Full Length Research Paper

A comparison of effectiveness of analogy-based and laboratory-based instructions on students' achievement in chemical equilibrium

Nagihan Yıldırım¹, Alipaşa Ayas², Mehmet Küçük³

¹ Recep Tayyip Erdoğan University, Faculty of Education, Rize, Turkey.
² Bilkent University, Faculty of Education, Ankara, Turkey.

Accepted 27 August, 2013

The aim of this study is to find out the effects of analogy-based and laboratory-based instruction on students’ achievement of chemical equilibrium in comparison with traditional instruction. Quasi-experimental design was used. The sample was composed of 69 students selected from 11th grade students in three different classes in an Anatolian High School in Trabzon. The classes were randomly determined as two experiment and one control group. In one of the experimental groups, the topics were instructed by using analogy-based instruction method, while laboratory-based instruction method was used in the other. As for the control group, no intervention was made during the instruction of the topic. A two-tier concept test, semi-structured interview and unstructured observation were used as data gathering instruments. This test was administered to all groups as pre-test and post-test and analyzed by using Statistical Package for Social Sciences (SPSS 10.0). The data collected with semi-structured interviews was analyzed through descriptive analyses. In analysis of the unstructured observations, quotations were included as bullet points from notes taken during the implementations. At the end of the study a significant difference was found in favor of the laboratory group over analogy, and a significant difference was found in favor of the experimental groups over the control group.

Key words: Chemical equilibrium, factors affecting equilibrium, analogy, laboratory.

INTRODUCTION

Constructivist learning theory is defined as students’ construction of new knowledge by means of associating the knowledge they gain through their interaction with events and objects around with their previous knowledge. (Bodner 1986; Kılıç 2001; Canpolat 2002; Boddy et al. 2003). In contrary to the traditional methods of instruction which are teacher-centered and in which students are passive listeners; this model defends that students must be actively engaged in learning process. As constructivist learning theory claims that learners can construct their knowledge only by themselves, and scientific knowledge is not directly transferable to the students during the instruction; suitable environments should be provided so that students can work as scientists, discover scientific knowledge on their own, and construct knowledge through discussion with their peers (Nakiboğlu 1999). In other words, methods and techniques should be developed to motivate students, to encourage them to seek out reasons, discuss and question, observe, understand, and to think creatively and critically. In this way, learning can be more permanent. Review of literature shows that various methods and techniques including laboratory activities, analogy, worksheets, conceptual change texts, cooperative learning-based activities, animations, etc. are usually used to create such environments (Hameed et al. 1993; Özdemir 1998; Canpolat 2002; Akkuş et al. 2003; Özmen and Yıldırım 2005; Bilgin and Geban 2006; Dibber 2006; Şimşek 2007; Sarıçayır 2007; Atasoy et al. 2009; Arslan Karakethüdaoğlu 2010). In these studies comparison of instruction performed by using such activities with instruction that no intervention was made with instruction,
mostly the students in the former group were found more successful. While there is abundance of studies regarding this in the literature, those about effectiveness on student achievement of different methods are limited. There is a need to look at how to improve students' achievement by making use of different methods of instruction which is our main aim in this research.

The studies carried out in chemistry reveal that students have difficulties in learning chemical equilibrium (Gussarsky and Gorodesky 1990; Huddle and Pillay 1996; Wheeler and Kass 1978; Yıldırım 2000; Sepet et al. 2004; Quilez 2004). However, as a consequence of both national and international literature review about chemical equilibrium, it is found out that students have misconceptions regarding dynamic nature of equilibrium, $K_c$, heterogeneous equilibriums, gas equilibriums, and Le Chatelier principle. (Hackling and Garnett 1985; Gorodesky and Hoz 1985; Berguest and Heikkinen 1990; Huddle and Pillay 1996; Thomas and Schwenz 1998; Voska and Heikkinen 2000; Akküş 2000, Yıldırım 2000; Kousthana and Tsaparalis 2002; Chiu et al. 2002; Özgen 2002; Akküş et al. 2003; Sepet et al. 2004; Alkan and Benlikaya 2004; Piquette and Heikkinen 2005, Doğan et al. 2007; Atasoy et al. 2009, Şatay 2010). The root of misconceptions regarding chemical equilibrium is the fact that students are unable to imagine events taking place at the moment of equilibrium due to its abstract nature (Johnstone et al. 1977; Wheeler and Kass 1978; Tyson et al. 1999; Kousathana and Tsaparlis 2002; Sepet et al. 2004; Akküş 2005). Students must be able to think the equilibrium at macro, micro and symbolic levels so that they can conceptually understand it. Hence, teachers need to employ methods that help students concretize the events taking place during equilibrium at three levels in the instruction process. Two of these methods are analogy and laboratory-based instruction.

There are studies in the literature comparing effectiveness of analogies and laboratory methods with traditional instruction in separate studies (Canpolat 2002; Koray et al. 2004; Vural 2005; Dilber 2006; Kozcu 2006; Başer and Geban 2007; Sarıçayır 2007). However, we could not find any studies in the literature comparing effectiveness of these two methods. In this sense, the aim of this study is to find out the effects of analogy-based and laboratory-based instruction on students' achievement of chemical equilibrium and factors affecting equilibrium. Sub-problems of the study are as follows:

1) As a consequence of comparing Analogy-based and Laboratory-based instruction with traditional method, to what extent are they influential on students' achievement regarding dynamic nature of chemical equilibrium and factors affecting the equilibrium?
2) To what extent are Analogy-based and Laboratory-based instruction influential on students' achievement regarding dynamic nature of chemical equilibrium and factors affecting the equilibrium?
3) What are views of students regarding the effectiveness of the materials and the implementation process?

**Materials and Method**

Quasi-experimental design was used. In quasi experimental design, it was possible to place students randomly into experiment and control groups in the study school. Also, quasi-experimental design is a common practice in educational researches (Çepni 2007; Bilgin and Geban 2006; Özdemir 1998; Hameed et al. 1993). Abbreviations regarding the sample and transactions made are shown in Table 1.

The sample was composed of 69 students selected from 11th grade students in three different classes in an Anatolian High School in the city center of Trabzon. Numbers of students in the experiment and control groups are given in Table 2.

---

**Table 1. Abbreviations in research.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABEG</td>
<td>Experiment group taught with analogy based instruction</td>
</tr>
<tr>
<td>LBEG</td>
<td>Experiment group taught with laboratory based instruction</td>
</tr>
<tr>
<td>CG</td>
<td>Experiment group taught with traditional instruction</td>
</tr>
<tr>
<td>SAn</td>
<td>$n^{th}$ student of the experiment group taught with analogy based instruction</td>
</tr>
<tr>
<td>SLn</td>
<td>$n^{th}$ student of the experiment group taught with laboratory based instruction</td>
</tr>
</tbody>
</table>

**Table 2. Number of students in the experiment and control groups.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABEG</td>
<td>20</td>
</tr>
<tr>
<td>LBEG</td>
<td>26</td>
</tr>
<tr>
<td>CG</td>
<td>23</td>
</tr>
</tbody>
</table>
Table 3. The data gathering instruments required by the sub-problems.

<table>
<thead>
<tr>
<th>Sub-problem</th>
<th>CECT</th>
<th>SSI</th>
<th>USO</th>
</tr>
</thead>
<tbody>
<tr>
<td>As a consequence of comparing Analogy-based and Laboratory-based instruction with traditional method, to what extent are they influential on students' success regarding dynamic nature of equilibrium and factors affecting equilibrium?</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>To what extent are Analogy-based and Laboratory-based instruction influential on students' success regarding dynamic nature of equilibrium and factors affecting equilibrium?</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>What are students' views regarding effectiveness of the materials prepared and the implementation process?</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Table 4. Kruskal Wallis test results of pre test and post test scores of the control and experiment groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean rank</th>
<th>Sd</th>
<th>$K^2$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABEG</td>
<td>20</td>
<td>34.28</td>
<td>2</td>
<td>0.31</td>
<td>0.85</td>
</tr>
<tr>
<td>LBEG</td>
<td>26</td>
<td>33.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td>23</td>
<td>36.78</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The classes were randomly determined as two experiment and one control group. In one of the experimental groups, the topics of chemical equilibrium and factors affecting the equilibrium were taught by using analogy-based instruction method, while laboratory-based instruction method was used in the other. As for the control group, no intervention was made during the teaching of the topic.

**Teachers' and students' materials used in the research**

During development of the materials, initially the topic of chemical equilibrium, constructivist learning and material development activities were examined in related literature. In the light of the collected data, two teachers' guide materials were developed on the basis of the 4E model of constructivist learning theory. One of the teachers' guide materials used analogy-based activities (ABEG), while the other used laboratory-based activities (LBEG). For practical use, activities to be realized by teachers are given as detailed lesson plans in the teacher's guide materials. Five lesson plans of ten hours were prepared in each of ABEG and LBEG. As for students, five worksheets were developed for each. In the worksheets comprising of analogy-based activities, the 'Water tank analogy' of Russell (1988) was used. In their study, Wilson, (1998), Harrison and Buckley, (2000), Canpolat (2002), Sarıçayır, Şahin and Üce, (2006) expected students to understand whether inputs involved after the equilibrium moment and respective outputs change or not by only looking at number of balls, number of matches or water level in the graduated cylinder remaining stable. In present study, colored liquid and water was put in the graduated cylinders; so colors of the liquids in the graduated cylinders changed as liquid transfer started (the graduated cylinder was colorless at the beginning, but then turned yellow, whereas the liquid in the graduated cylinder with orange liquid turned into yellow), color of liquids in the graduated cylinders remained unchanged at the moment of equilibrium was linked to not changing of the reactants and products after the equilibrium moment. Also the relations between source and target concepts in analogies used in such studies were directly given to the students. On the other hand, in this study, worksheets were given to students to help them apply the analogy, and guide them throughout the work. The students find this relation by themselves through following instructions on the worksheets.

In worksheets containing laboratory-based activities, experiments were used. In the worksheet regarding effect of pressure on equilibrium, though intended to use an experiment, it could not be applied. Instead, the animation regarding effect of pressure on equilibrium in URL1 link was used for convenience.

**Data gathering instruments**

In this study, a two-tier concept test, Chemical Equilibrium Concept Test (CECT), a semi-structured interview (SSI) and unstructured observation (USO) were used as data gathering instruments. The data were gathered instruments used required by the sub-problems are given in Table 3.

**Chemical Equilibrium Concept Test in the Study**

A two-tier concept test was developed in order to identify effects of the three methods used in this study on students' success regarding chemical equilibrium. For the pilot study of the test was held with 40 students attending
the 11th grade in a high school in Trabzon. After making necessary amendments according to the item analysis results, the test was given to another group of 11th grade 40 students in another high school. As a result of the item analysis, Sperman Brown reliability coefficient was calculated as 0.94 and Pearson product-moment correlation coefficient as 0.88. Then, lastly, the test was investigated by two chemistry teachers; one academician specialized in chemistry teaching and another academician on analytic chemistry in order to find out whether its scope is sufficient for measuring relevant knowledge. Such applications increase reliability and validity of the test (Çalık 2006). The test took its final shape after all necessary amendments. Test implementation time was identified as 25 minutes.

There are 16 items in the test. 8 of them are multiple choice two-tier test items, while the other 8 are open-ended two-tier test items. This test was administered to all groups as pre-test and post-test.

Semi-structured interview

In this study, semi-structured interviews were used to deeply find out students’ knowledge about the topic. The interviews basically contained 3 questions, 2 of which are about equilibrium and factors affecting on the equilibrium, 1 of which is about the implementation carried out. Also every question has its sub-questions.

Each question was written on cards during application of the interviews. The interviews were held with 6 students of the experiment groups after implementation. The students were in the experiment groups and got low, intermediate and high grades from the post-test. The interviews lasting for 35–40 minutes were tape-recorded with students’ permission.

Unstructured observation

In this study, unstructured observations were held for 18 lesson hours in each group. In these observations, notes were taken related to students’ answers, and talks to each other and teachers and behaviors on their own.

Data analyzing methods

The CECT used in the research is comprised of two-tier items. Following the pilot study, the students’ answers to the test questions were examined, and it was found out that the categories Çalık (2006) used in his dissertation covered all answers of the students and scored. After grouping students’ answers into the categories above, statistical analysis was carried out by using Statistical Package for Social Sciences (SPSS 10.0) taking into consideration total scores they got from the pre-test and post-test. Comparisons were made within and among groups between pre-test and post-test scores gained from the experiment and control groups. Since students’ answers were grouped and number of samples in each group was below 30, the comparisons among groups were analyzed by using Kruskall Wallis test, a nonparametric test, and Mann Whitney U test.

In this research, the data collected with semi-structured interviews held with students was analyzed with descriptive analysis. Resulting data is summarized and interpreted in the light of predetermined themes. Also direct quotations are frequently referred for reflecting interviewees’ ideas in a striking way (Yıldırım and Şimşek 2003). The students’ answer to each question is given between quotation marks and with drawings as relevant. In analysis of the unstructured observations, quotations were included as bullet points from notes taken during the implementations.

Findings

In this chapter, findings obtained from the CECT, semi-structured interviews and unstructured observations are presented in separate sections.
Table 7. Mann Whitney U test results of post test scores of the ABEG and CG.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean rank</th>
<th>Sum of rank</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABEG</td>
<td>20</td>
<td>27.88</td>
<td>557.50</td>
<td>112.50</td>
<td>0.004</td>
</tr>
<tr>
<td>CG</td>
<td>23</td>
<td>16.89</td>
<td>388.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Mann Whitney U test results of post test scores of the LBEG and CG.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Sıra Ort</th>
<th>Sıra Top</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBEG</td>
<td>26</td>
<td>33.87</td>
<td>880.50</td>
<td>68.50</td>
<td>0.000</td>
</tr>
<tr>
<td>Control</td>
<td>23</td>
<td>14.98</td>
<td>344.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9. ABEG and LBEG students’ answers and drawings for question one.

<table>
<thead>
<tr>
<th>Student codes</th>
<th>Explanations</th>
<th>Drawings</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA1</td>
<td>‘In the beginning, there is some $N_2O_4$. After, it decreases. Then it stops. It reaches the equilibrium. There wasn’t any NO$_2$ in the beginning. It is produced after a while, increases and increases then reaches the equilibrium. No change occurs in concentrations after the equilibrium.’</td>
<td></td>
</tr>
<tr>
<td>SA2</td>
<td>‘There was some $N_2O_4$ but no NO$_2$ in the beginning. $N_2O_4$ decreases, the other one increases. Then, they will be stable because they will reach equilibrium.’</td>
<td></td>
</tr>
<tr>
<td>SA3</td>
<td>‘First of all, $N_2O_4$ is the starting substance. It gradually decreases and reaches the equilibrium. There was not any NO$_2$ in the products at the beginning. It was produced later and reached the equilibrium. No change occurs in concentrations after the equilibrium.’</td>
<td></td>
</tr>
<tr>
<td>SL1</td>
<td>‘$N_2O_4$ will decrease; there was not any NO$_2$ in the beginning. Then, it was produced slowly, increased and then became stable. Because they reached the equilibrium. No change will occur in concentrations after the equilibrium.’</td>
<td></td>
</tr>
<tr>
<td>SL2</td>
<td>‘Because NO$_2$ is produced after a while, $N_2O_4$ first decreases and then becomes stable. There wasn’t any NO$_2$ in the beginning, and then it increased and became stable. Because forward reaction rate is equal to back reaction rate. There is a constant changing. This is the equilibrium moment.’</td>
<td></td>
</tr>
<tr>
<td>SL3</td>
<td>‘$N_2O_4$ will decrease, but NO$_2$ will increase. Then forward reaction rate will be equal to backward reaction rate, and concentrations will be stable because of the equilibrium’.</td>
<td></td>
</tr>
</tbody>
</table>

**Results obtained from statistical comparison of students’ answers to the chemical equilibrium concept test**

Inter-group comparisons between pre-test and post-test scores got from the CECT given to both experiment and control groups were carried out by using Kruskal Wallis Test and Mann Whitney U Test, and results are presented in tables, 4, 5, 6, 7 and 8.

The results in Table 4 indicate that there isn’t a significant difference between the scores the three groups got from the pre-test ($\chi^2(2) = 0.31$, $p>.05$). The mean ranks of the groups do not indicate a significant difference between the groups prior to the application.

The results in Table 5 indicate that there is a significant difference between the scores the three groups got from the post-test ($\chi^2(2) = 23.52$, $p<.05$). Mann Whitney U test was applied to find out the cause of such difference. The results are given below.

The results in Table 6 indicate that there is a significant difference between the scores the ABEG and LBEG students got from the post-test ($U=159.5; p<0.05$). The
Table 10. ABEG and LBEG students’ answers and drawings for item 2i under question two.

<table>
<thead>
<tr>
<th>Student codes</th>
<th>Explanations</th>
<th>Drawings</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA1</td>
<td>The reaction shifts to products because $K_c$ can change with temperature only. As equilibrium shifts to products, $K_c$'s value increases. It can be decreased by increasing concentration of the inputs. So, it shifts to the products. ‘As for the moment after the equilibrium, we added, it suddenly increased, and then it decreased. It does not return to the previous case because we added and increased the concentration under all circumstances. It never returns to the former status. The other slowly increases and reaches the equilibrium again.’</td>
<td><img src="Image" alt="SA1_drawings" /></td>
</tr>
<tr>
<td>SA2</td>
<td>'The equilibrium shifts to the products. NO$_2$ concentration increases due to adding N$_2$O$_4$, it does not return to its formal concentration, its concentration increases in comparison to the formal status, too. ‘$K_c$ does not change because it changes with temperature only.’</td>
<td><img src="Image" alt="SA2_drawings" /></td>
</tr>
<tr>
<td>SA3</td>
<td>'The system shifts to the products. When we add N$_2$O$_4$, it resolves and produces NO$_2$. So when we add some more, it resolves and more products are produced. Because of the high amount of substances, more collisions will take place in a closed vessel, and more products will be produced. N$_2$O$_4$ concentration does not return to its formal status because some substance was added. It will not return to its formal status regardless how much is spent.’</td>
<td><img src="Image" alt="SA3_drawings" /></td>
</tr>
<tr>
<td>SL1</td>
<td>'N$_2$O$_4$ increases. For reaching equilibrium, the equilibrium must shift to the inputs, it is forward, NO$_2$ concentration increases, N$_2$O$_4$ concentration decreases and I increased it. Then, parabolic decreased but it will not go below the formal status. NO$_2$ will increase and reach the equilibrium back after a certain point. ‘$K_c$ does not change.’</td>
<td><img src="Image" alt="SL1_drawings" /></td>
</tr>
<tr>
<td>SL2</td>
<td>'When added, NO$_2$ starts increasing. Due to the increased amount of inputs, the equilibrium will be needed. And the products will increase. For example, it will jump from 5 to 10. Then, it will decrease because it will be spent. But it will not decrease down to its formal value. N$_2$O$_4$ concentration increases in comparison with formal concentrations, but NO$_2$ concentration increases even more. ‘$K_c$ does not change under normal circumstances, but pseudo $K_c$ decreases, and gets back to its formal status after a while.’</td>
<td><img src="Image" alt="SL2_drawings" /></td>
</tr>
<tr>
<td>SL3</td>
<td>'N$_2$O$_4$ concentration increases in comparison with its formal status because it was the added substance. NO$_2$ concentration increases, too, because the equilibrium shifts to that side. ‘$K_c$ does not change because it changes with temperature only.’</td>
<td><img src="Image" alt="SL3_drawings" /></td>
</tr>
</tbody>
</table>

The difference is in favor of the LBEG group. While the mean rank of the ABEG group is 18.48; that of the LABEG group is 27.37.

The results in Table 7 indicate that there is a significant difference between the scores the ABEG and control group students got from the post-test (U=112.50; p<.05). The difference is in favor of the ABEG group. While the mean rank of the control group is 16.89; that of the ABEG group is 27.88. The results in Table 8 indicate that there is a significant difference between the scores the LBEG and control group students got from the post-test (U=68.50; p<.05). The difference is in favor of the LBEG group. While the mean rank of the control group is 14.98; that of the LBEG group is 33.87.

Results obtained from semi-structured interviews

Question one was about events taking place at the equilibrium in relation to this equation Heat + N$_2$O$_4(g)$ $\rightleftharpoons$ 2NO$_2(g)$, and factors affecting equilibrium (such as temperature, pressure, concentration).

Initially, the students were told that in reaction of colorless N$_2$O$_4$ gas producing colored NO$_2$ gas, reaction started with N$_2$O$_4$ gas at a certain temperature and volume, and the system reached the equilibrium after a certain time. The students were asked how concentration-time graphic would be in relation to the changes of N$_2$O$_4$ and NO$_2$ concentrations. The graphics the students drew are given in Table 9.

According to Table 9, the students generally explained the representations with that N$_2$O$_4$ concentration is used in the reaction process, while NO$_2$ is produced during this process, and the concentration becomes stable upon reaching the equilibrium when forward-backward rates become equal after a certain point.

In question two, while the reaction in the first question
Table 11. ABEG and LBEG students’ answers for item 2ii.

<table>
<thead>
<tr>
<th>Student codes</th>
<th>Explanations</th>
<th>Drawings</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA1</td>
<td>It shifts towards products because the products are at higher temperature, are inclined to be stable, NO₂ concentration increases, N₂O₄ concentration decreases, the system reaches the equilibrium back, the second equilibrium. ‘K_c will increase in turn.’</td>
<td></td>
</tr>
<tr>
<td>SA2</td>
<td>‘Since it is endothermic, it shifts towards products. N₂O₄ concentration decreases, while NO₂ concentration increases. Then, the system reaches the equilibrium back.’ ‘K_c will increase as products’ concentration increases. Because the products are in the dividend, the inputs are in the denominator.’</td>
<td></td>
</tr>
<tr>
<td>SA3</td>
<td>N₂O₄ concentration decreases, but NO₂ concentration increases. ‘K_c increases as products increase.’</td>
<td></td>
</tr>
<tr>
<td>SL1</td>
<td>Max disarrange, min energy shifts to the products, concentration increases, but concentration of the inputs decreases, then it comes to the second equilibrium back. ‘K_c increases because concentration of the products increases.’</td>
<td></td>
</tr>
<tr>
<td>SL2</td>
<td>‘Endothermic shifts to the products again, NO₂ concentration increases, but N₂O₄ concentration decreases. The second equilibrium will be reached then.’ ‘K_c increases because products increased and they get more as they are in the dividend’</td>
<td></td>
</tr>
<tr>
<td>SL3</td>
<td>‘The equilibrium shifts to products and concentration of the products increases, while concentration of the products increases. Then it reaches the equilibrium back, and concentrations become stable.’ ‘K_c increases because concentration of products increases, while concentration of inputs decreases.’</td>
<td></td>
</tr>
</tbody>
</table>

is at the equilibrium:

2i: Some N₂O₄ is added at constant temperature and volume
2ii: Temperature is increased at constant volume
2iii: Volume is decreased at constant temperature

The students were asked to explain how the equilibrium is affected under these circumstances by referring to the collision theory, Le Chatelier principle and the equilibrium constant law, K_c, and to draw time graphics of corresponding concentration. Below are the students’ answers to these questions.

As seen in Table 10, the students said that the equilibrium will shift to the products and NO₂ concentration will increase when some amount of N₂O₄ gas is added to the environment at constant temperature and volume for Heat + N₂O₄(g) ⇌ 2NO₂(g) reaction. As for N₂O₄, they explained that its concentration is higher than its first level although it is spent following reaching the equilibrium. The reason is that it is the added substance. They also noted that K_c is not affected because it changes with temperature only. The graphics reveal N₂O₄ constant at equilibrium at first (the first equilibrium status), then its concentration suddenly increases, then decreases and becomes constant due to adding N₂O₄ (the second equilibrium status). As for the NO₂ concentration, it is shown constant first, then decreases and reaches the equilibrium back (the second equilibrium status).

According to Table 11, all of the students explained that the equilibrium will shift towards products, and thus concentration of the products will increase, but concentration of the reactant will decrease if temperature of the reaction at constant volume increases. They added that value of the K_c will increase. Their graphic representations show that NO₂ concentration will first become stable to determine the first equilibrium status, then it will increase again before becoming stable (indicates the second equilibrium status). N₂O₄ concentration will first become stable, then decrease until being stable again (indicates the second equilibrium status).

According to Table 12, the students explained that
Table 12. ABEG and LBEG students’ answers for item 2iii.

<table>
<thead>
<tr>
<th>Student codes</th>
<th>Explanations</th>
<th>Drawings</th>
</tr>
</thead>
</table>
| SA1           | ‘If volume is halved, pressure is doubled because moles are stable. If pressure increases, it wants to decrease. For this, it shifts to the side with small number of moles. N₂O₄ increases, but NO₂ decreases.’
 |                | ‘K_c changes with temperature only.’                                                               |          |
| SA2           | ‘The highest increase occurs in the side with the higher of moles. For decreasing this, the system shifts to the side with small number of moles. There is stability in this, too. Because it will reach the equilibrium back.’
 |                | ‘K_c does not change because temperature is constant.’                                              |          |
| SA3           | ‘The side with higher number of moles will be affected more, and pressure increases more here. For decreasing this, it shifts to the side with smaller number of moles. N₂O₄ increases, NO₂ decreases.’
 |                | ‘K_c does not change.’                                                                            |          |
| SL1           | ‘If Molarity=n/v volume decreases, concentration is doubled. Concentration of all of them will increase. NO₂ increases more. For decreasing, it shifts to the N₂O₄ side.’
 |                | ‘K_c does not change.’                                                                            |          |
| SL2           | ‘Volume decreases, it shifts to the side where there is a small number of moles.’
 |                | ‘K_c does not change because temperature did not change.’                                          |          |
| SL3           | ‘Decreased volume causes the equilibrium to shift towards the side with smaller number of moles. As volume decreases, first all their concentration increases, then the equilibrium shifts towards the inputs side.’
 |                | ‘K_c changes with temperature only.’                                                               |          |

equilibrium shifts to the side with smaller number of moles if volume is decreased under constant temperature for the reaction given, because the side with higher number of moles is affected more by increased pressure, and the equilibrium shifts towards the side with smaller number of moles to decrease this. Only SL1 stated that concentration of both of them increases if volume is decreased, then N₂O₄ concentration increases, while NO₂ decreases. S/he drew the concentration-time graphic in parallel with the explanations. However; in the other students' graphics for the mixture of N₂O₄ and NO₂, which is at equilibrium, N₂O₄ concentration gradually decreases and is stabilized again, and NO₂ concentration gradually decreases and reaches stability again. Lastly, the students were asked for their opinion regarding the implementation in question three. Their answers are given in Table 13.

When the students were asked for their opinion regarding the implementation, the ABEG students said that they had difficulty in making up the table with data collected after transactions made in analogy. They also told that decimals in the calculations were confusing, so it would be easier with integers. Moreover; they had challenges in transferring from one cylinder to another. They also think that experiments to be made with real reactions at laboratory would be effective. In relation with the implementation, their overall idea is that concretized concepts became effective in learning such an abstract topic, and it was funny to work in the laboratory. The LBEG students agreed with the other students. However, one student told s/he was not interested because questions at university entrance exam would be totally different. Still, s/he found it funny to work in the laboratory.

Results Obtained from Unstructured Observations

Unstructured observations conducted during the implementations in ABEG and LBEG groups are given in detail as follows:

-   The students in these groups said that at the beginning such activities were irrelevant for the exam, so they wanted to make more practice in solving problems. Particularly the ABEG students were unwilling to participate in the first practical lesson because they could not understand the analogy. The teacher reacted by
Table 13. ABEG and LBEG students’ answers for question three.

<table>
<thead>
<tr>
<th>Student</th>
<th>Challenges faced in implementation</th>
<th>Recommendations</th>
<th>Overall idea regarding implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA1</td>
<td>Decimals in the table caused confusion to some extent. Integers would be more feasible.</td>
<td>It would be suitable to use experiments rather than analogy.</td>
<td>It became permanent as we could see what we pictured in mind.</td>
</tr>
<tr>
<td>SA2</td>
<td>It was difficult to put from one to another cylinder. It sometimes caused confusion.</td>
<td>It would be more efficient to see real reactions.</td>
<td>At first, I did not understand what we did, but I started understanding after the second lesson, and had fun. It was funny to come to the laboratory also.</td>
</tr>
<tr>
<td>SA3</td>
<td></td>
<td>Certainly it improved me. It is better to learn by seeing than studying in books. Because it finds a place in our memory. We can understand the problem and stop memorizing formulas after getting the main idea.</td>
<td></td>
</tr>
<tr>
<td>SL1</td>
<td>There is something missing, but I don’t know what. Should we have done experiments after the lecture?</td>
<td>In our experiments, color changed so I could better understand to which direction the system shifted. I don’t forget if I understand by seeing. I understand better when I study books, but as I consider, I visualize all we did, consequently I remember.</td>
<td></td>
</tr>
<tr>
<td>SL2</td>
<td></td>
<td>For me, it was good and funny. First when we were answering questions, we said that the equilibrium shifts to that or this side, but now I saw how these happen. I think what I learn will be more permanent.</td>
<td></td>
</tr>
<tr>
<td>SL3</td>
<td></td>
<td>It is hardly interesting to me because it is not in this way in ÖSS. It was funny to be in the lab only.</td>
<td></td>
</tr>
</tbody>
</table>

The groups distributed tasks among themselves. While they were busy with the activity, the teacher walked between groups and led the students for the correct answer by asking questions regarding forward-back reaction rate, concentration, $K_c$ etc (ABEG-LBEG). One person in each group explained what they did to their peers and the teacher. The students gave detailed explanations for the questions (ABEG-LBEG). The teacher, while making explanations, used the course book and other resources as material (ABEG-LBEG). The LBEG students seemed more curious and willing than the other group to do the activities.

**DISCUSSION AND CONCLUSIONS**

Before teaching the topic of chemical equilibrium, all students in both experiment and control groups were given CECT as pre-test. Kruskal Wallis Test was applied to pre-test scores of the three groups. The results do not show a significant difference among them ($\chi^2(2)= 0.31$, $p>0.05$). This indicates that students’ achievement in the experimental and control groups about chemical equilibrium was almost the same before starting the
implementation.

To determine the most successful group, a Kruskall Wallis Test was applied to the post-test scores. The test results show significant differences between the groups. (K$^+$2)= 23.52, p<.05, Table 10). To explain such a significant difference, a Mann Whitney U Test was applied between two groups. The results of the Mann Whitney U Test gained from the groups' post-test scores demonstrate significant differences to the support of the LBEG in the case of LBEG-ABEG (U=159,5; p<0.05); LBEG group in the case of LBEG-Control groups (U=68,50; p<.05), and ABEG group in the case of ABEG-Control groups (U=112,50; p<.05). This indicates that the ABEG and LBEG students are more successful than the control group students, and the LBEG students are more successful than the ABEG students in relation to the topic of the chemical equilibrium. It can be inferred that laboratory-based teaching is more effective in students' learning of the concepts of chemical equilibrium than traditional and analogy-based instruction (Sanger, 2000).

Likewise, concerning their recommendations about the implementation, the students in the analogy-based group reported that experiments with real reactions would be more effective than analogy. This suggests that learning becomes more lasting if students learn by carrying out activities and/or doing experiments. The literature says that in teaching chemistry, students cannot get permanent knowledge unless knowledge is transferred in an experiment-centered media, and also the behaviors acquired by students while they are active prove more meaningful and permanent than those acquired via visual or audial means only (Ayas et al. 1997; Temel et al. 2000; Üce et al. 2003; Demircioğlu et al. 2004).

The unit on chemical equilibrium is given during the 11th grade in high school curriculum. Until then, the only one-way reactions are taught to students. Students see two-way reactions in the 'Chemical Equilibrium' unit for the first time. After that stage, they are expected to think that forward-reaction reactions occur simultaneously though they cannot observe. Therefore, this requires students to change their previous knowledge. In this process, it is essential that teachers employ methods and techniques that concretize events in two-sided reactions (Driel et al. 2002). In present study, worksheets about 'Water Tank' analogy were given to the group where concepts related with the dynamic nature of equilibrium and factors affecting equilibrium were taught by using analogy-based instruction, while experiment-based worksheets were used for the group which was taught by means of laboratory-based instruction. In parallel, question one in the interviews asked students to draw the concentration-time graphic regarding realization process of given reaction (HEAT + N$_2$O$_4$(g) ⇌ 2NO$_2$(g)). According to Table 9, all of the students could make up the graphic accurately, and bridged forward-backward reaction rates with concentration of the reactants and products in their explanations. This indicates that both the Water Tank analogy and the experiments were effective in teaching students concepts about the dynamic nature of equilibrium. In analogy and experiment-based learning media, students actively participate in the instructional process. In this process, students use equipment as much as possible, make observations, record data and draw conclusions. Students’ activities are important for turning abstract knowledge into concrete and help better learning of it. Other studies also suggest that such activities help students learn abstract and difficult topics such as chemical equilibrium, and support meaningful learning (Ayas et al. 1994; Çepni et al. 1995; Daunt 1997; Serin 2002; Böyük and Erol 2008).

Item one of question 2 (2i) requires students to explain changes that take place in equilibrium and K$_c$ after adding more N$_2$O$_4$ gas under constant temperature and volume when the reaction in question one is at the equilibrium, and to draw the concentration-time graphic accordingly. It is seen in Table 10 that the students provided accurate drawings, and particularly explained correctly the sudden increase of the concentration of the added substance, and increased concentration in comparison with the previous value after the second equilibrium. While giving their explanations, SA1 used K$_c$, SA3 used the collision theory and the other students Le Chatelier principle, though they did not give the exact term. During implementations, the teacher always warned students to refer to the collision theory, K$_c$, and Le Chatelier principle, and made her/his own explanations by doing so. In this sense, it can be said that the methods and problem-solving techniques used by teachers proved quite effective in students' learning (Quilez and Solaz 1995; Solomonidou and Stavridou 2001). Also while answering the comprehension questions in the end of the worksheets, students in both groups were asked to answer them on the basis of these three events. The students must refer to other facts besides Le Chatelier principle so that they can explain accurately the changes that take place in case of having an impact on a system which is at the equilibrium (Quilez and Solaz 1995; Niaz 1998; Quilez 2004). The literature includes evidences which show that students can reach correct results by applying Le Chatelier principle, or think that, by looking at the generic definition in the course books (as having an impact on a system that is at the equilibrium, the system reacts to offset such an impact), the system shifts to the products after adding more of the reactants, and concentration of the products increases while that of the reactants decreases (Pedrosa and Dias 2000; Quilez 2004, Yıldırım et al. 2007). In this framework, the materials developed can be said to help students to be able to explain the effect of concentration on the equilibrium.

According to Table 11, all of the participants could understand the fact that if reaction temperature is increased under constant volume, equilibrium shifts to the products and thus concentration of the products...
increases, while concentration of the reactants decreases. In addition, they supported their explanations with correct graphs. Also they noted that $K_c$ value increases. The ABEG and LBEG students' answers regarding impact of temperature on equilibrium reveal that both analogy-based and laboratory-based instruction are effective in students' understanding the impact of temperature on the equilibrium.

Table 12 shows that the experiment students could explain how change of volume affects equilibrium and $K_c$ in given reaction. In the laboratory-based instruction group, SL1 and SL3 said that as a response to the change of volume, concentration of all substances in the reaction first increases, and then the equilibrium is distorted against the side with higher increase of concentration. They drew corresponding graphics. Those students' answers are “decreasing volume shifts the equilibrium to the side with smaller number of moles. If volume decreases, concentration of all substances first increases, then shifts towards the reactants.’ ‘Molarity=n/v if volume decreases, concentration is doubled; concentration of all substances increases, concentration of NO$_2$ increases more, it shifts to N$_2$O$_4$ to decrease it.’ SA1 answered the question as ‘If we halve volume, pressure is increased twice because moles are stable. If pressure increases, it needs decreasing. For this, it shifts to the side with less number of moles. N$_2$O$_4$ increases, but NO$_2$ decreases.’ But s/he could not complete the graphic (Table 12). SA2, SA3 and SL2 could accurately explain events that might take place in the equilibrium in case of volume change, but did not provide any explanations regarding to the sudden increase of reactant and product concentration at the very moment of the change. Quilez (2004) found that students were not able to make connection between volume change and resulting concentration change. To get over that challenge, it was suggested to teach equilibrium according to $K_c$ term instead of teaching in an algorithmic way as many course books and teachers do. We think that this suggestion was taken into consideration while developing materials and carrying out the implementation. To this end, the students generally made accurate explanations for the questions in the interview except for that SA1 could not draw the relevant graphic. The results are supported with findings of Yildirim (2000) and Karataş (2002). According to Wheeler and Kass (1978), concentration-time graphics are crucial for students to understand changes as a result of having an impact on the system at the equilibrium (Camacho and Good 1989; Huddle and Pillay 1996). The reason for students' not being able to draw such graphics is the fact that they have difficulty in showing in a different way what they learnt or creating corresponding graphics. It might be explained with the instruction methods previously applied to the students. At least we know that traditional instruction methods do not encourage learners to apply what they learn to other cases.

The last question in the interviews was for obtaining students' views about the implementation process. When asked about challenges faced in the experiment group with analogy-based instruction, the students mentioned that they had difficulty in completing the table regarding ‘Water Tank’ analogy because of the decimals in the table. In addition, the students said that at the beginning they were confused liquids while transferring from one to another. The observations show that the students faced challenges in filling in the tables regarding to the analogy on the first worksheet as they reported during interviews. But after implementing each worksheet, together with the analogy map in explanations of the students or teachers, discussion was done on similarities and differences between the target and source concepts reported by students to make the analogy clearer. Harrison and Treagust (1993) emphasize that clarifying similarities and differences between target and sources concepts in analogies enable students to use and understand the analogy at the same time prevent them from raising alternative concepts. In parallel with this, the same students said in the interviews ‘At first, I did not understand what we did, but I started understanding after the second lesson, and had fun.’ Besides, we observed some students asking their teacher what chemical reaction happened when they transferred liquid from the cylinders. This implies that students were not informed about how chemical reactions happen and how to observe them because they had never studied in laboratory before. Thus the teacher continuously reminded the students of the analogy and necessary activities, and helped them during this lesson. It is important to make related definitions and explanations for the analogy in the beginning (Thiele and Treagust 1991). Otherwise, students may misinterpret the analogy or think that a real chemical reaction happens as in the analogy. We know that students fail if they cannot understand the analogy as intended (Harrison and Treagust 1993; Pitmann 1999).

The LBEG students mixed given materials without taking into consideration instructions on the worksheets and took different substances from the shelves in early lessons. This might be explained with the fact that the students didn't take part in laboratory activities before. Özmen and Yıldırım (2005) also found a similar result. In the following lessons, the students could do the activities themselves and be more practical. Still, LBEG students took longer to start working systematically than ABEG students.

In lessons with worksheets, the students in the both experimental groups seemed happy in the laboratory, and kept watching the laboratory and equipment curiously. It is known that students become more successful if they find the environment interesting (Greenbowe et al. 1998; Mistler-Jackson and Songer 2000). In interviews, the students said that they did an experiment in the laboratory for the first time. Students’
reactions indicate that though teachers cannot use the laboratory method due to various reasons (Çepni et al. 1995; Silay et al. 1998; Üce et al. 2000), the students are bored with traditional classrooms and need new and different learning environments. In interviews following the implementation, the students expressed their ideas as "...Certainly it improved me. It is better to learn by seeing than studying in books, because it finds a place in our memory. We can understand the problem and stop memorizing formulas after getting the main idea...", "For me, it was good and funny. First when we were answering questions, we said that the equilibrium shifts to that or this side, but now I saw how these happen. I think what I learn will be more permanent", "...In our experiments, color changed so I could better understand to which direction the system shifted. I don't forget if I understand by seeing. I understand better when I study books, but as I consider, I visualize all we did, consequently I remember...." Students' comments show that analogy-based and laboratory-based implementations increased participation and interaction in both groups, so the activities played a motivating role in meaningful learning (Thiele and Treagust 1991, Ayas et al. 1993; Thiele and Treagust 1994; Glynn and Takahaski 1998; Heywood 2002; Damarer 2006; Koçcu 2006; Yıldırım et al. 2009). SL3 from the group with laboratory-based instruction only spoke "...I was not interested because questions at university entrance exam would be totally different. Laboratory was fun only...." This clearly shows the nervousness over the exam among students in our country.

Implications

In this study, we found that in teaching the dynamic nature of the equilibrium and factors affecting on the equilibrium, analogy-based and laboratory-based instruction methods are more effective than the traditional methods. Also, laboratory-based instruction method is more effective than the analogy-based method. As a consequence of this study, we note following recommendations;

- In present study, effect of the materials on students' achievement was searched. In the end of the study, the students stated that activities in both laboratory-based and analogy-based instruction were interesting and funny. In longitudinal studies to be carried out on the same topic or other topics employing such materials, their effects on students' affective behaviors can be investigated.

- As a consequence of this practical study, it was realized that students' success improved thanks to their active involvement in the learning process. Thus, activities promoting active learning should be used more in teaching. For this, teachers need to be equipped with necessary knowledge and skills regarding new and contemporary instructional methods and techniques. However, some studies in the literature prove that teachers regard themselves weak in this aspect, and they need on-the-job in-service training seminars (Kurt and Yıldırım 2010; Ceng et al. 2010). To meet such a need, teachers can be provided in-service training regarding new and contemporary instruction methods and techniques.

- All participants in the experimental groups said that they had never carried practical work in laboratory. However, later the students in both analogy-based and laboratory-based instruction groups had fun while practicing in the laboratory, and watching-handling the laboratory equipment attentively. In interviews also they reported positive comments. We suggest that teachers should include these activities in teaching although they cannot apply to the laboratory practices due to several reasons. We think that learning outcomes are more permanent if students are actively engaged in the learning process.

ACKNOWLEDGEMENTS

The work presented in this paper is supported by the ‘Developing, Implementing and Evaluating Materials Based on Different Learning Theories Related to Concepts in Chemistry Program on Secondary Education’ Project that is funded by the Karadeniz Technical University Scientific Research Project (BAP) Number: 2008.116.002.1).

REFERENCES


Scholarly J. Educ. 74


