reports were not used in the data analysis for this study. The students attended seven more class sessions including investigations about types of chemical reactions, and classification and separation of mixtures. For each investigation, the students followed the same approach. Some class sessions lasted 2 h, but some of them lasted more than 2 h.

Instruction in Comparison Group

In the comparison group, the teacher mainly used lecture and discussion methods while teaching chemical change and mixture concepts. The chemistry textbook was the primary source of knowledge in this group. Students were required to read the related topic from the textbook prior to each lesson. The teacher was highly active throughout the instruction. The teacher announced the goals of the lesson in advance, wrote the key concepts on the board, and explained each concept by giving examples. During the transmission of knowledge, the teacher did not consider students’ prior understandings and frequently used the board to write chemical formulas and equations and draw some figures. In order to ensure that all of the students understood the concepts in the same way, the teacher asked questions as follows, “What is …?” and “Could you give an example of …?” Such teacher-driven questions contributed to the creation of a discussion between teacher and students. Then, the teacher summarized the concepts under consideration and prompted students to take notes. Toward the end of the class session, the teacher wrote some algorithmic problems on the board and asked students to solve those problems individually. The teacher moved around the classroom and warned the students who were not trying to solve the problem. Then, the teacher asked a student to come to the board and solve a problem. The teacher helped that student while solving the problem. The problems that were not solved during the class session were given as homework.

The students also engaged in laboratory activities; however, the nature of their laboratory activities was traditional in nature. In this group, the aim of the laboratory activities was to verify what students learned in the classroom. Prior to the laboratory session, students were asked to read the procedures of the laboratory experiment in their textbook. At the laboratory, the teacher explained the purpose and procedures of the experiment, and then requested the students to follow the step-by-step instructions for the experiment. Working in groups ($n=5$), all the students conducted the same experiment in their textbook under the direct control of the teacher. The teacher helped students during the experimentation process, especially in setting up the apparatus for experiment. During the activity, the teacher moved around the groups and warned the students who were not engaging in the activity. The students were asked to record their observations and data. They were not required to reason about the data in a deeper manner. In addition, the teacher asked each group to respond to the questions about the experiment included in their textbook. When students failed to answer those questions, the teacher answered them directly without giving any hint to the students. At the end of the laboratory activity, students were asked to write a laboratory report in traditional format, including purpose, procedure, observations and data, results, and discussion. The teacher asked questions and helped students during the activity to facilitate their connection of laboratory activity with what they learned in the classroom.

Results

The major findings of the study were reported in this section through the analyses of statistical and interview data.

Analyses of Statistical Data

ANCOVA was used to take the unwanted effects of the pre- on post-CCMCT. The results indicated that that there was a significant mean difference between the groups with respect to post-CCMCT when the effects of pre-CCMCT mean scores were controlled, F (1,117)=12.50, $p<0.05$. The students in the treatment group (M= 36.74, SD=11.10) had higher mean scores on the post-CCMCT than those in the comparison group (M=30.01, SD=10.24).

The size of the mean difference between the groups was medium (Cohen 1992), which means that 10 % of the variance on the post-CCMCT was associated with the treatment. These findings revealed that the difference found between the treatment and comparison groups arose from the treatment effect, and this difference had practical importance. What is more, students' previous knowledge as measured by the pre-CCMCT contributed significantly to their post-CCMCT scores, F (1,117)=26.77, $p<0.05$, by explaining 19 % of the variation on the post-CCMCT.

Students' written responses on the second tier of the CCMCT were coded by the researchers based on the predetermined criteria as wrong response, specific misconception, partially correct response, and correct response. Two experts in science education examined these codes; revisions were made in accordance with the feedback given by those experts. Generally, the proportions of correct responses given for the first-tier items were higher than second-tier items. In the second-tier items, some students in both groups had partial understanding, some had no understanding, and some held misconceptions when they were explaining the reason of their choice to the multiple-choice questions given in the first-tier items. There were differences in the proportion of misconceptions between treatment and comparison groups. The proportion of misconceptions held by students in the comparison group was higher than that in the treatment group in most items (Table 3).

For example, in one item related to chemical change, students were asked the type of change occurring when a teaspoon of salt is added to a glass of water and then asked to explain their reason. For the treatment group, 92 % of the students answered this item correctly as “physical change,” but only 57 % of students in the comparison group answered this item correctly. When explaining their reason, some students (7 % in the treatment group, 32 % in the comparison group) showed misconceptions (e.g., it is a physical change because the salt melts in water). In another item related to chemical change, the students were asked the type of change when a silver ring tarnishes. At the beginning of the treatment, 65 % of the treatment group and 48 % of the comparison group students incorrectly thought that “if a silver ring tarnishes, physical change occurs”; at the end of the treatment, these percentages decreased from 65 to 14 % and from 48 to 22 %, respectively. Moreover, some students (11 % in the treatment group and 23 % in the comparison group) showed misconceptions when they were explaining their reason (e.g., if a silver ring tarnishes, there is a physical change because we can get rid of the tarnish of the silver ring).

In an item related to mixture, students were asked what could be the mass of the solution when 1 g salt and 20 g water were mixed together. After the treatment, 82 % of the treatment group and 58 % of the comparison group students correctly responded to this item as 21 g. On the other hand, some students (27 % in the comparison group and 7 % in the treatment group) held some incorrect explanations (e.g., the mass is <21 g because the salt disappears in water). In another item related to mixture, students were asked what happens to the sugar when it is put into a glass of water. Many students used the terms *melting* and *dissolving* interchangeably. At the beginning of the treatment, the proportion of students having this misconception was 55 % in the treatment group and 53 % in the comparison group; at the end of the treatment, the students having this misconception were 22 and 43 %, respectively. The students were also asked a question about the state of solutions. After the treatment, the percentages of students who answered this item correctly as “Solutions could be in the form of solids, liquids, or gases” were 61 % in the treatment group and 45 % in the comparison group, while the corresponding percentages in the pretest were 27 and 30 %, respectively. The alternative conceptions observed in both groups were as follows: (a) All solutions are in the form of liquid—only the liquids could be a solvent; (b) solutions could be in the form of either liquid or gases—solids cannot be dissolved among each other; and (c) solutions could be in the form of either liquid or solid—gases cannot be dissolved, and there are not any solvent gases.

Analyses of Interview Data

For the analyses of the interview data, the audio recordings were transcribed in full. The first three interview transcripts were coded independently by the researchers, and 90% interrater agreement on coding categories was obtained. The discrepancies were discussed, and the remaining transcripts were coded by one of the researchers. The codes that were close to each other were collected and categorized into three general themes: definition of the concepts, examples of the concepts, and relationship among the concepts (Marshall and

Table 3 Distribution of percentage of students' responses to the pre- and post-CCMCT across groups

Item	Pre-CCMCT										Post-CCMCT									
	1st tier		2nd tier								1st tier		2nd tier							
	% Correct response		% Wrong response		% Misconception		% Partial correct *R*		% Correct response		%Correct response		% Wrong response		% Misconception		% Partial correct *R*		% Correct response	
	TG	CG	TG	CG	TG	CG	TG	CG	TG	CG	TG	CG	TG	CG	TG	CG	TG	CG	TG	CG
1	50	50	14	22	53	55	29	18	0	0	64	75	27	27	22	28	11	30	39	15
2	82	77	8	10	11	13	64	58	13	13	97	92	26	23	0	5	0	43	74	28
3	53	32	19	23	56	48	13	23	8	0	92	57	29	42	7	32	7	15	58	11
4	57	72	54	60	11	15	27	20	3	0	85	72	58	80	3	3	3	8	35	5
5	35	52	27	35	48	37	19	22	2	2	86	78	31	35	11	23	18	25	40	17
6	50	25	26	33	61	58	10	3	0	0	38	26	40	57	35	32	7	8	18	3
7	64	72	32	33	40	33	23	23	2	5	92	82	31	48	5	12	16	27	48	12
8	43	38	48	50	42	42	6	3	0	0	77	35	43	53	32	47	0	0	24	0
9	35	47	47	62	43	25	5	8	2	0	61	33	61	73	11	25	7	0	21	2
10	71	63	24	33	6	17	35	32	31	13	87	35	42	83	0	15	0	0	58	2
11	64	63	68	73	11	8	13	7	5	7	92	72	55	72	2	13	7	12	37	3
12	18	20	55	57	31	23	10	12	2	3	63	27	55	63	6	27	5	7	34	5
13	50	37	42	43	13	20	27	23	14	8	69	35	45	53	5	22	2	18	48	7
14	43	30	43	38	24	40	24	15	5	2	82	58	48	46	7	21	0	25	45	8
15	27	20	53	53	30	20	3	17	10	5	45	17	65	68	8	17	2	10	26	5
16	69	72	35	33	27	28	34	33	0	0	76	72	40	52	3	17	18	20	39	12
17	21	30	42	50	47	38	8	5	0	2	48	32	55	67	19	30	7	0	19	3
18	53	67	34	32	34	27	24	32	5	5	85	70	37	55	2	18	3	15	58	12
19	35	37	32	43	50	33	11	18	3	0	73	47	50	68	3	13	5	10	42	8
20	27	30	61	63	21	25	14	5	0	2	61	45	66	78	11	17	0	0	22	5

TG treatment group, *CG* comparison group

Table 4 Distribution of percentage of students across the codes identified from semistructured interviews

Code	Treatment group				Comparison group			
	NA	M	PC	C	NA	M	PC	C
Definition of the concepts								
Definition of physical change	0	0	23	77	0	0	50	50
Definition of chemical change	0	0	15	85	12	25	12	50
Definition of mixture	0	0	31	69	12	25	50	25
Definition of solution	0	8	61	31	0	37	62	0
Examples of the concepts								
Examples of physical change	8	0	0	92	12	25	0	62
Examples of chemical change	0	0	0	100	0	0	0	100
Examples of mixtures	0	8	0	92	0	0	0	100
Examples of solution	15	31	23	31	0	50	25	25
Relationship among the concepts								
Physical and chemical change	0	46	23	31	0	75	12	12
Rusting and weight	8	38	23	31	12	62	12	12
Mixture and solution	8	0	0	92	25	25	0	37
Solubility and pressure	0	8	31	61	0	12	75	12
Solubility and temperature	8	23	46	23	0	50	37	12
Dissolving, melting and disappearance	0	15	23	61	0	62	12	25

NA no answer, *M* misconception, *PC* partially correct, *C* correct

Rossman 2006). The interview data were interpreted based on the codes and categories as shown in Table 4.

Definition of the Concepts

Most of the students in the treatment group and some students in the comparison group defined physical change correctly (e.g., a change in the physical properties of matter without a change in its chemical properties), but some defined it partially correct (e.g., a change in matter without a change in its properties). About the concept of chemical change, there were correct definitions in both groups (e.g., a change in the chemical properties of matter). There were also some partially correct definitions in both groups (e.g., a change from one matter to another matter). Some students in the comparison group could not define this term, and some defined it incorrectly (e.g., it is the decaying or molding of matter without losing its properties).

Most of the students in the treatment group and a few students in the comparison group could define the mixture correctly (e.g., the process of mixing two or more than two substances without any constant proportion). Some students in both groups defined this term partially correct (e.g., the process of mixing two substances), and some in the comparison group defined this term incorrectly (e.g., the process of mixing two elements). Students in both groups had difficulty in defining the term *solution*. Some students in the treatment group defined it correctly (e.g., a homogeneous mixture of two or more substances), but none of the students in the comparison group could make a correct definition. Many students in both groups defined solution partially correct (e.g., a matter that is formed through the combination of a solvent and a solute). Some students in the comparison group and a few students in the treatment group thought a solution was dissolution of a solid in a liquid matter.

Examples of the Concepts

Students in both groups gave similar examples to the physical change (e.g., cutting paper into pieces, and state changes as melting of an ice and a candle) and chemical change (e.g., burning, tarnishing, and rusting processes). A few students in both groups could not give any example of a physical change. Some comparison group students gave “spoiling of yoghurt” and “burning of candle” as incorrect examples of a physical change.

Related to the mixture, most students in both groups stated “salt–water” and “sugar–water” as examples. One student in the treatment group wrongly stated “ice water” as an example of mixture. Almost all examples given by students in both groups were the mixtures in which water and solid were used. Like mixture examples, most of the examples of solutions were in the form of liquid. The most common ones were “salt–water” and “sugar–water.” Some students in both groups could not give any examples of solid and gaseous solutions although they stated there could be solid and gaseous solutions. Some students in both groups believed that all solutions are in the form of liquid. For example, a student incorrectly claimed, “There should be a liquid as a solvent in a solution because solids and liquids cannot be a solvent.”

Relationship Among the Concepts

Most of the students in the comparison group and some students in the treatment group had difficulty in discriminating between physical and chemical change; discriminating among dissolving, melting, and disappearance; explaining the effect of temperature and pressure on solubility; and linking between solution and mixture; and interpreting the weight change in rusting. Students’ main criterion in discriminating between physical and chemical change was irreversibility. They usually thought that all chemical changes are irreversible and all physical changes are reversible. Accordingly, these students interpreted rusting and tarnishing as physical processes (e.g., it is physical because we can make the silver ring shiny again by immersing the tarnished silver in a special liquid). Similarly, students had difficulty in using the terms *melting*, *dissolving*, and *disappearance* scientifically. Some of them used dissolving and melting (e.g., sugar melts in water, that is, it dissolves) and dissolving and disappearance (e.g., sugar dissolves and then disappears) interchangeably. The relation between solution and mixture could not be interpreted scientifically by some of the students (e.g., all the mixtures are not solutions because a solution always includes water in it).

It was also difficult for the students to interpret weight change in the rusting process. For the rusting of a metal nail, some students incorrectly thought that its weight does not change (e.g., because there is no external effect on rusting, it occurs within the structure of the matter), and some thought that its weight decreases (e.g., because it loses its hardness). Some students could not explain the reason for their answer scientifically although they stated weight change in the rusting process correctly (e.g., rust comes from outside onto the metal nail, and this makes an extra weight to the metal nail).

Some students failed to explain the effect of temperature (e.g., dissolved amount of carbon dioxide does not change when the soda–water is put into the refrigerator because its lid is closed) and pressure (e.g., dissolved amount of carbon dioxide does not change when the lid of the soda–water is opened because the dissolved amount of the substance is constant in a certain soda–water) on the solubility of gases in liquids. Some students claimed that the dissolved amount of carbon dioxide increases when the soda–water is put into the refrigerator, but they could not justify their claims scientifically (e.g., in the refrigerator, the pressure increases, for this reason, the dissolved amount of carbon dioxide in soda–water increases).

Discussion

In this study, previous learning about chemical change and mixture made a statistically significant contribution to the variation in students' understanding of chemistry concepts measured by the posttest. Prior learning is very important in construction of knowledge; it may affect students' further learning positively or negatively (Gooding et al. 1990), and the degree to which prior knowledge is consistent with the new concepts (subject matter) is an indicator of the improved science learning. In this study, it was found that students instructed by the SWH approach scored significantly higher than those instructed by the traditional approach in the units of chemical change and mixture. The findings obtained from this study are consistent with the findings of other national and international studies in terms of supporting the idea that the SWH approach leads to greater conceptual understanding (Akkus et al. 2007; Günel et al. 2010; Keys et al. 1999).

In both groups, students held some misconceptions related to chemical change and mixture even after the instruction. Especially, the misconceptions uncovered by the items 1, 6, 8, and 17 in Table 3 were prevalent among the students in both groups. For example; after instruction some students in the experimental group still could not justify their answers in a scientific way. Many students still could not discriminate between physical and chemical changes; they thought that chemical changes were irreversible while physical changes were reversible (Abraham et al. 1994; Eilks et al. 2007; Gabel 1999; Johnson 2000) although most of the chemical changes are reversible. These findings suggest that misconceptions never go completely away even with the best intentions (Bilgin and Geban 2006; Garnett et al. 1995; Pınarbaşı et al. 2006). However, as shown in Table 3, the percentage of reduction after using the SWH is quite strong and indicates that this approach closes the misconception gap better than traditional instruction. In other words, the proportion of misconceptions held by students in the comparison group was higher than that in the treatment group. This finding supports the notion that it is not easy to eliminate misconceptions just by employing traditional instructions (Duit 2007). The difference between classroom activities provided in SWH and traditional approaches may cause the difference in students' acquisition of the scientific conceptions. Teaching for conceptual change requires identification of prior learning, resolution of the conflict between prior understandings and new information, and the application of new concepts into new situations. These steps were embedded in the implementation of the SWH approach. In the treatment group, students' prior conceptions were taken into account, and their misconceptions were activated through discussions in argument-based inquiry activities. Students were dissatisfied with their existing conceptions through the laboratory investigations; therefore, scientific conceptions were negotiated in small-group and whole-class discussions. The important part of the SWH approach was the social interaction because the scientific concepts were discussed through student–student and student–teacher interactions. These discussions facilitated students' understanding of chemical change and mixture concepts through conceptual change (Pintrich et al. 1993) and encouraged the involvement of the students in the learning process. On the other hand, in the comparison group, a traditional approach was used. The teacher taught the concepts of chemical change and mixture directly without considering students' existing conceptions.

The results also revealed that the misconceptions observed in the interviews were consistent with those detected as a result of the concept test. Many interviewed students in the comparison group and some students in the treatment group could not support their ideas scientifically. For example, when asked the type of change when a candle burns, students answered in such a way that all burning processes were a type of chemical change. When asked for further explanation, most of them failed to explain; they asserted that they were always told that all burning processes were chemical change. These students were engaged in verbatim learning in their previous years; they just memorized without considering the meaning of the concepts or without thinking what was happening at the microscopic level because in traditional classrooms the teacher aims to teach the content rather than the concepts. If the focus of the teaching becomes content, the expected information from students becomes more. For this reason, most of the students were involved in rote learning in traditional chemistry classes. However, SWH classes focus on acquisition of scientific concepts rather than the content, and big ideas are determined in advance (Ebenezer 1992; Keys et al. 1999). In addition, the examples of physical and chemical changes given by the students were very similar. Students probably developed these examples because the majority of the examples presented in textbooks or practiced in the classroom environment have those examples.

Moreover, there were striking differences between the groups in interpreting the relationships between the concepts (mixture and solution; pressure and solubility; and dissolving, melting, and disappearance) in favor of the treatment group as shown in Table 4. Failure to understand those relationships may be related to lack of knowledge or misinterpretation of particulate nature of matter (Ardac and Akaygun 2004) and interpreting all solutions as dissolution of a solid into a liquid (Ebenezer 1992). A possible reason for the success of SWH approach on those aspects of the topic may be active participation of students in the learning process. In the SWH classes, students constructed their own knowledge both individually and as a group through argumentation. The students engaged in investigations through which they tested their own questions. Seeking solutions to their own questions motivated them to learn and enhanced their awareness about the task under consideration. Working in small groups, they operated and manipulated experimental equipment, observed changes, took measurements, and negotiated and discussed their ideas during investigations.

What is more, with the SWH approach students were given opportunities to experience scientific phenomena and demonstrate scientific argumentation skills through the construction of claims and justification of those claims with evidence. Constructing arguments in such a learning environment means that students have learned the concepts under investigation without memorization (Cavagnetto 2010). In a nonthreatening learning environment, being able to express ideas about a phenomenon could provide valuable chance for students to reevaluate their own ideas under the light of others' views and data collected. This opportunity of argumentation enables students to refine, revise, and change their ideas with the help of individual writing activities where they have to engage with personal negotiation of their ideas.

Writing activities before, during, and after the SWH implementation would provide a space for students to reorganize their ideas about a phenomenon under investigation. At the beginning of the instruction, students wrote their own questions and the procedure for testing those questions. During the instruction, they wrote observations and data obtained from their investigations, and wrote claims and evidence based on their data. After the instruction, they wrote a report based on SWH student template. Report writing process helped students to make connections among questions, claims, and evidence, and to connect newly acquired knowledge with the previous ones. Therefore, the act of writing embedded in SWH approach supports the development of conceptual understanding at a deeper level. In short, considerable differences on a number of misconceptions between comparison and treatment groups appeared because the SWH group students had a number of opportunities for public and private negotiations of the ideas through oral and written argumentation tasks.

This study can be a guide for chemistry teachers about ways of eliciting students' prior learning. In this study, multiple-choice items, open-ended items, and preclass discussions were used in the determination of students' previous knowledge. Teachers should consider students' prior knowledge and alternative conceptions because they account for a significant proportion of student achievement in science (Pınarbaşı et al. 2006; Salta and Tzougraki 2011). In this study, students were confronted with their alternative conceptions and then encouraged to apply and use scientific conceptions through the use of private and public negotiations, and argumentation opportunities embedded in the SWH approach. This is an initial study into the use and value of using the SWH approach in a Turkish high school chemistry class, and the results do encourage future studies with larger sample size and different chemistry topics.

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