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Improving students' understanding and explaining real life problems on concepts of reaction rate by using a four step constructivist approach

Sevil Kurt[1,*], Alipasa Ayas[2]

[1]*Rize University, Faculty of Education, Department of Science Education, 53200, Rize, Turkey*
[2]*Bilkent University, Faculty of Education, 06800 Ankara, Turkey*

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Abstract

The aim of this study was to investigate the effects of activities developed based on a four-step constructivist approach on students' understanding and explaining real-life problems about reaction rate concepts in chemistry. The study was carried out with 41 eleventh grade students, from two different classes attending a secondary school in Turkey. Two classes were randomly designated as experimental and control groups. While teaching the subject, a four-step constructivist approach was used for the experimental group whereas in control group, students were taught by the traditional method. Teaching activities in both groups were observed by one of the researchers. In both groups, Real-life Relating Test (RRT), including the phenomena that students observe in their daily life about reaction rate concepts was implemented before and after the intervention. Also semi-structured interviews were conducted with 13 students chosen from the both groups. At the end of the study, it was determined that the intervention which was carried out based on a four-step constructivist approach helped more the students in explaining real-life problems in a scientific way and provide more lasting learning than traditional approach. It is suggested that such activities should be used in other abstract or problematic concepts in chemistry.

Keywords: Four-step constructivist approach; Reaction rate; Real-life problem; Concept understanding

1. Introduction

As distinct from other sciences, chemistry is almost in every part of our life. It is possible to run into chemistry in the kitchen, on our bodies, in cleaning, on our clothes and in a field of art. Chemistry is in search of answers for questions of events happen in all these fields. However, as a science area which is so much in our life it is challenging for students to understand it and it generally isn't used for explaining the various areas of life. Treagust,

*Corresponding author. Tel.: +90-464-532-2053; fax: +90-464-532-8612.
E-mail address: sevil.kurt@rize.edu.tr or aksusevil_@hotmail.com (S. Kurt).

Duit, and Nieswandt [1] stated that the major reason lying behind most of the challenges in learning and understanding chemistry is that it is considered as a science which is not related with daily life and is only an academic science. Wu [2] clarified this situation: isolating the school knowledge from the students' daily life experiences caused to form two unrelated knowledge systems in their minds. The first one is which they use to solve the problems encounter in science classes at school, the other is the one used to solve the problems in their real life. In this respect Songer and Linn [3] studied the secondary school students' point of views towards the sciences and found out that while some of the students considered science as dynamic, that is, "understandable", "interpretive" and related with daily life, others found it static, that is, intensively depending on memorization and unrelated to daily life. In Nieswandt's study [4] students' ideas about the phenomenon that they observe in their daily lives were investigated and a learning strategy was developed to achieve conceptual change. In this study, the researcher found out that students couldn't explain the events that they observe in their daily lives in a correct scientific language. The researcher stated that it is necessary to provide students with different opportunities in order to apply science concepts to their daily lives. In a sense, Nieswandt's study [4] corroborated Songer and Linn's findings [3]. The similar findings were also attained in Ben-Zwi and Gai's research [5] in which they analyzed the students' ability of associating and explaining the real-life phenomena in micro and macro levels. Also, Ng and Nguyen [6] whose studies support similar researches stated that students graduated from a traditional educational environment which is unrelated to their lives, get confused when they are in real life.

A common point most of the researchers who are in search of the origins for the problems in chemistry was defined as not to be providing the opportunities for students which they could experience in real-life examples. That means that students cannot take their knowledge beyond the classroom [2, 5-6]. However, knowledge which could be applied to different situations like daily life events is seen as an indicator of understanding of concepts [7]. In other words, if a meaningful learning is purposed, concepts should be able to be understood and explained by the students not only with their classroom meanings but also with their meanings in real life in a scientific view. Besides, national and international research studies in chemistry teaching reveal that students, no matter at which level they are, have problems in explaining scientific concepts that they come across in daily life in a scientific way [2, 8-9]. Among the chemistry concepts, concept of reaction rate is also one of the topics that students have difficulty in understanding and applying to real life. The reaction rate is an important one related to topics such as chemical reaction and chemical equilibrium. Additionally, reaction rate concepts have not been comprehensively investigated by the researchers. It is seen that the first anchoring related to reaction rate concepts are obtained under the title of chemical equilibrium [10-16]. The researchers in these studies determined that there were alternative conceptions in their samples such as the changes of back and forward reaction rate, the change of reaction rate in the first and last equilibrium situations in case adding reactant to equilibrium system, and the effect of catalyst on the back and forward reaction rates. Also, it was determined that students made an inconvenient connection between the reaction rate and the reaction yield, they interpreted the reaction rate according to the Le Chatelier principle and believed that catalyst provides more product, and increasing the heat would also increase the forward reaction rate of an exothermic reaction. Researchers pointed out that these difficulties and alternative conceptions are generally caused by not understanding the reaction rate subject meaningfully.

The result of the studies, investigating the reaction rate concepts as a focal point, shows that students have alternative conceptions about how reaction rate changes during a chemical reaction process and have trouble in understanding the issues such as relationship between ‘the reaction rate and heat’, relationship between ‘reaction rate and concentration’, ‘reaction rate-catalyst effect’ and in defining ‘collision theory and reaction rate’ and they constitute inappropriate conceptual frameworks [17-20]. These alternative conceptions are seen as important problems in science teaching because these alternative conceptions are robust and resistant to change.

In recent years, a learning theory explaining the reason of difference between the concepts in students’ minds and scientific community and which is embraced by many educators is constructivist learning theory. According to the constructivist learning theory every person constructs information in their minds actively. During this construction process, learners’ world views, attitudes and beliefs that they form with their experiences over the years, the environment they have lived in and the communication tools they have been exposed to play important roles [21].

Constructivist learning theory became the topics of many studies in the field of education. It is indicated that the learning environments based on constructivist theory are not only very effective in remedying the alternative concepts but also in meaningful learning of the concepts [22-29]. Various models were suggested in order to apply constructivist learning theory or approach in educational setting. There are models such as 3E, four-step constructivist approach, 5E, and 7E. No matter how different the numbers of phases are from each other, in all of these models, basically, the concepts were constructed actively thanks to students’ experiences, and students take the responsibility of their own learning. Teacher guides the students in this process. Additionally, it is seen as a difficult situation for the teacher to remember the phases as the number of the phases increases and to conduct the lessons in its usual course. Therefore, the four-step constructivist approach whose efficiency was proved by many studies was preferred for this study [30-31]. The four-step model is easy and practical to be used in teaching environment. In the first step of the model, students’ attention is tried to be taken to the concept and their pre-concepts and if there is any, their alternative concepts are discovered. This phase enables teachers to make plans considering the students’ levels. In the focusing phase which is the second step, the teacher makes an effort for the students to constitute their own experiences related to the concept through teaching activities such as group work, classroom discussions and experiments. In this phase, the teacher asks students some questions about the process in order to make them examine their experiences but the teacher doesn’t give them any clue about the correct answer. The third phase, is the phase in which students compare their knowledge to their pre-concepts, question and change them. In this phase, teacher makes explanations in order to enable students relate their experiences about the concept with the scientific explanation of the concept and clarifies the blind spots. In the last phase, students are asked to apply new knowledge into different situations. Some activities are performed like problem solving, writing essay, associating the events in daily life which can provide them with opportunities to make various practices related to concepts. Also, students’ prior knowledge is reminded and students are made to be aware of the difference between scientific knowledge and their prior knowledge. The most important feature of this phase is reinforcing the learned concepts with different practices [30-33].

In this study, the effect of activities, developed based on a four-step constructivist learning model, on the students’ understanding of the reaction rate concepts and applying them to the real-life events is investigated. There have been some studies on teaching and learning of reaction rate concepts in literature. For example, Tezcan and Yilmaz [34] investigated the effect of conceptual computer animations and traditional instruction method on the success of students in learning chemical reactions and collision theory. Two high school classes in equal success levels were chosen. And then control group is instructed about chemical reactions and collision theory by using the traditional instruction approach and the experimental group is instructed by using computer-based instruction approach. Before and after the instruction, a conceptual test consisting of 15 questions was administered. At the end of the research, it was determined that students in the experimental group were more successful than students in control group. It was also determined that success level depends on the gender; male students in the experimental group and female students in the control group were more successful than the others. Van Driel [35] investigated the effects of a research program about chemistry instruction in Netherlands on the development of students' concepts of particulate model in the context of chemical equilibrium and chemical kinetics. In this research program, the aim was to improve students' concepts on macroscopic chemical phenomenon in addition to the particulate nature of the matter. The data were regularly derived from a dozen of tenth grade chemistry classes in Netherlands. As a result, the researcher discussed the advantages and limitations of the course on students' concepts about chemical phenomenon and particulate nature of matter in terms of chemical equilibrium and chemical kinetics and made some suggestions. In Akkaya's [36] study, an investigation of traditional and experimental approaches on high schools students' achievements in reaction rate subject was undertaken. Scientific achievement test, attitude scale and previous chemistry achievement scores were used as a means of data collection. In the research, conducted with 60 students in control and experimental groups, it was determined that the academic achievement of the group who were instructed with the experimental teaching method is higher than that of the class instructed by the traditional teaching method. Atasoy and others [37] conducted a study for eliciting students' creative thinking process from their drawings and explanations. With this aim, one of the two groups consisting of the second grade of high school students was instructed on chemical reactions by using analogies and then their imagination abilities were determined from their drawings. In the other group, the topic of gases was taught using the teaching techniques by supporting creative thinking, and the students' ability of divergent thinking was presented from their explanations. Researchers determined that students in the group instructed by using analogies made appropriate drawings related to the effect of 'heat on reaction rate', the effect of 'concentration on the reaction rate' and 'collision theory' and pointed out that these courses developed the students' ability of imagining the concepts. In the learning environment which supported the creative thinking, it was seen that students could make creative explanations related to gases. The study referred to the importance of classroom activities that support students to produce ideas and constitute images. Çalık, Kolomuç and Karagölge [38] investigated the effect of conceptual change approach on reaction rate concepts. While in one of the groups animations were used during the instruction, in the other one traditional teaching method was used. At the end of the study, the researcher determined that the instruction in the experimental group in which animations were used was more effective in remedying the alternative conceptions in the subject of reaction rate and in providing a lasting learning effect. In their studies Chairam, Somsook and Coll [39] investigated the effects of a research-based and student-oriented teaching environment. In the study, a research-based course was developed in which students made experiments by using predict-observe-explain (POE) technique related to the chemical kinetic. The researchers aimed to bring out whether this course supported the students' learning of chemical kinetic; if it supported, how it did and whether the students liked this teaching environment compared to their usual experimental courses. At the end of the research, they found that most of the students could explain the changes in chemical reaction rate better and also found that conceptual comprehension of the students related to chemical kinetic concepts increased both qualitatively and quantitatively. Researchers suggested chemistry teachers to use research-based approaches in which materials related to daily life processes and simple chemical reactions in teaching the chemical kinetic at secondary level.

When the above studies are examined, it is seen that reaction rate concepts were investigated with another concept, or only a few concepts were considered in chemical reaction topic. Besides, it is seen in these studies that the effect of analogy, animations and experimental methods on the success was investigated and students' comprehensions were not compared to the aspect of explaining real-life events. In this study, the reaction rate topic in secondary chemistry was examined with its sub-concepts separately and the effect of a four-step constructivist approach on the learning and understanding of the reaction rate concepts was presented via comparing students' achievements in explaining the real-life events. With this aspect, this study is thought to provide a different point of view about the concepts of reaction rate.

The aim of this study was to investigate the effects of activities developed based on a four-step constructivist approach on students' understanding and explaining real-life problems about reaction rate concepts in chemistry.

2. **Method**

2. 1. Research design and sample

It is seen in the related literature that, experimental design is generally preferred in the studies for determining effectiveness. Experimental method has types such as true experimental, quasi-experimental, and simple experimental and also, it is stated that it is suitable to use quasi-experimental method when we are not able to select the students for groups randomly. Because of the structure of Turkish education system it is not possible to place students into the control and experimental groups randomly so that in this study a pre-test post-test quasi-experimental study design was used. The sample of the study consisted of 41 students who were from two different classrooms in a state secondary school (grade 11, age about 17) in Turkey; classrooms were randomly designated as control and experimental groups. The students in both classrooms have lived in the same region for at least 10 years and they have similar cultural, socio-economic and educational backgrounds. Teaching activities in both control and experimental groups are conducted by the school's chemistry teacher. The course teacher who has got 12 years of experience was informed regularly about the intervention, the materials to use and four-step constructivist approach two weeks before the beginning of the study. Also, some experiments and activities were practically shown to the teacher by the researchers. Besides, both the learning environments were observed by one of the researchers in order to display how learning processes were conducted in experimental and control groups.

2. 1. 1. Data Collection

Real-life relating test (RRT) consisting of 12 open-ended questions was administered at the beginning and at the end of the learning activities as pre- and post-tests for both groups. The pilot test of the test was conducted with 47 students, and unclear expressions and the statements not to be understood by the students were changed. Also, face validity and content validity were provided by examining the questions in the test by two chemistry lecturers and a chemistry teacher. Before intervention the developed test was administered to elicit whether the pre-conceptions of the students in the control and the experimental groups about the subject were similar or not. After instruction, Real-life relating test (RRT) was reapplied to both groups in order to compare their perceptions about the topic. Some examples of the questions in the test are given below.

Question 1: *Hydrogen peroxide used in hair dyes to bleaching hair color reacts to form water and oxygen gas according to* $2H_2O_2(aq) \rightarrow 2H_2O(l)+O_2(g)$ *reaction. There are two hair dressing salons side by side and peroxide was used in concentrations %6 and %10 in the salons for bleaching hair color. Which hair dressing salon should have been selected by a woman who wants to change her hair color and is in a hurry?*

Question 2: *According to kinetic molecular theory, in gas phase and 1 ml volume millions of dual collisions happen in a second at 25 °C and at 1 atm. Despite this, very few of these collisions end with a reaction. For example, whenever oxygen and hydrogen come together, they don't turn into water; iron does not rust suddenly or nitric acid doesn't compose although there are necessary gases in the air to constitute nitric acid. Considering these examples how can you explain the reason why a chemical reaction doesn't happen for every* *collision?*

About a month later from the learning activities, interviews were conducted with 13 students (6 students in experimental and 7 students in control group) from the two groups. Students were chosen randomly among volunteers. Some of the questions selected from the test were asked again in the interviews. In these interviews, students were asked to explain their answers in a more detailed way. This way, the students' knowledge about the subject and the responses for the questions were investigated thoroughly. Because the test in the study was administrated to both the groups twice, it wasn't administrated again as a delayed test. Because of students may remember the questions when the test was implemented again and this situation might influence the reliability of the study negatively; the interviews also helped to have an idea about the lasting of knowledge.

2. 1. 2. Data analysis

Using criteria in data analysis is a common method because they show the relationships between the data of the study in which students' understanding levels were investigated via open-ended questions and they make it possible to present the data regularly [40-42]. In this method, students' answers for the questions were classified and the answers were scored according to these categories. In this study, criteria suggested by Abraham et al. [43] were followed for data analysis. In Table 1, the content and points awarded to each of the categories used in the study are presented.

Table 1. The categories and points used in data analysis and their explanation [43].

Abbreviation	Content	Point
S.U	Sound understanding: responses that included all components of the validated answers.	4
P.A	Partial understanding: responses that included at least one of the components of a validated response, but not all the components.	3
PA-S.A.C	Partial understanding with specific alternative conception: responses that showed concept was understood partially and also included an alternative conception.	2
S. A. C	Specific alternative conception: responses that included incorrect or illogical information.	1
N.U.	No understanding: no response or statements like "I don't know, I could not understand", repeating the question, irrelevant or unclear responses.	0

Students' answers for the test were scored according to the categories above and students' total scores for pre-test and post-test were calculated. And then total scores were statically analyzed, using SPSS statistical program.

The comparison of pre-test and post-test scores between the control and experimental groups were analyzed by using Mann–Whitney *U*-Test. Wilcoxon signed rank test was used for comparisons in groups. Non-parametric tests were used since the number of the students in both groups was less than 30.

The interview data were analyzed descriptively. First, the data recorded in digital media were turned into written form, meaningless phrases and the parts that were unrelated to the research question in the data were removed and the data were simplified. Later, the statements show that signs of difficulty in understanding or alternative conceptions in the students' answers were classified under related concept and shown in a table. Also, direct quotations from the students' statements were presented. The students in the experimental group were coded as E1, E2, E3 … and the students in the control group were coded as C1, C2, C3….

2. 1. 3. Intervention

Six activities were developed according to the four-step constructivist approach related to the teaching of concepts about reaction rate by the researchers. While the activities were being developed attention was paid, especially to use the materials that students encountered in daily life and they were accustomed. During the teaching student worksheets were used to track students, follow the directions given by the teacher more easily and to be efficient for time use. The pilot test of the developed activities and worksheets was conducted with 16 students and the activities were revised.

The activities were applied in experimental group in 7-hour courses during the three-week period. Before starting the activities, the teacher divided the students into small groups and explained the group work and how they would use worksheets. The lessons in the experimental group were conducted as follows: in the first phase of some lessons students watched a video or animation and then teacher asked students the question in the first part of the worksheet for eliciting students' pre conceptions. In some lessons the question in the first part of the worksheet was directly asked for eliciting students' pre-conceptions. At this step, teacher didn't comment about the students' responses and she stated that they would find out for themselves whether their ideas were correct or not from the activities they would do. In the second step, students would perform the activities in the second part of the worksheets with their group members. During this process, the teacher asked questions as a guide without giving the conclusion. Besides, students shared their ideas by discussing with their group members. The teacher checked the students' works and encouraged them to do the activities as a group and answer the questions in the worksheets individually.

In the third step, the teacher asked each group to tell what they did in the activity and explain their ideas and findings to the whole class. During this process students shared their different ideas and discussed. After the class discussion, the teacher explained the concept scientifically and answered the questions.

In the fourth step, different questions were asked to apply the concept in different situations, and activities were conducted to reinforce the concept.

With regard to the lessons in the control group, the teacher explained generally about the concept, gave examples and asked questions. In these processes, the teacher didn't use any laboratory activity that students could be interested in actively nor did they use any alternative practice. The teacher gave examples relating to real life about the subject only twice. In addition to this, it was observed that the teacher tried to make students active by asking question and used university entrance exam (which is a competitive exam done yearly for secondary graduates to place them in universities) as a motivation tool. This teaching method is the traditional and teacher-centered approach, which is followed generally in schools.

3. Findings

The result of the Mann–Whitney *U* test (Table 2) related to the pre-test scores indicates that there is no significant difference between experimental and control group students in their RRT pre-test scores ($U = 190.00$; $p > 0.05$). The mean score of control group is 17.95 and that of the experimental group is 20.33. This result points out that the knowledge of the experimental and that of the control group students related to reaction rate concepts were similar before the teaching process.

Table 2. Mann Whitney U Test results of RRT pre test scores of the experimental and control groups

Groups	n	$\bar{X}$	Mean Rank	Sum of Ranks	U	p
Control	20	17.95	20.00	400.00	190.00	0.601
Experimental	21	20.33	21.95	461.00		

Wilcoxon Signed Rank Test revealed if there was a significance difference in students' perception after teaching activities conducted in both groups compared to before the instruction (Tables 3 and 4).

Table 3. Wilcoxon Signed Ranks Test results of RRT pre test and post test scores of the experimental group

Post Test-Pre Test	n	Mean rank	Sum of ranks	z	p
Negative ranks	2	7.25	14.50		
Positive ranks	18	10.86	195.50	3.38*	0.001
Ties	1				

* Based on negative ranks.

Examination of the results given in Table 3 indicates that there is a significant difference between the experimental group students' RRT pre-test and post-test scores ($z = 3.38$, $p < 0.05$). Considering row averages and sums of the difference scores, this difference is in favor of the positive ranks and post-test scores. Wilcoxon Signed Ranks Test results of RRT pre test and post test scores of the control group are presented in Table 4.

The results given in Table 4 show that there is also a significant difference between pre-test and post-test scores obtained from the control group ($z = 2.98$, $p < 0.05$). Considering row averages and sums of the difference scores, this difference is in favor of the post-test scores.

In Table 5 Mann–Whitney *U* test analysis results that showed the comparison between RRT post-test scores of the control and experimental group are given.

Table 4. Wilcoxon Signed Ranks Test results of RRT pre test and post test scores of the control group

Post Test-Pre Test	n	Mean rank	Sum of ranks	z	p
Negative ranks	4	6.25	25		
Positive ranks	16	11.56	185	2.98*	0.003
Ties	0				

* Based on negative ranks

Table 5. *Mann Whitney U Test results of R.R.T post test scores of the experimental and control groups*

Groups	n	$\bar{X}$	Mean Rank	Sum of Ranks	U	p
Control	20	24.80	13.72	274.50	64.50	0.000
Experimental	21	35.80	27.93	586.50		

The results given in Table 5 indicate a significant difference between post--test scores obtained from the control and experimental groups ($U = 64.50$; $p < 0.05$). The difference is in favor of the experimental group. Mean score of the control group is 24.80 while it is 35.80 in the experimental group.

Students' alternative conceptions and difficulties in understanding obtained from the interviews are presented in Table 6.

Table 6. Students' alternative conceptions and understanding difficulties found in interviews

	Groups	
Students' Ideas	Control	Experimental
Catalyst; Confusion between the catalyst and intermediate, thinking that catalyst doesn't affect the reaction anyway.	C1, C4, C5	-
Knowing catalyst increases the reaction rate but not able to explain its reason	C3, C6	E3, E6
Thinking catalyst increases the reaction rate because of increasing of collision number.	C5	-
Temperature effect Knowing reaction rate will increase when temperature increases but not be able to explain its reason.	C2, C3	-
Generating an inconvenient relation between temperature-number of collision and reaction rate, lack of understanding if reaction rate increases the temperature or temperature increases the reaction rate.	C5	-
Explaining increasing of reaction rate depending temperature increase by using chemical equilibrium principles in exothermic reactions.	C4, C7	E3
Concentration Effect Thinking when concentration of reactants increases reaction will take longer because of there will be much more particles to collide.	C3	-
Surface Area Lack of understanding effect of surface area	C3	-

During these meetings students were asked to explain some of the questions in RRT test about the effect of catalyst, temperature, concentration, and surface area in detail. When students' explanations were examined (see Table 6) it was determined that some of the control group students couldn't explain reaction rate concepts meaningfully or they had some alternative conceptions. For example, it was determined that 3 students in the control group explained the question about enzymes which are biological catalysts by using the properties of an intermediate product and thought that catalyst doesn't have any influence on the reaction. For instance, a student coded as C1 had an explanation like this:

"Without reacting, catalysts formed in the first reaction and they are consumed in the second reaction and they only speed up the reaction. They have no influence, just speed up".

When students were asked how catalyst increased the rate of reaction without affecting the reaction by the researcher, it was determined that the students coded as C1 and C4 couldn't give any explanations and the student coded as C5 stated that the catalyst increased the rate by increasing the number of collisions. It was also decided, relating to the catalyst concept, that some of the students in both control and experimental group could express their knowledge in this matter that catalyst increased the rate but couldn't give any explanation about its reason (Table 6).

When examined students' ideas in both groups the question about the temperature effect in exothermic and endothermic reactions, five of the control group students could state that reaction rate increased with the increase of temperature but couldn't explain the reason behind it. A control group student coded as C2 explained his ideas like this:

"I don't know it in detail; I just know that temperature increases the rate of reaction. I don't know its explanation."

Control group student coded as C5 tried to explain his ideas by associating temperature, number of collisions and rate as follows:

"I think, the rate of the colliding particles will increase so that rate probably will increase. Therefore, temperature will increase."

In the interviews it was determined that control group students C4 and C7 and experimental group student E3 used chemical equilibrium principles in their explanations. For example, in his explanation, C4 used the following statements.

"This reaction releases heat so it is an exothermic reaction; when we increase reaction temperature, the reaction shifts towards the reactants."

In the interviews, it was determined that some of the control group students thought that reaction would continue longer since the number of the colliding particles would increase when concentration increased. Also, a student in the control group had difficulty explaining the effect of surface area (Table 6).

Interviews provided to have more information about the experimental and control group students' development of understanding about the reaction rate topic after the different teaching approaches.

4. Conclusions

In this experimental study which was aimed to elicit the effects of a four-step constructivist approach on understanding reaction rate concepts, both qualitative and quantitative data were collected. Before the intervention, it was examined whether the control and experimental group students' knowledge about the reaction rate were similar by using Mann–Whitney *U* test. The results of the analysis revealed that statistically there was no significant difference between the groups' pre-test scores ($U=190.00$; $p>.05$, see Table 1). At this point, it can be said that the students in both groups had a similar level of understanding on reaction rate before the instruction.

While the control group students were taught the concepts in a traditional way, the experimental group students were taught by using a four-step constructivist approach. After instruction if there was a significant difference in RRT scores in both experimental and control groups compared to their knowledge before the instruction process was investigated by Wilcoxon Signed Rank Test. And it was determined that there was a significant difference between students' understanding levels on reaction rate concepts before and after instruction period within each group. Also, it was identified the differences were in favor of post-test for both groups. So it can be said that for both groups the students' understanding level on reaction rate concepts and their success in explaining the real-life events about the subject increased meaningfully compared to their understanding level before instruction (Tables 3 and 4). In Turkey, the reaction rate of chemical reaction unit is first taught at the eleventh grade of secondary school chemistry curriculum and students first begin formally to learn about the concepts like collision theory, activation energy and order of reactions at that stage [44].

So the significant differences for both experimental and control groups can be explained as a result of learning after instruction. It will be more meaningful to compare the RRT post-test scores of both groups with one another. Mann–Whitney *U* test result for groups' RRT post-test scores indicates that there is a significant difference and the difference is in favor of experimental group ($U=64.50$; $p<.05$, see Table 5). It means that the experimental group students who were taught based on a four-step constructivist approach comprehended the reaction–rate concepts better and they were more successful in explaining the real-life problems about the subject than the control group students.

The findings of the interviews after instruction also supported that result. During the interviews students were asked to explain the events related to the concepts of reaction rate that they had come across in their daily life. In the interviews it was found out that most of the control group students had difficulty in explaining these events and had some alternative conceptions. For example, some of the control group students thought that catalyst didn't affect the reaction and they confused the properties of intermediate product with the properties of catalyst. A student thought that catalyst increases the rate of reaction because it leads to an increase in the number of collisions. It is also stated in Cakmakci's study [45] that the intermediate product was confused with catalyst by the students.

Besides, it was determined that even though some of the students of both control and experimental groups correctly explained that catalyst increased the reaction rate but they couldn't explain why the reaction rate increased. These results are in parallel with the findings of the literature that students had trouble in understanding the effect of catalyst [11, 16, 46-49].

Generally students know that a catalyst increases the rate of reactions but they do not know how it happens. In some respect, this shows that students have the knowledge of "what" about the concept but have no knowledge of "why and how". In the interviews, it was found that the temperature concept was difficult to be understood by the control group students. Just as it was about the catalyst, although the students stated that the rate of reaction would increase with the rise of temperature, they couldn't explain properly why and how it increased. For example, the student coded as C2 in control group stated his ideas like this: "I don't know it in detail; I just know that temperature increases the rate of reaction. I don't know its explanation". In some respects it indicates that the students in the control group made explanations without considering the conceptual processes; they just used result-oriented and rote expressions.

It is possible to say there can be three different learning outputs in a learning environment: the first one is learning doesn't occur at all; second is rote learning occurs and the third one is a meaningful learning that has occurred successfully. The first learning type is the one in which no learning occurs. When the rote learning is taken into consideration which is the second learning output, students can tell the features of a given concept properly but can't transfer the concept to other situations. Rote learning mostly occurs in teaching environments which are teacher centered and the student is a passive receiver of the information [50-56**]**.

Moreover, the attempts of students to try to explain the effect of temperature with the chemical equilibrium principles existed in both groups. Numerous studies also report that students confused the concepts about reaction rate with the concepts of equilibrium and established inappropriate relationships between rate of reaction and chemical equilibrium [20, 45, 57]. One of the reasons why students try to answer the effect of temperature by relating it to the equilibrium topic may be that chemical equilibrium subject follows the teaching of reaction rate topic so students may focus on the equilibrium [44].

On the other hand, in the Turkish educational system students have to take a multiple-choice nation- wide exam for university entrance (YGS). So these students develop their own methods by studying in *Dershanes (Cramer School)* to answer as many as multiple-choice test questions in a short time. In this study, the reason why students tried to answer the question about reaction rate according to the chemical equilibrium principles can be explained that it is easier for students to solve questions by memorizing the rules and it is easy for them to answer the questions according to these rules instead of thinking about the processes, reasons and microscopic features involved. And it is an indicator that the concepts are not understood completely, but the students just only try to solve questions in the shortest way.

Other results emerging from the study were that some of the students from control group thought that the reaction would last longer because there would be more particles to collide when the concentration increased and had trouble in explaining the effect of surface area on the reaction. Similar difficulties are reported in Nakiboğlu et al.'s [17] study. It can be said that the students have difficulty in thinking of the microscopic side of the events and they perceive chemical events like the events they observe macroscopically in the external world. Chemistry really includes many abstract concepts that are difficult to understand and it is difficult for students to understand the processes in micro-level in many occasions [42, 58]. In numerous studies, it was reported that students try to explain the concepts in a macroscopic form without thinking the microscopic processes [41, 59-61].

The interviews in the scope of this study were implemented about a month later after the instruction. This is to ensure that the learning of the concepts has lasted and the interview findings prove this aspect for both groups.

In the interviews it was found that generally control group students tried to explain the questions by rote statements; they had difficulty in explaining the reasons and processes although they could explain the results of the events correctly. They had some alternative conceptions about the topics as well. At this point, it can be said that the instructional method in the control group doesn't help students to learn the concepts deeply. In meaningful learning, the processes related to the concepts can be explained with their reasons and can be transferred to different situations. At the same time the concepts can be remembered after the instruction [51].

However, it was determined that some students from the experimental group had some understanding difficulties even though they were a small number. This finding reveals that in spite of the instruction, it is not easy to change the ideas students have and one of the important factors affecting the learning is individual learning needs [62-64]. Even, the educational studies report that the more different students there are in a class, the more various learning methods should be taken into consideration and developed [65-67].

In this study, it was determined that the teaching activities based on a four-step constructivist approach was more effective in understanding the concepts about the rate of chemical reaction and explaining the real-life events than the traditional teaching approach. It was also concluded that the students could remember the concepts better and had less alternative conceptions and difficulty in understanding in experimental group than the students who were taught based on the traditional approach. The fact that the students in the experimental group were more successful about explaining the concepts related to real life than the control group students, and their better scientific explanation capacity shows that they have understood the concepts better and can transfer them into different situations. It is stated in the literature that to transfer knowledge into different areas means that students have an understanding of the concepts [7, 9, 68-70].

In this study it was determined that control group students were less successful in correlating the concepts about reaction rate with real-life experiences than the experimental group students. This finding reveals that the traditional methods are not very effective to increase students' achievement in correlating the concepts with real life sufficiently [7, 8, 69, 71-73]. Among the reasons why association is not at the enough level can be stated as, not giving the examples from real life in traditional learning environment clearly, not discussing these examples with their reasons in a detailed way, not providing students with various opportunities to apply the concept in their real life. The related literature reported that learning cannot go beyond rote learning and students' knowledge would be insufficient to explain different areas unless concepts are investigated with their reason–effect relationship and discussed in detail [46, 51, 74].

The students in the experimental group were equipped to use as many real-life examples as possible in activities. In the phase in which the attention was taken to the subject, students' interests were tried to be held by giving the events from their near environment, and in the focusing phase they were enabled to realize simple, not complex chemical reactions with familiar chemicals, unlike the laboratory studies in which there are many chemicals whose names are not known by and familiar with students. It is also emphasized that these learning environments support the learning of the concepts and transferring to different situations by some researchers [4, 39, 75-76].

In this study, it was decided that the teaching activities based on a four-step constructivist model is more effective for students to understand the rate of chemical reactions concept and to apply them in real-life events compared to the traditional teaching approach. Learning science is generally seen as difficult by students, so teachers in their teaching should be encouraged to use different approaches like a four-step constructivist approach used in this study. In this perspective, teachers should be encouraged to take part in applied seminars and to develop appropriate activities for the benefit of their own teaching and students. Besides, investigating and discussing real-life events and examples that are suitable for the topic will help them understand the chemical events in the external world.

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