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Effect of simulations enhanced with conceptual change texts on university students' understanding of chemical equilibrium

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Abstract: The aim of this research was to investigate the effect of computer simulations enhanced with conceptual change texts (CS-CCT) on first year university students' understanding of chemical equilibrium. A quasi-experimental design and one control group (CG, $N = 60$) as well as one experimental group (EG, $N = 65$) were used in the study. While students in CG were taught with traditional methods based on textbooks and blackboard, the EG studied the same unit with CS-CCT. The chemical equilibrium concept test (CECT) was administered as pre-test, post-test and delayed test to collect data. The results indicated that the students' scores in the EG were significantly higher than those in the CG in both post-test and delayed test. It was concluded that CS-CCT may become a more effective way for students to picture in their minds chemical equilibrium and improve their alternative interpretations. Also, such a combination is useful for students to enhance their conceptual understanding.

Keywords: chemistry education; conceptual change; chemical equilibrium; students' learning.

INTRODUCTION

Chemical equilibrium is one of the most difficult concepts in chemistry[1,2] owing to its abstract character and its demand of the comprehension of a large number of subordinate concepts.[1] The literature reports that students on different levels do not understand chemical equilibrium effectively.[3,4] One of the main reasons for this are the traditional teaching strategies that are ineffective to develop a complete understanding of the abstract concepts, to build correct conceptions, to alleviate alternative conceptions, and to promote conceptual change.[5] And also, the results of the studies indicate that students in various grades do not understand the particulate-level processes, which are necessary to explain the observed phenomena adequately, even after receiving the traditional education.[6]

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Moreover, the students develop different alternative conceptions which are persistent, stable and resistant to change at least by the traditional teaching methods, and difficult to alter even by the specific instructions designed to address them.[7,8]

There are considerable amount of studies discovering students' alternative interpretations and the reasons why many students have great difficulty in successfully developing a scientifically accepted understanding of chemical equilibrium for the last two decades.[3,4,9] But, it is well known that knowing learners' alternative conceptions is not equivalent to having instructional methodology that could promote their conceptual change.[5] Also, student's intuitive beliefs influence how they learn new scientific knowledge and play an essential role in the subsequent learning. Because of this, teachers may need to consider the alternative teaching approaches – particularly for difficult and abstract science concepts. In the literature, a variety of successful teaching techniques have been documented and computer simulations (CS) as well as conceptual change texts (CCT) are two among them.[9–11]

Based on the increasing availability of computers, CS have become an integral part of many science curricula[12] and have been used in science education to promote the meaningful learning and to enhance the conceptual change.[13,14] Several researchers have argued that animations and CS are useful tools to show particulate interactions, which are necessary to explain the observed chemical phenomena,[15,16] as well as to help students understand chemistry by increasing their ability to visualize particle-level processes.[13,17] Also, some studies have suggested that students may develop better understanding of the concepts and may be able to answer conceptual questions about the particulate phenomena in a more scientifically accurate way by using the computer animations and/or CS.[13,18–20] In the literature, there have been several studies related to the effectiveness of CS in science teaching and learning.[21–23] Recently, Smetana and Bell[24] and Rutten, van Joolingen and van der Veen[12] reviewed the studies that were related to the effects of CS on understanding and suggested that CS can be more effective than traditional instructional practices in promoting science content knowledge, developing the process skills and facilitating the conceptual change.

CCT are designed to change students' alternative conceptions and focus on strategies to promote the conceptual change by producing discontent, followed by a correct explanation which is both understandable and plausible to the students.[9] These texts are also used to teach chemistry concepts including chemical equilibrium in the literature.[9,25]

It is clear that CS can be powerful learning tools in science education and their usage in the science classrooms has the potential to generate higher learning outcomes in ways not previously possible.[12,26] But, Tversky and Morrison[27] concluded that some of the CS does not have a beneficial effect on understanding although they can convey more information about micro-steps. Also, they suggested that a verbal explanation is required in addition to simulations. On the other hand, CCT are effective tools in correcting alternative conceptions but students do not see the microscopic nature of the chemistry by using CCT. In another words, both methods have insufficiencies when they are used on their own. In addition, Türk and Çalık[28] suggested that using a single teaching method may in fact result in new learning difficulties because students may become bored, reducing their motivation to learn. Similarly, some researchers, for example Jacobson and Kozma,[29] suggested a need for including supplementary material with CS. The idea that each method should be combined with some type of supportive activities is well known in the literature.[28,30] This idea raises the question of how we can increase the effectiveness of CS on students' learning of science.

We can easily say that there have been made several studies related to the determination of effectiveness of CS on students' understanding and learning outcomes in science. In recent time, Rutten, van Joolingen and van der Veen[12] listed these studies in a review in detail. But, studies that combine CS with other instructional practices such as CCT, laboratory work, concept mapping, group discussion, analogies, and so on are very limited. If it is necessary to give examples, Carlen and Thomas[31] used micro CS and CCT to overcome students' preconceptions about electric circuits. Similarly, Nurmi and Jaakkola[32] used CS, laboratory equipments and conceptual change pedagogies to improve students' understanding of the simple electricity. In chemistry, Özmen[33] tried to determine the effect of animations enhanced with CCT on 6 grade students' understanding of the particulate nature of matter and the transformation during the phase changes. Similarly, Özmen, Demircioğlu and Demircioğlu[34] used the CCT enhanced with animation to overcome students' alternative conceptions of chemical bonding. In another study, Trey and Khan[35] investigated the effect of CS that included a dynamic analogy on students' understanding of Le Chatelier's Principle and found that dynamic computer-based analogies can enhance students' learning of unobservable phenomena in chemistry.

The results of these studies show that if computer-based technologies are incorporated with other instructional practices, they can be more effective tools in improving students' conceptual understanding. Also, we can easily see from the literature that the combination of CS and CCT has been studied by few researchers, especially in chemistry. Starting from this perspective, we decided to combine them to determine the effectiveness of this combination on the university students' understanding of chemical equilibrium. In an attempt to address these issues, this study aims to identify how CS–CCT are effective on students' understanding of the chemical equilibrium. Such a combination does not only consider students' alternative conceptions, but also helps students to see their microscopic world *via* CS.

EXPERIMENTAL

Design

A quasi-experimental design utilized "a pre-test/post-test non-equivalent control group design" and one control group (CG) and one experimental group (EG) were used in the study. The groups were chosen randomly as CG and EG. Each group was given both a pre-test and a post-test, measuring the dependent variable both before and after exposure to the independent variable. In the study, a delayed-test was also implemented to both groups to determine the retention of the knowledge.

Sample

The study was carried out in two different classes in the department of science in Fatih Faculty of Education at Karadeniz Technical University in Turkey during the spring semester of 2015–2016 academic years. Participants in the study were 125 university students who enrolled in the general chemistry course, from the two classes of the same teacher. One class was randomly assigned to the EG ($N = 65$) while the other was selected the CG ($N = 60$).

The chemical equilibrium concept test (CECT)

The CECT, including 20 two-tier multiple choice items, was used in the study to collect the data. The first tier of test items consisted of a content question in multiple-choice format with three choices. The second tier consisted of four possible reasons for a possible answer to the first part: three erroneous reasons and one correct reason. While some of the questions in the CECT were taken from the literature[3], the others were prepared by the researchers. Distracters for the questions were taken from the related literature.[3,8] The CECT contains five major conceptual areas. These areas were: a) approach to equilibrium, b) application of Le Chatelier's principle, c) constancy of equilibrium constant, d) heterogeneous equilibrium and e) effect of a catalyst. The areas evaluated in the tests are given in Supplementary material to this paper, as well as some of the test questions.

Table S-I of the Supplementary material summarizes the characteristics of CECT. The reliability of the test was estimated to be 0.71 using the Cronbach alpha formula.

The difficulty indices ranged from 0.25 to 0.86, providing a wide range of difficulty items. The discrimination indices ranged from 0.34 to 0.78. A value of 0.30 was established as a minimum, and those greater than 0.30 were considered acceptable without the need for further revision of the test items. The content validity of the test was established by a commission consisting of three university chemistry educators and four chemistry teachers.

Computer simulations (CS)

Six CS, three of them were adapted from literature[36,37] and the others were designed by the researchers, were used in the study. QuickTime Pro, Adobe Flash Player and Microsoft Office Power Point were used to simulate a chemical equilibrium concept. The conceptual areas covered by the CS were; the approach to equilibrium, the application of Le Chatelier's principle, the rate of forward and reverse reactions, the constancy of the equilibrium constant and heterogeneous equilibrium. All of the CS was used to show students submicroscopic nature of the chemical equilibrium and to correct alternative conceptions. For example, one of the six CS taken from the literature[37] was used to challenge the alternative conceptions that "forward reaction goes to completion before the reverse reaction starts". This simulation showed a model of an equilibrium system for a unimolecular reaction. For this aim, blue and red spheres that move within a box were used to represent the reactants and products. Blue spheres represent the reactants while red spheres represent the products. The value for the equilibrium constant K can be set to less than 1, equal to 1, or greater than 1. As the CS runs, the number of blue and red spheres is indicated. In the CS, the progression of a reversible reaction and the establishing of the chemical equilibrium were showed to students step by step. It is possible to see that the reactant molecules (blue spheres) collide and form product molecules (red spheres), so that the reactant concentrations drop as reaction proceeds. In this process, the number of red spheres increases while the number of blue spheres decreases. At a certain time, the concentration of the reactants and products become constant but the numbers of blue and red spheres do not become equal. Based on this CS, students are able to see that forward reaction does not go to completion before the reverse reaction starts in equilibrium reactions.

All of the CS is related to chemical equilibrium concept and content validity of them was presented by a commission including three university chemistry educators and four chemistry teachers.

Conceptual change texts (CCT)

Five CCT, four of them were prepared by the researchers, while the fifth one was taken from the literature,[9] were used in the study. The texts were prepared by taking into consideration the students' alternative conceptions determined with the CECT and gathered from the literature. The conceptual areas covered by the CCT were: the approach to equilibrium, the application of Le Chatelier's principle, the rate of forward and reverse reactions, the constancy of the equilibrium constant and heterogeneous equilibrium. Each text aims to correct the alternative conceptions identified previously, which were related to these conceptual areas. In the texts, a question was presented to students at the top of the text and they were asked for making an assumption. The purpose of this question was to activate students' alternative conceptions. Following the assumption phase, the students were presented the alternative conceptions with their evidence and then discussed in the texts. In this way, students are expected to be discontent with their present conceptions. Finally, the students were informed of the correct scientific explanations supported by examples. A commission including three chemistry educators from university and four chemistry teachers were examined the CCT with respect to scientific accuracy and suitability to students' level. Based on their comments some minor revisions were made in CCT. An example of the CCT designed to challenge the alternative conceptions that "the rate of forward reaction is greater than the reverse reaction one" and "forward reaction goes to completion before the reverse reaction starts" is presented in Supplementary material.

Procedure

The chemical equilibrium is one of the most important concepts in chemistry program in Turkey. Students in secondary schools take eight semester chemistry courses before entering the university. Students take four hours per week chemistry courses in grades 11 and 12. Chemical equilibrium is given in 11 grade students in detail. Therefore, when students come to the university, we expect that they have learned chemical equilibrium concepts in secondary education, have lots of prior knowledge on these concepts, and will give correct answers to the questions. Based on this, if students have some alternative conceptions in pre-test, we believe that these are rather not the results of the lack of knowledge, and the results of pre-test indicate the existence of alternative conceptions. Based on this thought, we firstly implemented the pre-test both to comparison the initial level of the students and to diagnose students' alternative conceptions on chemical equilibrium. Secondly, we carried out implementation in both groups. While students in CG were taught with traditional methods based on textbooks and blackboard, the EG studied the same unit with CS-CCT. Six CS and five CCT were used in EG. During a five-week period; each group received an equal amount of instruction. Duration of the lesson was two 90-minute time periods in a week. In general, students were given equal opportunities to perform the activities in each group. CG received the traditional instruction which involved lessons using lecture methods to teach the concepts. The teaching strategies relied on teacher explanation and textbooks, without taking the students' alternative conceptions into consideration. CS–CCT was used as instructional materials for teaching EG. In this process, each pair of students shared a computer. During the instruction in EG, teacher firstly taught the concepts verbally and then he showed the related CS to the students, to reinforce the effect of verbal explanations. After the students finished the CS, CCT were used with the intention of further helping students to understand the scientific concept and to realize the limitations of their own ideas. Thirdly, the CECT was applied to both groups' students as the post-test after the implementation. Also, the CECT was applied to both groups' students as the delayed-test eight weeks after the post-test.

Data analysis

In the analysis of the CECT, the total score of each student in both groups as well as the mean score of each group were computed. It was used following criteria to analyze students' responses: Correct choice with correct reason = 2 points, correct choice with incorrect reason = 1 point, incorrect choice with correct reason = 1 point and incorrect choice with incorrect reason = 0 point. If a student responded to all items correctly, a maximum of 40 points was possible. The pre-test scores of the groups were compared by using independent *t*-test to determine whether a statistically significant difference in the means existed between CG and EG. Because there was no statistically significant difference between the pre-test results, the post-test results were also compared using the independent *t*-test to see the effects of intervention on students' understanding of target concepts. In addition, the analysis of covariance (ANCOVA) was run to compare the retention of students' knowledge related to the underlying concepts from post-test to delayed-test.

RESULTS AND DISCUSSION

As seen in Table I, while there is no statistically significant difference between groups in pre-test (t = 0.121, p = 0.904), there is a difference between groups in post-test, which indicates the successful nature of the CS–CCT compared to the traditional instruction (t = 7.411, p = 0.000). The results of the delayed-test reflected that mean score of EG was higher than CG and there was significant differences between groups (t = 9.193, p = 0.000). This result showed that teaching with CS–CCT caused a better retention of the concept than the traditional instruction. The results of the studies in the related literature are harmonious with the current study with this manner.[33]

After the delayed-test was conducted to the both group students, the analysis of covariance (ANCOVA) was used to compare the retention of the knowledge acquired during the intervention. In this analysis, post-test scores were used as covariate to control the group differences. The results of ANCOVA showed the significant main affects for treatments on students' retain their knowledge (F (1,122) = 84.507, $p < 0.05$). Although the students' CECT scores in both groups decreased from post-test to delayed-test, the decrease in EG students' scores is lower than in CG ones. Specifically, while the mean score of students in EG decreased from 57.27 to 53.60, a drop of 3.67, the mean score of the students in CG decreased from 36.07 to 30.27, a drop of 5.8. The adjusted mean score of EG was 47.20 on delayed-test and that of CG was 25.40 (Table II).

TABLE I. Independent group *t*-test results for pre-, post- and delayed-test scores of the CECT

Parameter	Pre-test		Post-test		Delayed-test	
	EG	CG	EG	CG	EG	CG
N	65	60	65	60	65	60
Mean (20 items)	18.00	17.80	57.27	36.07	53.60	30.27
Standard deviation	5.801	6.965	11.89	10.205	11.485	7.834
t	0.121		7.411		9.193	
p	0.904		0.000		0.000	

TABLE II. Summary of ANCOVA on students' delayed-test scores

Test	Experimental group			Control group			*F*
	Mean	*SD*	Adj. mean	Mean	*SD*	Adj. mean	
Post-test	57.27	11.89	–	36.07	10.205	–	84.507
Delayed-test	53.60	11.485	47.20	30.27	7.834	25.40	$p < 0.05$

In the study, one of the main aims was to determine the effect of CS-CCT instruction on students' understanding of the chemical equilibrium. As seen in Table III, the performance of both groups' students increased from pre-test to post-test and decreased to delayed-test. EG students' performance is significantly greater than CG ones in both post-test and delayed-test. This is an indicator of the effectiveness of CS–CCT instruction on students' understanding and retention time of the knowledge.

As seen in Table S-II of the Supplementary material, the ranges of correct answer for the first tier of the items were 23 to 35 % for CG and 26 to 29 % in EG in pre-test. When both tiers were combined, the correct response was reduced to a range of 10 to 15 % for CG and 12 to 20 % for EG. These results show that students did not have a satisfactory understanding of chemical equilibrium before the implementation. When post-test scores of both group students in CECT were examined, it was seen that the performance of students in both groups increased from pre-test to post-test. While the ratios of the correct answers for the first tiers of the items in post-test were between 30 and 73 % for CG and 32 and 98 % in EG (Table S-II). On the other hand, both tiers were combined; the correct response was between 15–55 % for CG and 32–94 % for EG. These results are not surprising for us because, although the techniques used with the EG were different from those used with the CG, both groups received instruction on the chemical equilibrium during the implementation period. Therefore, improvement in both group students' understanding is a normal development. However, the results clearly show that the EG students' performances are greater than the CG ones and this is an indication of the benefits of the CS–CCT instruction. Indeed, while the mean scores of the EG is 57.27, the same score of the CG is 36.07 in post-test.

TABLE III. Percentages of students' correct responses in first tier and both tier of CECT in pre-test, post-test and delayed-test; CQ: content question (the first tier of the question); C: correct response combination (the both tier of the question)

Item No.	Control group (*N* = 60)						Experimental group (*N* = 65)					
	Pre-test		Post-test		Delayed-test		Pre-test		Post-test		Delayed-test	
	CQ	C	CQ	C	CQ	C	CQ	C	CQ	C	CQ	C
1	30	15	60	45	53	43	29	17	83	72	75	66
2	25	15	50	43	45	40	26	12	60	54	57	51
3	35	15	73	55	63	55	29	12	98	98	94	91
4	33	15	70	55	60	55	29	17	75	63	66	60
5	25	15	30	15	20	15	29	20	75	69	69	63
6	35	20	70	50	63	45	29	12	95	94	91	91
7	30	15	63	53	55	53	29	17	95	91	91	83
8	25	10	30	15	25	15	29	20	83	72	72	66
9	25	13	35	23	33	20	29	12	57	54	54	49
10	33	15	70	55	63	53	29	12	83	80	75	69
11	25	13	43	35	40	30	29	14	86	72	80	66
12	25	10	33	15	23	15	29	12	32	23	29	20
13	30	15	55	50	50	43	29	20	83	69	75	63
14	23	10	30	23	25	15	29	15	66	60	60	60
15	23	13	35	15	25	13	26	15	57	49	54	46
16	30	15	55	45	50	35	29	17	91	75	86	66
17	35	15	70	50	63	40	29	17	83	66	75	60
18	35	20	93	53	83	45	29	17	91	69	91	66
19	23	10	30	15	25	13	26	14	72	37	66	29
20	30	13	50	25	43	23	26	17	75	32	69	32

On the other hand, the performance of students in both groups decreased from post-test to delayed-test with the passing of time. This is also normal because the CECT was administered to both groups three months after the post-test, students in both groups may have forgotten some of the material and as a result, a reduction in the scores may be expected. Although the students' achievement scores in both groups decreased from post-test to delayed-test, the decrease in the EG students' scores is lower than in the CG ones. Specifically, while the mean score of students in the EG decreased from 57.27 to 53.60, a drop of 3.67, the mean score of the students in the CG decreased from 36.07 to 30.27, a drop of 5.8. The adjusted mean score of the EG was 47.20 on delayed test and that of the CG was 25.40. These scores also showed differences the between groups in favour of EG students.

It is important to consider that the EG students' scores are significantly greater than the CG ones in both post-test and delayed-test and this may be interpreted as an indication of the effectiveness of CS–CCT instruction on students' understanding and alternative conceptions. The reason for this is probably due to the detailed explanations found in CCT and dynamic and interactive nature of CS. While the CG students were taught with more traditional instruction, the EG students received a different instruction which addresses students' alternative conceptions and used computer animations that show the microscopic behaviours of the particles. Based on this, such a combination improved students' learning and understanding of chemical equilibrium concepts. Literature includes numerous studies indicating the effect of both CCT and CS on students' understanding of different chemistry concepts.[16,17,33,34] The results of this study are in agreement with the literature.

One of the other main aims of this study was to determine the effectiveness of CS–CCT based instruction in changing students' alternative conceptions. Twenty four alternative conceptions were identified in the study and these were grouped under the headings of approach to equilibrium, application of Le Chatelier's principle, constancy of the equilibrium constant, heterogeneous equilibrium, effect of a catalyst and reversible and non-reversible reactions. The percentages of the alternative conceptions in pre-test, post-test and delayed-test were given in Table S-II.

As can be seen from Table S-II, students in both groups held almost the same alternative conceptions in pre-test and at about the similar percentages. In the literature, several studies reported similar types and levels of student alternative conceptions.[1,3,9] The percentages of EG students' alternative conceptions in pre-test ranged from 46 to 70 %, and those of the CG students' ranged from 48 to 68 %. Table S-II of the Supplementary material shows that there is a significant difference between the percentages of holding alternative conceptions in both groups in post-test and delayed-test. These results showed that CS and CCT oriented instruction helped students to change their alternative conceptions for scientifically accepted ones.

One of the most common alternative conceptions held by both groups' students was that "the forward reaction goes to completion before the reverse reaction starts". 70 % of EG and 68 % of CG held this alternative conception in pre-test. A similar alternative conception had been reported in the literature.[3,9,38,39] In both groups, the percentages of this alternative conception decreased in the post-test, but the EG did better than the CG. The CS and CCT related to this alternative conception was probably the reason for the better scores of the EG students. In the CS, students had the chance to see that the reverse reaction starts before the forward reaction complete and also both reactions proceed during the process. In addition, they read the CCT and learned that if the forward reaction goes to completion, concentration of at least one of the reactants becomes zero at the end of the reaction. This means that the equilibrium constant will be unlimited and this is impossible. This explanation enabled the EG students to be more successful than the CG ones in the post-test.

Another alternative conception was that "the rate of forward reaction is greater than the reverse reaction one". This was held by 66 % of the EG and 64 % of the CG students in the pre-test. In the literature, Hackling and Garnett[38] reported a similar alternative conception. Similarly, Niaz[40] reported an alternative conception that after the reaction has started, the rate of forward reaction increases with time and that of the reverse reaction decreases, until equilibrium is reached. These findings show that students do not have an appropriate understanding about the equality of the rate of forward and reverse reactions at equilibrium. In the study, CS and CCT helped students to remove this alternative conception. In the text, students read that as the forward reaction progresses, reactants are being turned into products and product is being turned into reactants at the same rate.[41] Based on this, the forward reaction slows down, the reverse reaction speeds up and eventually the two reaction rates become equal. They were able to see that while the forward reaction rate decreases, the reverse reaction rate increases during the reaction in CS. As seen in Table S-II, in both groups, the percentages of this alternative conception decreased on the post-test, but the EG did better than the CG.

One another alternative conception was that "Le Chatelier's principle can be applied in the initial state before the reaction has reached equilibrium". 66 % of the EG students and 64 % of the CG students held this alternative conception in pre-test. In the literature,[2,3,9] a similar alternative conception was reported. These students do not consider that Le Chatelier's principle can only be applied to the systems which are at equilibrium. This show that students made overextended use of the Le Chatelier's law, as they applied it in predicting the evolution of a system of initial substances before the system had reached the chemical equilibrium. On the other hand, some of the students think that "when a substance is added to equilibrium mixture, equilibrium will shift to the side of addition". This is also wrong and 56 % of the EG students and 64 % of the CG students hold this alternative conception in pre-test. In the literature, a similar alternative conception had been reported.[3,9] Moving from the Le Chatelier's principle, we can say that if we add more of one reactant, the reaction will proceed to the right side that consumes this reactant, and *vice versa*. Especially in CS, the students were able to see the application of the Le Chatelier's principle by adding or extracting some species on the reaction environment. This was also emphasized in CCT. With this way, we tried to remove both alternative conceptions and results show that EG students are more successful than the CG ones with this manner.

The temperature change is another way to disturb the chemical equilibrium. Three alternative conceptions related to the effects of temperature change on a system at equilibrium were determined in the study. Firstly, "when the temperature is changed, the type of reaction (endothermic or exothermic) does not affect the direction of the equilibrium shift". This was held by 58 % of the students in the EG and 65 % of the students in the CG in pre-test. A similar alternative conception was also reported in the literature.[3,9] Secondly, "when the temperature is increased, more products are formed", an alternative conception which was held by 62 % of the students in both EG and CG in pre-test. Özmen[3,9] and Voska and Heikkinen[42] reported a similar alternative conception. Thirdly, "increasing the temperature of an exothermic reaction would decrease the rate of the forward reaction" was another alternative conception and 52 % of the EG students and 58 % of the CG students held it in pre-test. All of the alternative conceptions were considered in designing the CCT and CS. We know that when the temperature is changed, the direction of an equilibrium shift cannot be predicted without knowing whether the reaction is endothermic or exothermic and we can use the Le Chatelier's principle to predict the direction of the shift. In CS, students had the chance to see the effect of temperature change on endothermic and exothermic reactions. They were able to see the shift by increasing and decreasing the temperature in different types of reactions. Based on this, CCT helped students to understand the temperature effect. For example, we asked for students to consider the temperature as a reactant or a product in the reaction mixture. If heat were a product, the addition of heat which must occur as the temperature is raised, drives the equilibrium backward, while if heat were a reactant then the addition of heat drives the equilibrium forward. Remembering Le Chatelier's principle, we can say that if the temperature is increased, the equilibrium will shift to the products' side in an endothermic reaction and if the temperature is increased, the equilibrium will shift to the reactants' side in an exothermic reaction, contrarily. This way, we managed to reduce the percentages of the alternative conceptions in post-test. The percentages of these alternative conceptions in both groups of students decreased in post-test, but the EG did better than the CG based on the CS–CCT instruction.

Another source of the alternative conceptions was the heading of constancy of equilibrium constant. It is possible to collect the alternative conceptions in two sub-heading: *i*) the effect of temperature change on the numerical value of K_{eq}, and *ii*) the effect of adding or extracting substance in the reaction mixture on the numerical value of K_{eq}. When the effect of the temperature change was considered, two alternative conceptions were determined. These were; "an increase in temperature always increases the numerical value of K_{eq}", which is held by 59

% of the students in EG and 57 % of the CG students in pre-test. The other alternative conception is that "equilibrium constant, K_{eq}, will increase with increasing temperature in an exothermic reaction", which is held by 65 % of the students in EG and 61 % of the CG students in pre-test. Both alternative conceptions were also reported in the literature.[38,42] In CS, students were able to see the effect of temperature change on the numerical value of the equilibrium constant. They saw the shifting in the reaction and changing the concentrations based on the temperature change and the effect of these changes on equilibrium constant. In addition to the CS, we explained to the students in CCT that the change in the numerical value of the equilibrium constant with temperature depends on whether the reaction is endothermic or exothermic. In post-test, percentages of the both alternative conceptions decreased in both groups, but the EG did better than the CG, based on the CS–CCT instruction.

The effect of adding, or extracting the substance in the reaction mixture, on the numerical value of K_{eq} is the other source of the alternative conceptions. Three alternative conceptions were determined on this subject. There were; "when more reactants are added to an equilibrium system, K_{eq} will change", "when more products are added to an equilibrium system at constant temperature, K_{eq} will increase" and "the numerical value of K_{eq} changes with the amounts of reactants or products". Both groups of students held these alternative conceptions in pre-test with different percentages. Similar alternative conceptions were reported in the literature.[3,9,42] These students think that the numerical value of equilibrium constant depends on concentrations and changes with the amounts of reactants or products. In both CS and CCT, students were explained that at a given temperature, the value of the equilibrium constant is independent of the initial conditions. This means that the numerical value of K_{eq} does not change with the amounts of reactants or products. In addition, the students were also explained that the value of the equilibrium constant only changes with temperature. Based on these explanations, EG students removed these alternative conceptions in post-test.

The heterogeneous equilibrium and the effect of a catalyst were the other sources of the alternative conceptions in the study. With this manner, we encountered four alternative conceptions: *i*) Le Chatelier's principle can be applied in all systems, including heterogeneous equilibrium systems. This alternative conception has been reported in the literature.[3,9,39,43,44] *ii*) When a solid substance is added to an equilibrium system at constant temperature, K_{eq} will change. Literature also reported such an alternative conception.[3,9] These students believed that increasing the amount of a solid ionic substance, which is at equilibrium, causes more dissolved ions to be produced. However, we know that adding or removing a solid to the system at equilibrium does not change the equilibrium state, if the solid is present originally when the system is in the equilibrium state[45]. *iii*) The rate of the forward and reverse reactions could be affected differently by the addition of a catalyst. Similar alternative conceptions have been reported previously.[38,42,43] *iv*) The catalyst increases the value of equilibrium constant. These alternative conceptions were considered and tried to be removed by using CS and CCT. Results showed that CS–CCT instruction became more effective on students' understanding than the other way with a degree.

In this study, a delayed-test was used to determine the perststence of the concept in students' minds. When it is compared how students in both groups retain the concepts in delayed-test, it is seen that students in EG (M = 53.60) are better than the students in CG (M = 30.27, see Table II). These results show a statistically significant difference between two groups towards the delayed-test results. Although the ratios of the alternative conceptions increased from the post-test to delayed-test, EG students are more successful than the CG ones in delayed-test.

It is known that the traditional chemistry instruction use the similar methods as it did in past and do not adequately integrate computer technology into the classroom.[46–48] This is also true for the approach employed in CG group in this study. On the other hand, EG students took both CS–CCT instruction and the results show that such a combination improves students' learning and understanding. In the literature, there are some studies reporting the positive effect of CCT enhanced with animations related to different chemistry concepts such as chemical bonding and the particulate nature of matter.[33,34] The results of this study are also in accordance with the literature for this manner.

CONCLUSIONS

In this study, we assumed that CS–CCT instructions not only consider the students' alternative conceptions, but also helps students to see the microscopic world *via* CS. We tried to combine CCT, which predominantly consisted of verbal explanations, with CS which included a series of visual interactive images displayed in rapid succession on a computer screen. The combination of these methods was used in the study and became effective for students' understanding of the chemical equilibrium. These results confirm previous studies in which CCT and CS instruction can facilitate the learning of scientific concepts. We suggest that the combining the methods of CS and CCT may be a useful way for teaching the chemical equilibrium. In addition, in the literature, there are a few convenient ways to describe chemical phenomena, especially chemical equilibrium. Animations, analogies, laboratory activities, and etc. are among these. Researchers may also improve our approach by integrating new teaching methods into this cooperation.

In the present study, CS–CCT instruction was new for the EG students. Although the students are familiar with the use of computers in lessons, teachers generally use the computers for demonstration and/or power point presentation tools. In this study, the students actively used the computers and made interactive applications, a change which the students found exciting. In addition, the CCT are also new tools for the students. Although the CCT are written texts, their combination of figures, examples, and explanations increases their effect. In the study, animations were also used to increase the effectiveness of the texts. The use of novel instructional methodologies likely contributed to the students' enthusiasm to learn.

On the other hand, although different teaching methods including CCT and CS maybe effective in teaching of chemistry concepts and in changing students alternative conceptions, it is undoubtedly true that chemistry is an experimental science. Literature suggests that students find laboratory works enjoying, exiting and motivating because they have a chance to engage in hands-on activities.[50,51] Laboratory activities should also be used to teach some abstract concepts on chemical equilibrium. For example, the experiment of chromate/dichromate equilibrium may be used to teach the application of the Le Chatelier's principle. So, the experiments performed in the laboratories are vital and indivisible part of the chemistry teaching.

Although there have been made several studies on chemical equilibrium, Quilez-Pardo and Solaz-Portoles[1] state that results of these studies have little effect on actual classroom practices, namely many of the chemistry teachers have continued to teach chemistry without considering the result of these studies. This is still an important problem for chemistry teaching. It may be suitable to say that the aims of the studies on teaching and learning of chemistry are to improve the students' understanding, to correct the students' alternative conceptions, to help teachers in teaching of chemistry, and to develop the alternative teaching approaches for teaching of chemistry. Because the chemistry teachers do not consider or are not aware of these studies, they may not reflect the results of the studies into in-class activities. In this situation, the studies remain hidden in researchers' personal files or library shelves. For this reason, to inform teachers about the results of the studies is as important as to make researches.

In future, researches, in collaboration with teachers and curriculum developers, should develop new teaching materials about the chemical equilibrium and implement them in classrooms in an experimental setting, so that they may better understand the effects of different teaching techniques and materials on alternative conceptions. The pre-test results show that students have several alternative conceptions on chemical equilibrium although they learned this concept in secondary level. This means that in-class teaching activities may cause students to develop alternative conceptions and these alternative conceptions are transferred to the upper level. So, we cannot sit and wait for the alternative conceptions to be turned into the scientific concepts without any effort.

Limitations of the study

The study has four limitations. The first of them is the number of the students in the EG which consists of 65 students and this number is a bit more to deal with all active students. In a smaller group, the teacher may have the chance to deal with students more effectively. The second of them is number of the computers. During the intervention, each pair of students used one computer because of inadequate resources. Based on this, none of the students could not study independently and the teacher could not control the students effectively. In order to make more repeatable applications, each of the students should have one computer, which would be more suitable. The third of them is data collection tools. Although the two-tier multiple choice questions give an opportunity for researchers to collect data related to the conceptual understanding, interviews and open-ended questions may be more effective to acquire more comprehensive data in this manner. Finally, the lack of laboratory activities and/or experiments is the another limitation of the study. Besides of CCT and CS applications, the experiments on chemical equilibrium should be made by the students.

SUPPLEMENTARY MATERIAL

The areas evaluated in the tests and some of the test questions are available electronically at the pages of journal website: http://www.shd.org.rs/JSCS/, or from the corresponding author on request.

И З В О Д

ЕФЕКАТ СИМУЛАЦИЈЕ ПОБОЉШАН КОНЦЕПТУАЛНОМ ПРОМЕНОМ ТЕКСТА НА РАЗУМЕВАЊЕ ХЕМИЈСКЕ РАВНОТЕЖЕ ОД СТРАНЕ УНИВЕРЗИТЕТСКИХ СТУДЕНАТА

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Циљ истраживања је да се испита ефекат компјутерских симулација са концептуалном променом текста (CS–CCT) на студенте прве године универзитетских студија, када је у питању разумевање хемијске равнотеже. У истраживање су биле укључене једна контролна група од 60 студената и једна експериментална група од 65. Док је контролна група учила на класичан начин, на експерименталну је примењен CS–CCT. Показало се да је CS–CCT ефикаснији начин да се студентима прикаже и објасни хемијска равнотежа и побољша њихов начин разумевања концепта у хемији.

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