Karaelmas Science and Engineering Journal
Journal home page: http://fbd.beun.edu.tr
DOI: 10.7212%2Fzkufbd.v8i1.1171

Research Article
Received / Geliş tarihi : 24.10.2017
Accepted / Kabul tarihi : 23.11.2017

Students' Opinions About Problem-Based Learning (PBL) and Scenario Applied in Teaching Electrochemistry

Elektrokimya Öğretiminde Uygulanan Probleme-Dayalı Öğrenme (PDÖ) ve Senaryoya İlişkin Öğrenci Görüşleri

Tuğçe Günter[1*], Sibel Kılınç Alpat[2]

[1]Department of Medical Laboratory Techniques, Ahmet Erdogan Vocational School of Health Services, Bulent Ecevit University, Zonguldak,Turkey

[2]Department of Chemistry Education, Buca Education Faculty, Dokuz Eylul University, Izmir,Turkey

Abstract

This research aimed to determine students' opinions about both problem-based scenario developed and the sessions of problem-based learning (PBL) used for the topic of 'Electrochemistry' in an Analytical Chemistry course. The research was conducted with students who were studying in the fourth year in the Department of Chemistry Education, Secondary Science and Mathematics Education, Faculty of Buca Education, Dokuz Eylul University (N=15). Students' opinions concerning the scenario and the PBL sessions were gathered by using a structured data collection tool. In addition, the attempt was made to determine whether the students could themselves design a scenario or different learning materials for the relevant topic. The data obtained from the structured data collection tool consisted of answers to 11 open-ended questions which were evaluated by content analysis. Students stated positive opinions related to PBL sessions and problem-based scenario in general. The study proposes that the scope of the applied scenario could be further expanded by increasing content of the topic related to activities associated with daily life.

Keywords: Analytical chemistry, Electrochemistry, Opinions, Problem-based learning

Öz

Araştırma, Analitik Kimya dersinde 'Elektrokimya' konusunda geliştirilen ve kullanılan probleme-dayalı öğrenme (PDÖ) oturumları ve senaryosuna ilişkin öğrenci görüşlerini belirlemeyi amaçlamıştır. Çalışma Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Ortaöğretim Fen ve Matematik Alanlar Kimya Eğitimi'nde okuyan dördüncü sınıf öğrencileriyle gerçekleştirilmiştir (N=15). Senaryo ve PDÖ eğitim oturumlarına ilişkin öğrenci görüşleri yapılandırılmış görüşme formu kullanılarak alınmıştır. Ek olarak, öğrencilerden söz konusu konuya ilişkin farklı bir senaryo ve öğretim materyali tasarlama önerileri de istenmiştir. 11 açık-uçlı sorudan oluşan yapılandırılmış görüşme formundan elde edilen veriler içerik analiziyle değerlendirilmiştir. Genel olarak öğrenciler PDÖ eğitim oturumları ve senaryoya ilişkin olumlu görüşler belirtmişlerdir. Çalışmada uygulanan senaryonun,günlük hayatla ilişkili etkinliklerle konu içeriğinin arttırılarak genişletilebileceği önerilmiştir.

Anahtar Kelimeler: Analitik kimya, Elektrokimya, Görüşler, Probleme-dayalı öğrenme

1. Introduction

PBL, which supports learning by using problems encountered in daily life, helps individuals find appropriate solutions for these problems using different methods. Information learned in an educational or training process can be made more meaningful and enduring when it is associated with daily life (Hung et al. 2008). Therefore, PBL is an instructional method which initiates students' learning by creating a need to solve an authentic problem and during PBL process students construct content knowledge, identify study priorities for the scenario, formulate learning objectives, do independent and self-directed study before returning to their groups to discuss, refine their acquired knowledge and identify areas for improvement while working toward a solution to the problems (Allen et al. 2011, Barrows 1996, Hung et al. 2008, Kilroy 2004, Strobel and Van Barneveld 2009, Wood 2003). PBL has been utilized for teaching in

*Corresponding author: tugcegunter85@gmail.com

Tuğçe Günter orcid.org/0000-0001-7416-2967
Sibel Kılınç Alpat orcid.org/0000-0001-7149-3779

domains like medicine, engineering, science and economics and especially it can be seen that PBL appropriate to the nature and teaching of science has been applied particularly in the field of chemistry education (Belt et al. 2002, Boud and Feletti 1997, Dods 1996, Dunlap 1997, Kitto and Griffiths 2001, Mackenzie et al. 2003, Ram 1999, Selco et al. 2003, Senocak et al. 2007, Tarhan et al. 2008, Tarhan and Sesen 2013, Tunc 2015, Ying 2003).

The purpose of chemistry education is to ensure that individuals are able to establish connections between topics in chemistry and daily life, query problems encountered and reach solutions using scientific methods (Tan and Temiz 2003). The Analytical Chemistry course within the undergraduate program of Chemistry is also important in helping students to gain these qualifications and skills, because it includes problem-solving stages such as analyzing a problem, identifying possible variables, doing an experiment, obtaining data, establishing relations with variables by analyzing experimental data, offering solutions and testing the quality of solutions (Say 2009). Electroanalytical methods are widely used in the analyses of environmental samples, the quality control of industrial products and various biomedical fields. The specific topic of electrochemistry, based on electroanalytical methods, is, however, known to be a topic that students have difficulties in understanding because it contains concrete concepts, intensive mathematical calculations and interpretations (Akram et al. 2014, Cullen and Pentecost 2011, Obomanu and Onuoha 2012, Rahayu et al. 2011, Rogers et al. 2000, Sanger and Greenbowe 1997). It has been considered that PBL, the basic philosophy of which is to allow students to gain problem-solving, research, inquiry and evaluation skills and to make them into active learners, will be appropriate for teaching Analytical Chemistry and that in this manner students will more easily understand the topic of electrochemistry (Tunc 2015). In addition, there are numerous studies concerning students' opinions upon PBL and case-based learning derived from this approach in the literature. In the study of Mandeville et al. (2017), they investigated that the effect of PBL concerning undergraduate Kinesiology course on the students' oral communication competencies. In the result of this research, they concluded that collaborative learning in PBL approach improved students' oral communication competencies. In the research of Cresswell and Loughlin (2017), they concluded that a case-based scenario with an interdisciplinary guided-inquiry experience in chemistry and biology courses enabled the undergraduate forensic science students to have positive opinions especially about group work and the students expressed that the developed and implemented scenario was more interesting. In their research, Eveillard et al. (2017) concluded that Master's students expressed positive opinions about that they participated actively in the group work and group work facilitated interpersonal communication in PBL approach concerning antibiotic exposure and bacterial resistance in human and veterinary medicine. In their research of Tarkın and Uzuntiryaki-Kondakcı (2017), they concluded that the secondary school students had positive opinions about that chemistry lessons were more interesting and enjoyable via case-based instruction concerning the topic of electrochemistry. In this research, some students also expressed negative opinions such as that the method was unfamiliar. In the study of Canturk-Gunhan and Baser (2009), they implemented PBL in the mathematics course and they investigated the opinions of primary education grade students concerning PBL. They concluded that students had positive opinions concerning that PBL enabled them to associate mathematics with daily life, to learn, to gain problem solving, communication, cooperative working, interpretation skills and to do research. In the research of Musal et al. (2003), they concluded that the undergraduate medical students and tutors had positive opinions about PBL's effectiveness such as gaining clinical reasoning, communication and problem solving skills.

Therefore, it is considered that as learning material is related to students' daily lives, the students can find the scenario more interesting and enjoyable during application process and participate actively in the course. In addition, this kind of the study could make a significant contribution to the chemistry education literature concerning electrochemistry topic in terms of developing scenarios and taking students' opinions about the developed scenario could provide an insight for creating and widening the scope of such a daily life scenario in the future studies. Within this context, developing a scenario associated with daily life while also concerning electrochemistry, and assessing students' opinions about this scenario and the PBL sessions given both have an importance. The aim of this study was thus to answer the question: 'What are the opinions of students concerning a PBL scenario developed and PBL sessions oriented towards the topic of electrochemistry within an Analytical Chemistry course in an undergraduate chemistry program?'. One sub-question was as follows: 'Do the students have any opinions relating to designing a different scenario or other materials for this topic?'.

2. Materials and Method

2.1. The Study Group

The study group consisted of students who were studying in the fourth year in the Department of Chemistry Education, Secondary Science and Mathematics Education, Faculty of Buca Education, Dokuz Eylul University (N=15). All of the students had similar backgrounds. They had attained similar scores on the exams conducted by student selection and placement center and were socioeconomically similar. The ages of the students were in the range of 18-21. A PBL scenario about 'electrochemistry' topic consisted of four education sessions in total and was prepared and implemented, taking into account the views of four analytical chemistry and pedagogical experts (Gunter and Kılınc Alpat 2017). The information concerning the developed scenario titled 'Wow, Emre, Wow!' are given in **Appendix 1.** This study was conducted in the fall semester of the 2015-2016 academic year. All students' opinions were taken after being informed about PBL scenario developed and its education sessions.

2.2. Data Collection Tools

2.2.1. Structured Interview Form

The students' opinions relating to the PBL sessions and scenario were gathered using a structured interview form consisting of 13 open-ended questions. Furthermore, two questions tried to determine how students would themselves design a scenario or different material concerning the relevant topic. Data was evaluated by content analysis. These open-ended questions were developed by taking opinions of four both pedagogical and chemistry experts.

2.3. Data Analysis

In the content analyses of the data collected by structured interviews, categories were formed and evaluations were made in accordance with these categories and then revised after six months by two researchers and the percentages of agreement of the categories were found. For the reliability of data, the coding consistency of these categories created separately by two researchers was examined. In the calculation of the agreement percentage $P= N_a.100/N_a+N_d$ formula (N_a= the amount of agreement; N_d=the amount of disagreement, P= the percentage of agreement) was used. For the responses given by the students in the structured interview, the average percentage of agreement was found to be 83.5%. For the validity of this data, same researchers reviewed the data, errors were minimized. In accordance with the data obtained, a percentage of agreement of 0.70 or higher agreement percentage indicates that reliability has been provided (Birkimer and Brown 1979, Cavanagh 1997, Sencan 2005, Tunc 2015).

3. Results and Discussion

3.1. Results Concerning Students' Opinions about the PBL Education Sessions

The content analysis of students' opinions concerning the questions "Do PBL sessions have any positive and negative aspects?" and "Are the sessions appropriate for the specific knowledge to be acquired?"is given in Table 1. Some students' comments about the sessions are also given in Table 2. As seen in Table 1 and Table 2, all students expressed positive opinions:

Table 1. Students' Opinions about Education Sessions of PBL

Positive Opinions	Frequency (f)	Percentage (%)
Main Theme 1: Education Session I	**29**	**26.61**
Sub-themes: Entirely Positive	14	48.28
Appropriate	15	51.72
Main Theme 2: Education Session II	**27**	**24.77**
Sub-themes: Entirely Positive	12	44.44
Appropriate	15	55.56
Main Theme 3: Education Session III	**28**	**25.69**
Sub-themes: Entirely Positive	14	50.00
Appropriate	14	50.00
Main Theme 4: Education Session IV	**25**	**22.94**
Sub-themes: Entirely Positive	12	48.00
Appropriate	13	52.00

Some students answered the questions "What do you think about how these sessions can be developed?" and "Could anything be added to or subtracted from them?" as follows (Table 3). In general, when the opinions of students are evaluated, it is seen that all students expressed positive opinions, such as the idea that all four education sessions were

Table 2. Students' Comments about the PBL sessions

The PBL Sessions	Students' Comments
Education Session I	*"Because we're doing research in chemistry and health we need to learn terms and preliminary information concerning both daily life and the course. I don't think that there was any negative aspect. The preliminary information was given well in the introductory part and I don't think anything was missing."* ***(S2)*** *"The diseases were found and information was obtained from which interpretations were to be made. It was positive."* ***(S11)***
Education Session II	*"In the second education session, Emre's disease became gradually clear and we investigated what the reasons for it could be (how the matches had an effect). As a result, it was positive and it was appropriate to the acquisition of knowledge it was targeting."* ***(S3)*** *"According to the results of analyses, the problem was determined and the process of treatment was begun. From this standpoint it was positive. It is suitable for what needed to be understood. This was poisoning as a result of the reaction of the ion of iron in the haemoglobin with the potassium chlorate in the matchstick."* ***(S10)***
Education Session III	*"We were introduced to the redox reactions as we investigated methemoglobinemia, and the ion of* Fe^{2+} *in the structure of haemoglobin in the blood was oxidized to the ion of* Fe^{3+}*. The results were obtained by the occurrence of* $\Delta G < 0$ *(Gibbs free energy) in the body. I think it was very appropriate."* ***(S7)*** *"The positive aspect was that this session involved many chemistry topics, it was made more understandable due to the interest of the students."* ***(S15)***
Education Session IV	*"In the fourth education session, we looked at and schematized the entire structure of the course. We consolidated what we did. We saw that the usage of the material was appropriate to the topic of electrochemistry"* ***(S6)*** *"Making a flow chart together with the general review was very good in terms of both repetition and comprehension."* ***(S14)***

Table 3. Examples of Students' Suggestions for PBL Education Sessions

The PBL Sessions	Students' Suggestions for Sessions
Education Session I	*"More detailed and confusing situations relating to his disease could have been written. In accordance with this request and the topic, it could be added to."* ***(S4)*** *"The number of applications for the analyses could be increased."* *(S12)*
Education Session II	*"People who had previously had the same disease could have been shown in a small visual or short film"* ***(S7)*** *"Maybe, if another disease was also discussed in the occurrence of redox reactions, this could be reinforced by a second or third example of redox reactions."* *(S15)*
Education Session III	*"In addition, the sessions could be supported by visual aids or a short animation"****(S8)*** *"More experiments could be done in order to ascertain the substances found in the structure of matches."* *(S11)*
Education Session IV	*"In the last education session, nothing could be improved"****(S1)*** *"The redox reactions could have been different."* *(S15)*

appropriate. Students made suggestions such as including a greater number of diseases, having an increased number of applications of analyses, involving more research and experiments about the content of matches, having different redox reactions in the scenario, that a different substance as well as potassium chlorate could have been present as a result of poisoning and that the students would therefore have the opportunity to choose between two substances, and that the scenario be supported by visual aids or a short film:

3.2. Results Concerning Students' Opinions about the Scenario

The results of the content analysis of the open-ended questions about the scenario are given below (Table 4):

Table 4. Positive and Negative Opinions about the Scenario

Positive Opinions	f	%	Negative Opinions	f	%
Main Theme 5: Name of the Scenario	**18**	**81.82**	**Main Theme 5:** Name of the Scenario	**4**	**18.18**
Sub-themes:			**Sub-themes:**		
Very interesting	11	61.11	Not very interesting	3	75.00
Appropriate for the topic	7	38.89	Not appropriate	1	25.00
Main Theme 6: Memorability	**52**	**98.11**	**Main Theme 6:** Memorability	**1**	**1.89**
Sub-themes:			**Sub-themes:**		
Redox reactions	9	17.31	Not remember the solutions of any problems	1	100.0
Cathode/Anode	7	13.46			
Oxidation/Reduction	5	9.62			
Reaction of potassium chlorate with the ion of iron (+2), Oxidation of iron (+2) to iron (+3)	4	7.69			
In the event of, $\Delta G < 0$; the reaction occurs spontaneously	4	7.69			
Salt bridge	3	5.77			
Redox titrations	3	5.77			
$Kd\,(\Delta G = -RT \ln Kd)$, Values of K_d- K_{sp}	3	5.77			
Establishing a connection with electrochemistry on the basis of the effect of matches on the metabolism, Poisoning of Emre from potassium chlorate as a result of eating matches	3	5.77			
Nernst equation	3	5.77			
ΔG Gibbs free energy	2	3.85			
Electrode potentials	2	3.85			
Occurrence of various complications resulted in the changes of pH in the body	2	3.85			
Acidosis and hyperkalemia	1	1.92			
Standard electrode potential	1	1.92			
Main Theme 7: Suitability of the Scenario to the Topic of Electrochemistry	**29**	**96.67**	**Main Theme 7:** Suitability of the Scenario to the Topic of Electrochemistry	**1**	**3.33**
Sub-themes:			**Sub-themes:**		
Suitable for purpose and the topic	14	48.28	Not appropriate	1	100.0
Challenging/Intriguing	6	20.69			
Associated with daily life	3	10.35			
Leading to research	2	6.90			
Comprehensible and educational	2	6.90			

Table 4. Cont.

Positive Opinions	f	%	Negative Opinions	f	%
Memorable	2	6.90			
Main Theme 8: Quality of the Scenario	**27**	**96.43**	**Main Theme 8:** Quality of the Scenario	**1**	**3.57**
Sub-themes:			**Sub-themes:**		
Associated with daily life	14	51.85	Not associated with daily life	1	100.0
Challenging/Intriguing	12	44.44			
Increasing desire for research	1	3.70			
Main Theme 9: Preparation of the Scenario	**15**	**88.24**	**Main Theme 9:** Insufficient preparation of the Scenario	**2**	**11.77**
Sub-themes:			**Sub-themes:**		
Adequate	15	100.0	Duration	1	50.00
			Content	1	50.00
Main Theme 10: Advantages of the Scenario	**31**	**91.18**	**Main Theme 10:** Disadvantages of the Scenario	**3**	**8.82**
Sub-themes:			**Sub-themes:**		
Very advantageous	10	32.26	Duration	2	66.67
Challenging/Intriguing	7	22.58	Concern	1	33.33
Associated with daily life	6	19.36			
Memorable	4	12.90			
Increasing desire for research	2	6.45			
Comprehensible and educational	2	6.45			
Main Theme 11: Parts of the Scenario Students Had Difficulty Understanding	**10**	**62.50**	**Main Theme 11:** Parts of the Scenario Students Had Difficulty Understanding	**6**	**37.50**
Sub-themes:			**Sub-themes:**		
None	10	100.0	Some terms	2	33.33
			Mathematical Calculations	1	16.67
			Names of diseases	1	16.67
			Requiring a different concern	1	16.67
			Unfamiliar method	1	16.67
Total (Positive Opinions)	**182**	**91.00**	**Total (Negative Opinions)**	**18**	**9.00**

As seen in Table 4, the majority of students expressed positive opinions about the scenario. The majority of students did not make any suggestions concerning the name of the scenario, while six students suggested that the scenario could alternatively be named *"What have you done, Emre?" (S1)*; *"What has happened to Emre?" (S2)*; *"The Kid Who Ate Matches" (S9)*; *"Unthinking Emre" (S13)*; *"Emre's Hospital Adventures" (S12)* and *"What Has Emre Done?" (S11)*. Furthermore, students were asked that they make suggestions regarding the question *"How do you think the scenario can be developed?"*. Most students considered that the scenario was already well enough developed, while only three students made suggestions as below:

"Disease can occur as a result of the influence of multiple substances, thus we could also investigate the oxidation and reduction of multiple substances" ***(S1)***

"Many abstract concepts have been well presented with scenarios like this and with visual aids. It could be improved with more visuals (i.e. pictures, a short film, a cartoon or animation)" ***(S7)***

"The child could also consume different substances besides matches." ***(S9)***

Some comments of students are given in Table 5. Evaluating the opinions of students in general, it can be determined that the name of the scenario was thought to be interesting and appropriate, the scenario was associated with daily life, it offered guidance for research, was comprehensible and ed-

ucational, was appropriate for the topic of electrochemistry, the stages of the scenario were well followed-through and had a fluid nature and the topic was memorable. The disadvantages of the scenario were said to be that it lasted too long, having difficulties in some mathematical calculations, students were unfamiliar with the method, the diversity of the scenario's concerns and difficulties with the names of diseases:

In the study of Akınoglu and Tandogan (2007), the PBL students expressed that the scenarios were enjoyable, they spent a very good time by both having fun and learning, they liked to add their own ideas and discuss within groups. In addition, in the research, it was pointed out that PBL also have some limitations concerning time-consuming, requiring rich material and research. In the study of Canturk-Gunhan and Baser (2009), the secondary school students expressed positive opinions about the developed scenarios should be interesting, appropriate to their grades, in association with their daily lives in PBL approach. In the research of Wright et al. (2014), they concluded that the majority of undergraduate students in pharmacy education expressed that PBL enhanced their ability to manage their own learning. In the research of Arı and Katrancı (2014), they investigated the opinions of student teachers in mathematics education concerning PBL application. The results showed that the majority of student teachers expressed that PBL and preparing comprehensive PBL scenarios were difficult and time-consuming but these problems could help to raise students as real problem solvers in their future lives and could attract their attention. In addition, the majority of students also expressed that they would use PBL. In the research of Baysal (2017), she implemented PBL in social studies education for pre-service elementary school teachers. The result of this research indicated that most of the students expressed positive opinions regarding PBL in terms of learning, democracy education and skills acquisition and one student had negative opinion such as that PBL was unproductive.

In addition, in this research, especially for the results of memorable parts of the topic of electrochemistry in the developed scenario, it was determined that the students' responses were more comprehensive and scientific. Some examples of their responses are as follows:

*"The redox reactions include the reactions of oxidation and reduction. In this scenario, the reaction of oxidation is the oxidation of the ion of iron (II) (Fe^{2+}) to the ion of iron (III) (Fe^{3+}). On the other words, the substance gives up an electron. In this situation, taking up an electron means reduction, whereas giving up an electron means oxidation. For instance, the ion of chlorate (ClO_3^-) reduced to the ion of chloride (Cl^-)." (**S1**)*

*"For instance, in the reaction of $Fe^{2+} + Ce^{4+} \rightleftharpoons Fe^{3+} + Ce^{3+}$; when the electron numbers of the ions of iron (II) (Fe^{2+}) and cerium (IV) (Ce^{4+}) are equal to each other, Nernst Equations of anode and cathode are written separately. And both of them means equivalence point electrode potentials. Both of them are accumulated and are divided to the electron number. When the electron numbers of the relevant ions in this reaction are not equal, equivalence point electrode potentials are also multiplied and accumulated and the resulted value again is divided to the electron number." (**S3**)*

*"We can find the equilibrium constant via the formula of $\Delta G = -RT\,In\,K_d$ or via Nernst Equation $E = E^0 - \frac{0.0592}{n}\log\frac{Products}{Reactants}$. At the equilibrium situation $E_{cathode} = E_{anode} = E_{cell} = 0$. Therefore, we can the equilibrium constant." (**S5**)*

*"ΔG is the Gibbs free energy. $\Delta G = -nFE_{cell}$ and $E = E^0 - \frac{0.0592}{n}\log Q$. In the event of $E_{cell} < 0$; the electrochemical cell's type is a galvanic cell. In the event of ; the electrochemical cell's type is a electrolyticcell. In the galvaniccell, the reaction occurs spontaneously, whereas in the electrolyticcell, the reaction does not occur spontaneously." (**S8**)*

3.3. Results Concerning Students' Opinions about the Scenario and Designing Material Appropriate to the Topic

The suggestions given by the students to the questions "How would you write a scenario appropriate to the topic of electrochemistry?" and "How would you design different materials appropriate to the topic of electrochemistry?" are indicated in Table 6. As seen in the comments, the students made very creative scientific suggestions for writing a scenario and designing material about the topic of electrochemistry. The students made suggestions for scenarios concerning health, chemical substances used in the plastics industry, the desire to eating soil in patients with iron deficiencies, the explosion of tankers carrying explosives in the sea, chemical fertilizers used on plants, involving finding different substances besides matches as the cause of substance intoxication, the death of an individual who took medications with coca-cola without drinking any water, connecting the severity of brain cancer with the oxidation state of iron, fires in mines, air pollution, the field of health, and positive and negative polarities. They also suggested demonstrating the association of these events with daily life by carrying out

Table 5. Comments of Students about the Scenario's Name, Memorable Parts, Suitability, Quality, Stages, Advantages/Disadvantages and Parts Students had Difficulty Understanding

The Scenario	Comments of Students
Name of the Scenario	*"Ending the adventure – which began with the naughtiness of a small child – in the hospital and making the connection with the topic of electrochemistry made it of suitable quality."* ***(S3)*** *"I wondered why Emre had got poisoned. After this, though, in accordance with blood tests, the reason came to light."* ***(S15)*** *"Because the material mentioned health problems, it came over to me as a little bit simple."* ***(S12) (Negative)***
Memorable Parts of the Topic of Electrochemistry	*"I remember the concepts of oxidation and reduction, redox reactions, ΔG Gibbs free energy, the redox titrations, K_d ($\Delta G = -RT\ In\ K_d$), electrode potential and standard electrode potential."* ***(S1)*** *"The poisoning of Emre after he ate a match occurred because of potassium chlorate and the development of various complications as a result of pH changes occurring in the body. The oxidation of the ion of Fe^{2+} to the ion of Fe^{3+}, the occurrence of the reaction spontaneously when Gibbs free energy is $\Delta G < 0$, the values of K_d and K_{sp}, and redox titrations stayed in my mind."* ***(S14)*** *"I remember the concepts of salt bridge, anode and cathode, the oxidation and reduction, redox reactions. But I cannot remember the solutions to the problems."* ***(S8) (Negative)***
Suitability of the Scenario to the Topic of Electrochemistry	*"The equilibrium in the body showed the presence of electrochemistry."* ***(S6)*** *"We have seen that the electrochemistry contributed to a health problem and what problem resulted in."* ***(S10)*** *"It is not appropriate."* ***(S13) (Negative)***
Quality of the Scenario	*"It was very compatible with analyses and tests which we all have performed in our daily lives."* ***(S7)*** *"It has managed to draw our attention with an example from daily life."* ***(S13)*** *"The usage of matches may be lower because matches have today been replaced by lighters."* ***(S9) (Negative)***
Stages of the Scenario	*"They were sufficient and there weren't any negative aspects. The best aspect was that they were intriguing and encouraged us to do research."* ***(S4)*** *"I think the stages given in the material were sufficient. There weren't any inadequate parts. I think it was also good that the kid didn't die."* ***(S9)*** *"It would be better if the teaching period for this scenario was extended over three to four weeks"* ***(S5) (Negative)***
Advantages and Disadvantages of the Scenario	*"It showed that we can deal with the problems in an example from daily life. It provided information to be remembered."* ***(S6)*** *"It has shown that we can overcome problems as we investigate and consider what problems will be encountered. The advantage of this material is that it contributes to our comprehension and understanding of the topic. Redox reactions – an ordinary chemistry topic– were introduced in a different way and this drew our attention."* ***(S10)*** *"Taking a long time was a disadvantage."* ***(S3) (Negative)*** *"If the material doesn't appeal to everyone's interests it can be disadvantageous."* ***(S15) (Negative)***
Parts Students Had Difficulty Understanding	*"No, there weren't any. Everything went very fluently and was comprehensible."* ***(S1)*** *"There weren't any. It was easier to understand the topic with this material."* ***(S11)*** *"I had difficulty with some mathematical calculations in electrochemistry."* ***(S8) (Negative)*** *"I had difficulty only with the names of diseases."* ***(S14) (Negative)***

Table 6. Suggestions of Students about the Scenario and Designing Material

Suggestions of Students about the Scenario	Suggestions of Students about Designing Material
"I would use a scenario like this: 'A man's car broke down when he was alone in a non-residential area. His phone's battery had run out and he couldn't get online. The battery of his car was dead. How can he start the car?'" ***(S1)***	*"The material we would use would be a battery. Batteries are good examples for the salt bridge, and electrodes in electrochemistry. I would ask students to try to make a battery with the substances (i.e. mercury, distilled water) they had"* ***(S1)***
	"I could prepare a model on the operating principles of batteries. I could present how this model works, what principles it is based on and its technical data. After that, if I had an opportunity, I would try to arrange a trip in order to show the functions of a power station." ***(S2)***
"I considered a scenario about intoxication from plants as a result of a redox reaction of a herbal medicine used by a farmer in consequence of analyses of tissue, leaf and soil samples in order to investigate anomalies in the life of a farmer" ***(S3)***	*"I would pay attention to the social standing and appeal to the interests if I prepared materials about electrochemistry"* ***(S3)***
	"It would be enough for materials to be comprehensible, clear, and fluent, and to be interesting, not to boring." ***(S4)***
"I would use scenarios about health because electrochemistry is based on the redox reactions." ***(S5)***	*"Using visual materials, more effective and permanent results could be achieved."* ***(S5)***
"I could imagine a scenario concerning a desire to eat soil in patients with iron deficiencies." ***(S6)***	*"I would design materials about investigating diseases resulting from iron deficiency in the blood"* ***(S6)***
"The scenario is about a tanker at the sea carrying toxic explosives when a redox reaction occurs with the ions of cyanide, potassium, nitrate and there is an explosion. I would use a scenario in which the officer in charge of reports to the coast guard with a Mayday message and the actions of the ships' personnel cause the deaths of people." ***(S7)***	*"I would make cartoon characters speak to each other in an animated cartoon. I could prepare materials and slides about electrochemistry with Bambi, Winnie The Pooh, Popeye The Sailor, and Looney Tunes characters. I could also ask for my students to prepare a summary of the topic and small illustrations."* ***(S7)***
"I could imagine a scenario about the redox reactions if all the substances involved in making plastics in industry were to explode." ***(S8)***	*"I would make a documentary film."* ***(S8)***
"I remember that there is scientific research about the relation between brain cancer and the oxidation state of iron ions and I would write a scenario about this issue." ***(S9)***	*"I would design computer-assisted material. I would design a game called "Chemistry Man" in order to help students understand the topic. It would be necessary for students to know the topic of electrochemistry fully in order to pass through the fifth level of the game."* ***(S9)***
"A scenario could be established about what happens to a person taken medication with coca-cola without drinking water. The cause of death could be found by investigating the relation between substances in the coca-cola and the chemicals in the medication." ***(S10)***	*"A salt bridge could be carried out to illustrate electrochemistry and this could be explained in the classroom visually"* ***(S10)***
"I would write a scenario about a child who didn't know positive and negative poles when he/she tried to make a circuit with a bulb by using a remote control battery." ***(S11)***	*"I would design a salt bridge by using metallic plates."* ***(S11)***

Table 6. Cont.

Suggestions of Students about the Scenario	Suggestions of Students about Designing Material
"I would want to look at the issue of air pollution by various gases." ***(S12)***	*"I would want to prepare material about the nature which could be developed and I would link biochemistry with the living natural environment."* ***(S12)***
"I would consider a scenario about fires breaking out in mines." ***(S13)***	*"I would design material for longer-lasting phone batteries."* ***(S13)***
"By giving values of different analyses about poisoning from matches and something else, we would have to choose from two or more things." ***(S14)***	*"If I were you, I would do it as a brainstorming. I think that I could give you a scenario about this topic and ask for the opinions of students and thus different ideas and conclusions will come out. I think that they would all think very hard and help each other."* ***(S14)***
"The essence of the material is that the students are wondering what is wrong with Emre and in the light of the results of analyses see that redox reactions occur. The aim is for students to learn about this situation. I could present some examples similar to Emre in order to reinforce this. With the aim of teaching more redox reactions, I could differentiate the scenario in terms of the material." ***(S15)***	*"If I were you, I could choose an interesting topic in the same way, in order to gain the attention of students. Maybe I would create a character whose car battery wasn't working and investigate the reason for this. Or I would use examples where redox reactions frequently occur in daily life. But I think this is a very good scenario and the scenario is interesting in terms of what illness Emre has."* ***(S15)***

tours and using models. In addition, they made suggestions for designing materials for the topic of electrochemistry so that the material could include visual, computer-supported and documentary information. They suggested investigating diseases which may cause iron deficiency in the blood, producing animated films, producing a battery and making a model showing the working principles of batteries, making a model of a longer-lasting phone battery, a model of the salt bridge with metallic plates and using materials from the natural environment. However, two students also indicated that the material provided was understandable, clear, and interestingly designed:

4. Conclusion

In this study, the aim was to gather students' opinions about the PBL scenario and the sessions of PBL given in order to teach electrochemistry. The results showed that the students had positive opinions concerning both the scenario and the sessions of PBL. They thought they were interesting, memorable, associated with daily life, comprehensible and educational, and that they led to further research. Besides the positive opinions, it was determined that some also had some negative opinions such as having different concerns, difficulties in terms of the names of diseases, and that the method was unfamiliar. These findings are supported by the studies in the literature (Akpınar and Ergin 2005, Ince Aka 2012, Kurt and Ayas, 2012, Lopes et al. 2011, Nazri et al. 2012, Schaber et al. 2011, Tarhan and Sesen 2013, Tatar 2007, Tosun 2010, Tosun and Taskesenligil 2013, Yadav et al. 2014). In the study of Belt et al. (2002), they concluded that the undergraduate students had positive opinions regarding developed scenarios in the analytical chemistry course. They stated that they enjoyed solving unfamiliar problems, working with others, thinking logically and critically, communicating their own ideas and linking between theory and practice. In the research of Flynn and Biggs (2012), the undergraduate students stated that PBL took more time and had work load. They also stated that they learnt more using PBL method in the synthetic organic and medicinal chemistry laboratory course.

5. Implications

According to this research and the experiences acquired during its delivery, it can be said that this scenario, prepared for PBL of 'electrochemistry' in the Analytical Chemistry course can be effective. The usage fields of glass membrane pH-electrode, pCO_2-electrode and pO_2-electrode and especially their usages in the analyses of blood gases could be added to the scenario (Severinghaus and Astrup 1985). The substance Luminol, used in the forensic analysis of blood, glows with a bluish color in a basic medium including an oxidizing agent such as hydrogen peroxide

and is a catalyst and highlights the traces of blood which is not otherwise seen. The ions of Fe (+2) included in the structure of haemoglobin in the blood catalyse the oxidation of Luminol to aminophthalate as a result of the reaction of Luminol with hydrogen peroxide (Semerci 2014). In the scope of the scenario, additions could be made to cover this kind of reaction. The visual aspect could be increased by the addition of cartoons and pictures to the scenario. Computer-supported PBL applications could also be considered in terms of increasing visuality. As well as drawing these implications from students' suggestions, be new scenarios could be made, which would, for example, emphasize the links between the natural environment and biochemistry, make connections with explosive materials, looking at further health issues such as the connections between iron deficiency and soil-eating behavior, and looking at environmental pollution.

6. Acknowledgements

The authors wish to thank Assoc. Prof. Dr. Gülten Şendur and Assist. Prof. Dr. A. Murat Ellez for supporting this research.

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Appendices

Appendix 1. The Developed Scenario Titled 'Wow, Emre, Wow!'

The topic of the scenario was prepared on the grounds that a five-year old boy called Emre poisoned himself by eating matches secretly and was taken to the emergency service of a hospital with the symptoms of vomiting, diarrhea, respiratory distress and bruising. The developed scenario consisted of four education sessions and the first, second and third education sessions included four sections and the last education session included one section. The main theme of this scenario was based on considering the fact that the students found out that the matches contained a high concentration of potassium chlorate and the ion of chlorate () converted the (+2)-loaded iron atom in the structure of haemoglobin to the (+3)-loaded iron atom on the basis of the Emre's diseases of methemoglobinemia, hyperkalemia, cyanosis and acidosis and they reached to the related redox reaction of the ion of chlorate () and the ion of (+2)-loaded iron and measured the electrode potential and the Gibbs Free Energy of this reaction (Gunter and Kılınc Alpat, 2017).

In Education Session I; the students were given the results of the analyses of blood biochemistry, blood gas and urinalysis, electrocardiography and ultrasonography of Emre. They did research about the changes of the normal values and tried to determine what Emre's disease was. In Education Session II; doctor found out that methemoglobinemia, hyperkalemia, cyanosis and acidosis were taking place in Emre and started the appropriate treatment and also in this session it came to light that Emre poisoned by matches. The students gained information concerning these diseases and the substances included in matches after their researches, discussions and brainstorming. In Education Session III; students learned about the redox reaction of the ion of iron (II) and the ion of chlorate () and in the last education session they also learned about the extra treatment methods such as conventional hemodialyses and hyperbaric oxygen (Gunter and Kılınc Alpat, 2017). In addition, there are two activities in the scenario for the students to calculate the electrode potential of an electrochemical cell and to calculate the electrode potential of a redox reaction based on the solubility product constant. In the first activity, as a result of an explosion occurring in an automotive plant, a high concentration of hydroxylamine was mixed into the city's water supply and a high concentration of iron (II) ion was formed. Therefore, the purpose of this activity was that the students determined the related redox reactions and calculations of the electrode potential of these reactions. In the second activity, a high concentration of lead was found in the samples of mussels taken from Sinop and from the point where the waste materials from the Hopa Copper Enterprises in the Eastern Black Sea. Therefore, the purpose of this activity was that the students calculated the electrode potential of the solid lead iodide which has occurred in the sea (Gunter and Kılınc Alpat, 2017). In Education Session IV, the students learned some information concerning Emre's final condition and created a flowchart of the scenario for the general review. In this last education session, they discussed again the relevant topic in general (Gunter and Kılınc Alpat, 2017).