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PROBLEM BASED LEARNING IN ACIDS AND BASES: LEARNING ACHIEVEMENTS AND STUDENTS' BELIEFS

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Abstract. *This study aimed to investigate the effects of Problem Based Learning on high school students' understanding of ionization of water and acid and base strength. Students' beliefs about Problem Based Learning were also analysed. A quasi-experimental design was conducted in this study. While students in the experimental groups were instructed via Problem Based Learning, teacher-centred approach was used in the control groups. Before the instructions, a prerequisite knowledge test was applied to identify their prerequisite knowledge to learn the topics, and no significantly differences were found between experimental and control groups. After the instructions, a post-test was applied to determine their understanding of the topics. The results indicated that the mean scores of the students in the experimental groups were significantly higher than those in the control groups. Problem Based Learning Assessment Scale results reflected that students' positive beliefs increased after each activity. Based on these results, it can be concluded that PBL instruction is effective in concept learning in chemistry education.*

Key words: *acids and bases, acid and base strength, ionization of water, problem based learning.*

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Introduction

Problem Based Learning (PBL) is an active learning approach, which had been developed in medical education in the late 1960s to address the practical concern that the traditional approach was inadequate in preparing students to solve complex problems and transfer classroom learning to real world situations (Barrows 2000). Woods (1985) describes PBL as a learning environment in which a problem drives the learning. That is, before students learn some knowledge, a problem is given, and thereafter students discover that they need to learn some new knowledge about the topic at hand in order to solve the problem. As mentioned by Barrows (1986), PBL has the following main characteristics:

- Learning is student-centred as students assume a major responsibility for their own learning;
- Learning occurs in small groups;
- Teachers are facilitators or guides;
- Problems form the organizing focus and stimulus for learning;
- Problems, similar to those one would face in future professions are a vehicle for the development of problem-solving skills;
- New information is acquired through self-directed learning.

PBL provides a meaningful and concrete way to apply the essential principles of the constructivist theory, which states that learning is essentially an act of active knowledge construction on the part of a learner and so PBL can lead to the development of higher order thinking skills, encourages students to elaborate on what they already know, and to integrate their prior knowledge with new ones while they are working in collaborative groups to solve the problem (Hoffman & Ritchie 1997; Savery & Duffy 1995; Yuen Lie Lim 2011). Students, under the guidance of the teacher, discuss the problem, activate their prior knowledge, research and share newly discovered information to construct their knowledge during PBL process (Schmidt, Dauphinee & Patel 1987; Schmidt & Moust 2000; Ronis 2001).

Studies on PBL in medical education have shown that PBL helps students apply and integrate knowledge more effectively, and increases their motivations and attitudes toward learning (Albanese & Mitchell 1993; Norman & Schmidt 1992). Because of those benefits of PBL, researchers have begun to interest in using PBL in the other disciplines including high school education (Gallagher 1997).

PBL has recently been applied in science and especially in chemistry education (Dods 1996; Ram 1999; Mackenzie, Johnstone & Brown 2003; Yuzhi 2003; Kitto & Griffiths 2001). Larive (2004) indicated that PBL is an instructional approach that addresses many of the limitations of traditional methods by teaching important concepts in the context of solving real analytical chemistry problems. In another study, Yuzhi (2003) aimed to teach chemical analysis and instrumental analysis in analytical chemistry through PBL. The results indicated that students in the PBL groups were much more successful in the use of laboratory equipment, producing solutions to the problems, self-efficacy and theory production. It was also asserted that the students developed positive attitudes towards chemistry when they were taught through PBL. In addition, Ram (1999) and Ying (2003) conducted PBL in analytical chemistry. The results they obtained indicated PBL prepares students in tackling everyday life problems and engages them in learning information. In the other study, Senocak et al. (2007) compared the achievement of prospective primary science teachers in a problem-based curriculum with those in a conventional curriculum. Their results indicated that PBL is effective on students' learning about gases, and on increasing positive attitudes towards chemistry, on development self-directed learning, cooperative learning and critical thinking. In a study by Groh (2001), it was found that PBL in a general chemistry course is effective on students' understanding of the principles of solutions and their properties. At high school chemistry level, Tarhan & Acar (2007) investigated the effects of PBL on high school students' understanding of the factors that affect cell potential and the effect of PBL on students' social skills. Tarhan et al. (2008) also examined the effectiveness of PBL on 9th grade students' understanding of intermolecular forces. Both studies indicated that PBL is effective on students' learning achievement and helped to overcome alternative conceptions. The research on PBL indicated that it is an effective instructional approach for learning chemistry and in overcoming misconceptions (Belt et al. 2002; Boud & Felleti 1998; Senocak et. al. 2007; Tarhan et. al. 2008; Tarhan 2007). However, studies related to the implementation of PBL for learning acids and bases are limited. Delisle (1997), described PBL for teaching acids and bases on 11th and12th grades. In the study, an upset stomach was given students as a PBL problem, and it was aimed students learned neutralization reactions by associating indigestion and the use of antacid tablets. Karadeniz Bayrak and Bayram (2011) used problem-based learning in a web-environment, to examine its effects on primary school students' conceptual understanding of acids and bases. They prepared web based materials included animations on five problem situations concerning acids and bases. They found that use of unstructured daily life problem situations in a web environment improves students' conceptual understanding of acids and bases.

Purpose of Research

The purpose of this study was to investigate the impact of Problem Based Learning (PBL) activities on students' understanding of *ionization of water* and *acid and base strength.* Students' beliefs about PBL were also analyzed. In order to enhance this aim, the following research questions were investigated;

a) What is students' prerequisite knowledge to learn *ionization of water* and *acid and base strength?*
b) What is the effect of PBL on students' understanding of *ionization of water* and *acid and base strength?*
c) Do students' beliefs about PBL change during the learning process?

Methodology of Research

Participants of Research

This study was conducted with participation of 108 high school students in four classes in two schools in Izmir, Turkey. There were one experimental (n_{E-1}=21, n_{E-2}=32) and one control (n_{C-1}=24, n_{C-2}=31) groups in each high school, which were stratified randomly. While students in the experimental groups were taught through PBL, teacher centred with a lecture type format was used in the control groups. All the students in each group were similar in socioeconomic status with the majority of them coming from middle-class families. Instruction in the schools is strongly teacher centred with a lecture type format, and students passively participate in the learning process, only listen to teacher, write notes and use textbook as a learning material.

Procedure

This study was conducted based on a quasi-experimental design. The students in the experimental groups were taught the subjects of ionization of water and acid and base strength through PBL, whereas the students in the control groups were taught the same topics through regular teacher-centred instruction during four-week.

The PBL activities based on constructivism were developed in this study by considering students' alternative conceptions and learning difficulties reported into literature (such as; Banerjee 1991; Bradley & Mosimege 1998; Cros et al. 1986; Ross & Munby 1991; Sheppard 1997; Schmidt 1991). For the validity, the PBL activities were examined by four chemistry instructors and five high school chemistry teachers. After the corrections were made according to their comments, the PBL activities were piloted by participation of 23 high school students for the reliability, and the final versions were constructed.

Students in the experimental groups in both high schools were stratified according to their chemistry achievements in the first semester and their social abilities such as communication, using technology, and leadership, and then randomly assigned to their cooperative groups. Students' abilities were determined by using student information form which had been applied by Guidance and Psychological Counselling departments of the schools.

Before the instructions, an orientation was given to the students about PBL process, rules of working in cooperative groups, the objectives, the requirements roles, and the assessment strategies. The teacher acted as a facilitator to guide student learning through the learning cycle. According to this cycle, also known as the PBL tutorial process, the students were presented with a problem. They formulated and analyzed the problem by identifying the relevant facts from the problem. As students understood the problem better, they began to generate hypotheses about possible solutions. During the self-directed learning process in PBL, students researched the knowledge deficiencies and identified the concepts they need to learn more about in order to solve the problem, labelling these concepts as learning issues by considering the leading questions directed by the teachers. After each session accomplished in the classroom environment, students collected data and information from the library materials and resources on the internet and books. Students then shared what they have learned, reconsidered their hypotheses, and/or generated new hypotheses in light of their new knowledge. When completing the task, the students reflected on the abstract knowledge gained by oral presentation, and began to study on new PBL problem.

In this study, experimental group students studied on three PBL activities. The first PBL activity was related to *ionisation of water*. In this PBL activity, a problem about variations of ionization constant of pure water depends on temperature were presented to the students. On completion of this activity, it was aimed students to explain the reason of self-ionization of water, to write ionization equation and ionization constant of water, to explain the variations of water ionization constant depend on temperature by considering Le Chatelier Principle, and to comment the reason of having the equal concentration of H_3O^+ and OH^- in pure water at any temperature.

The second PBL activity was related to the *factors affecting strengths of acids and bases*. In the first part of this activity a problem about two conductivity experiments of 0.1M HCl and 0.1 M HF solutions at the same conditions were given to the students and they were asked to inquiry the reason of differences in the lighting bulb in HCl solution and in HF solution. During this activity students were required to discuss ionization of HCl and HF in H_2O by considering electron affinities and sizes of H, F, Cl and O atoms. On completion this PBL activity, it was aimed students to define strong and weak acids, to classify acids depend on their molecular structure, to write ionisation constant of weak acids, and to predict the strength of acids depend on their ionization constants. In the second part of the second PBL activity, a problem about conductivity of 0.1M NaOH and 0.1 M NH_3 solutions at the same conditions were given to the students and they were asked to inquiry the reason of differences in the lighting bulb in this two solutions. During this activity, students were asked to inquiry ionization of NaOH and NH_3 in H_2O by considering electron affinities of H, O, N and Na atoms. After completion the third PBL activity, it was aimed students would be able to define strong and weak bases, to classify bases depend on their molecular structure, to write ionisation constant of weak bases, to predict the strength of bases depend on their ionisation constants, and to explain the relations between K_a, K_b and K_w.

The third PBL activity was related to *identification of strengths of binary acids* which are molecular compounds in which hydrogen is combined with a second non-metallic element. In this PBL activity, pH values of HF, NH_3, HCl and H_2S solutions of the same concentration and at the same conditions were given as 2.1, 11.1, 1.1 and 4.1 respectively, and students were required to inquiry the reason of pH differences by considering molecular properties of acids and periodic trends. After completion this PBL activity, it was aimed students to explain the relations between acid strength and electronegativity and atom size depend on their variations in the periodic table, to comment the reason of changing the strengths of hydrogen halides depend on increasing of non-metals' electronegativities across to the right on the periodic table, and to comment the reason of changing the strengths of hydrogen halides depend on increasing of non-metal atomic size going down the periodic table. They learned the reason of acting NH_3 as base. Students were also inquired the acidic and basic properties of metal oxides.

Throughout the lessons in the control groups, teacher presented the same content and samples considering the same learning objectives. Teacher used lecturing method without engaging PBL activities in the control group. While teacher explained the topics, students listened to her and took notes. In addition, students solved some algorithmic problems individually in a giving time. Then volunteers solved the problems. Some of algorithmic problems were assigned as homework in order to ensure time equation in the experimental group.

Instruments

The Prerequisite Knowledge Test

The prerequisite knowledge test by 25 multiple-choice items was developed to identify students' prerequisite knowledge for learning *ionization constant of water* and *acid and base strength* by considering students' alternative conceptions reported in the literature (such as Ebenezer & Gaskell 1995; Griffiths & Preston 1992; Peterson, Treagust & Garnett 1989; Sanger 2000). The multiple-choice items consisted of one correct answer and four distracters which reflect students' alternative conceptions. The content of the test was validated by four experts in chemistry education and six high school chemistry teachers. The test was piloted with the sample of 148 high school grade students to determine the reliability. After the item analysis the reliability coefficient (KR-20) of the test was found to be 0.81. Since each correct answer was scored as 4, the maximum score students could get from this test is 100.

The Post-Test

The post-test consisting 25 multiple choice items with an open-ended part, where students are required to explain the reasons for their answers, was developed to identify students' understanding of ionization of water and acid and base strengths by considering students' alternative conceptions reported in the literature (such as Banerjee 1991; Bradley & Mosimege 1998; Cros et al. 1986; Ross &

Munby 1991; Sheppard 1997; Schmidt 1991). For the content validation, the items were examined by four experts in chemistry education and six high school chemistry teachers. The test was piloted with the sample of 196 high school students for the reliability. After the item analysis the reliability coefficient (KR-20) of the test was found to be 0.85.

The scoring scheme by Haidar and Abraham (1991) was adapted in this study. According to this scheme, firstly answers of the multiple-choice items were classified as correct (1 points), incorrect and no answers (0 points). The responses of the open-ended part of the test were categorized in four ways as described below: understanding, partial understanding, specific alternative conception, and no response.

Table 1. Scoring scheme of open-ended items in the post-test

Score	Description
Understanding (3 points)	The response reflects the learning objectives in a clear and detailed way. The student shows in-depth of understanding of the ideas related to the topic and understands important relationships.
Partial understanding (2 points)	The response is satisfactory, contains some details, is vague or not well developed, and includes some alternative conceptions or some inaccurate information. The response shows apparent gaps in the student's knowledge and understanding of the topic.
Specific alternative conception (1 point)	The response is poor, lacks clarity, and contains alternative conceptions, inaccurate or irrelevant information.
No response (0 points)	Answer area was left blank.

Each answers to the open-ended part was evaluated by researchers, two chemistry educators. Scores were discussed until an agreement was reached. The maximum score for the post-test, in which a student can achieve, is 100.

The PBL Assessment Scale

Students' beliefs about PBL activities were assessed by using 5-point Likert type PBL Assessment Scale with 27 statements developed by Tarhan (2008) in the extent of The Scientific and Technological Research Council of Turkey (TUBITAK) project. The items were developed by considering interviews with students who are experience in PBL and literature review (such as; Birgerard & Lindquist, 1998; Cooke & Moyle, 2002; Nowak, 2001). For the validity, the scale was reviewed by seven educators in the different universities, and then the scale was applied on 110 students for the reliability. The Cronbach's alpha reliability coefficient had found to be 0.85. The scale with 27 items was investigated in three dimensions as; (1) quality of the problem, (2) roles of students, (3) roles of instructor. The maximum score students could get from this scale is 135. The PBL Assessment Scale was applied on experiment group to investigate the changes of students' beliefs about PBL after each activity.

Data Analysis

The data obtained from the instruments were analyzed using the statistical program for social science (SPSS) in the study. A one-way between-groups analysis of variance (ANOVA) was conducted to explore whether there were any differences among groups in terms of prerequisite knowledge test, post-test and PBL Assessment Scale. The significant differences between groups were determined by using Scheffe test for the prerequisite and post tests. Bonferroni test was used to investigate the changes of students' beliefs about PBL.

Results and Discussion

The ANOVA results of the prerequisite knowledge test showed that the mean scores of experimental and control groups in the second high school were significantly higher than those in the first high school ($F_{(3-104)}$=14.23, $p<0.05$, Table 2). However, Scheffe test indicated that there were no significant differences between experimental and control groups in both schools (Table 3).

Table 2. ANOVA results of the prerequisite knowledge test.

Group	N	Means	Standard Deviation	F	p
Exp$_1$	21	40.14	3.69	14.23	0.00
Cont$_1$	24	41.92	3.59		
Exp$_2$	32	55.62	11.73		
Cont$_2$	31	53.03	15.00		
Total	108	48.82	12.36		

Table 3. Scheffe test results of the prerequisite knowledge test.

Group (I)	Group (II)	Mean Differences (I-II)	Standard Error	p
Exp-1	Cont-1	-1.77	3.15	0.957
	Exp-2	-15.48	2.96	0.000
	Cont-2	-12.89	2.98	0.001
Cont-1	Exp-1	1.77	3.15	0.957
	Exp-2	-13.71	2.85	0.000
	Cont-2	-11.12	2.87	0.003
Exp-2	Exp-1	15.48	2.96	0.000
	Cont-1	13.71	2.85	0.000
	Cont-2	2.59	2.66	0.813
Cont-2	Exp-1	12.89	2.98	0.001
	Cont-1	11.12	2.87	0.003
	Exp-2	-2.59	2.66	0.813

Based on the statistical analyses of the post-test, the mean scores of the students in the experimental groups were found as 78.81 and 80.72 and the mean scores of the students in the control groups were found as 45.58 and 46.97. The ANOVA results of the post-test indicated that there were significant differences between groups ($F_{(3-104)}$=165.32, $p<0.05$). For post-hoc comparisons Scheffe test was used and the results reflected that the mean scores for the experimental groups were significantly different from the control groups (Table 4).

Table 4. ANOVA results of the post-test.

Group	N	Mean	Standard Deviation	F	p
Exp_1	21	78.81	9.34	165.32	0.00
$Cont_1$	24	45.58	9.64		
Exp_2	32	80.72	5.73		
$Cont_2$	31	46.97	7.08		
Total	108	62.85	18.58		

Table 5. Scheffe test results of the post-test.

Grp (I)	Grp (II)	Mean Difference (I-II)	Standard Error	p
Exp1	Cont1	33.23*	2,34	0.00
	Exp2	-1.91	2,20	0.86
	Cont2	31.84*	2,22	0.00
Cont1	Exp1	-33.23*	2,34	0.00
	Exp2	-35.14*	2,12	0.00
	Cont2	-1.38	2,13	0.94
Exp2	Exp1	1.91	2,20	0.86
	Cont1	35.14*	2,12	0.00
	Cont2	33.75*	1,98	0.00
Cont2	Exp1	-31.84*	2,22	0.00
	Cont1	1.38	2,13	0.94
	Exp2	-33.75*	1,98	0.00

This significant differences between experimental and control groups indicated positive effects of PBL on learning achievement as mentioned in the other researches by Miller 2003; Tarhan et al 2008; Senocak et al. 2007. Students' responses to the post-test also showed that students in the experimental groups had significantly fewer alternative conceptions and understood the concepts more meaningfully than control groups. Totally fifteen alternative conceptions were determined in this study (Table 6). While five of these alternative conceptions were identified for the first time this study, the rests of them have been reported in the literature before (Bradley & Mosimege 1998; Demircioğlu, Ayas & Demircioğlu 2005; Ross & Munby 1991; Silverstein 2000).

It was found that generally control group students had alternative conceptions related to ionization of water and variations of water ionization constant depend on temperature, identification of acid strength in high percentages. Students' responses to the open ended part of the test underlined that students could not use their knowledge related to metals and non-metals, periodic properties as ionization energy, atomic radius, electron affinity, electronegativity, and chemical bonds in identifying acid and base strength. They only used their memorized knowledge that metals act as a base and non-metals act as an acid, and so they had difficulties in explaining the relation of basic properties of metal oxides and acidic properties of non-metal oxides with their molecular structures. Most of them could define concentrated and diluted solutions by comparing the amount of solute in a solution. However, it was found that they defined strong acids as concentrated acids and weak acids as diluted acids as reported in the literature (Demircioğlu, Ayas & Demircioğlu 2005). Those students did not deal with strength of acid with its molecular property and only took in account of concentration of H_3O^+ ion in acidic solution to determine whether it was strong or weak. The similar alternative conceptions had been reported before by Köseoğlu, Budak & Kavak (2002), Özmen, Ayas & Coştu (2002). The common alternative conceptions reported in the literature as "*while number of H increase in a molecule, its acidity increase*" and "*if the strength of an acid increases, the pH value increases*" were also determined in this study (Cakir, Uzuntiryaki & Geban 2002; Demircioğlu, Ayas & Demircioğlu 2005; Özmen, Ayas & Coştu 2003; Ross & Munby 1991; Sheppard 2006). Some of the students who had alternative conception as "*water ionisation constant does not change with temperature"* thought that auto ionization of water were not exothermic or endothermic. The others could not explain increasing of equilibrium constant for the auto ionization of water, which is an endothermic reaction, with increasing temperature. In parallel with this alternative conception, control group students had alternative conception as "*increasing of temperature does not affect* H_3O^+ *and* OH^- *ion concentration in the water. Because the pH of pure water is always 7.*" Students' written explanations underlined that they disregarded temperature effect and they thought that water ionization constant was always 1×10^{-14}, and concentrations H_3O^+ and OH^- ions were always equal to 1×10^{-7}. The obtained results underlined the positive effects of PBL on students' understandings as also mentioned in the other studies on PBL (Miller 2003; Rideout et al. 2002; Senocak et al. 2007; Tarhan et al. 2008).

Table 6. Percentages of students' alternative conceptions identified in the study.

Students' alternative conceptions	Exp-1	Cont-1	Exp-2	Cont-2
Basic property of a metal oxide reduces from top to bottom in a group in the periodic table.	0.00	12.50	0.00	9.68
A compound consists of oxygen and high electronegativity element has basic properties*.	0.00	8.33	0.00	9.68
Acidic property of an oxide increases from top to bottom in a group in the periodic table.	0.00	8.33	0.00	19.35
Water ionisation constant does not change with temperature.	0.00	29.17	3.13	19.35
Because water can ionize, it has ionic nature.	0.00	41.67	3.13	41.67
Increasing of temperature does not affect H3O+ and OH- ion concentration in the water. Because the pH of pure water is always 7.	0.00	33.34	0.00	37.10
Increasing of the strength of an acid raises its molar concentration *.	0.00	4.17	0.00	9.68
While a diluted solution of an acid is weak, its concentrated solution is strong.	4.76	25.00	6.25	22.58
Strong acids are always concentrated.	4.76	25.00	3.13	29.03
Concentrated acid is strong acid.	0.00	20.83	0.00	29.03
The pH values of strong acids are near to 7*	0.00	20.83	0.00	19.35
While number of H increase in a molecule, its acidity increase.	4.76	29.17	6.25	32.26
If the strength of an acid increase, the pH value increase.	0.00	16.67	0.00	9.68
The reason of increasing acid strength throughout a group is decreasing of electronegativity of atoms*.	0.00	16.67	0.00	25.81
The strength of an acid or base is related to its electronegativity or size*.	0.00	4.17	3.13	9.68

** Firstly identified alternative conceptions.*

To investigate the changes of students' beliefs about PBL, PBL Assessment Scale was applied after each activity. A one-way repeated measured ANOVA was conducted to compare scores on the PBL Assessment Scale. As seen in Table 7, students' mean scores significantly increased during the learning process in both experimental group ($F_{Exp\text{-}1(2\text{-}40)}=62.74$, $F_{Exp\text{-}2(2\text{-}62)}=91.86$, $p<0.05$). Bonferroni test results indicate that students' mean scores and so their positive beliefs increased significantly after each PBL session ($p<0.05$, Table 8 and 9).

Table 7. **ANOVA results on the PBL assessment scale.**

Group	N	Test No	Means ($\overline{X}$)	Standard Deviation (SD)	F	p
Exp-1	21	1	89.24	5.51	62.74	0.00
		2	97.09	7.06		
		3	102.76	5.40		
Exp-2	32	1	88.59	8.58	91.86	0.00
		2	95.91	6.15		
		3	102.34	5.48		

Table 8. **Bonferroni results of Exp-1 in the according to PBL assessment scale.**

Test No (I)	Test No (II)	Mean Differences (I-II)	Standard Error (SE)	p
1	2	-7.86	1.182	.000
	3	-13.52	1.350	.000
2	1	7.86	1.182	.000
	3	-5.67	1.092	.000
3	1	13.52	1.350	.000
	2	5.67	1.092	.000

Table 9. **Bonferroni results of Exp-2 according to PBL assessment scale .**

Test No (I)	Test No (II)	Mean Differences (I-II)	Standard Error (SE)	p
1	2	-7.31	.968	.000
	3	-13.75	1.237	.000
2	1	7.31	.968	.000
	3	-6.44	.790	.000
3	1	13.75	1.237	.000
	2	6.44	.790	.000

The results also indicated that after the PBL instructions, experimental groups' mean scores in the three sub-dimensions increased significantly as; (1) *The quality of a problem,* ($F_{Exp\text{-}1(2\text{-}40)}=13.29$, $F_{Exp\text{-}2\,(2\text{-}62)}=42.80$, $p<0.05$;), (2) *The role of a teacher*, ($F_{Exp\text{-}1(2\text{-}40)}=17.19$, $F_{Exp\text{-}2\,(2\text{-}62)}=25.40$, $p<0.05$; and (3) *The role of a student* ($F_{Exp\text{-}1(2\text{-}40)}=13.29$, $F_{Exp\text{-}2D(2\text{-}62)}=42.80$, $p<0.05$). The variation of experimental group students' mean scores for each item under the three sub-headings is given in Table 8.

Table 8. **The mean scores of experimental group students in the items under the sub-headings.**

		Means					
Sub-Dimensions	Items	1		2		3	
		Exp-1	Exp-2	Exp-1	Exp-2	Exp-1	Exp-2
The quality of a problem	1. Problem is understandable.	3.19	3.31	3.62	3.75	3.94	3.90
	2. Problem is related to my previous knowledge.	3.38	3.41	3.86	3.78	3.90	3.78
	3. Problem motivates me to learn.	3.57	3.47	3.67	3.81	3.76	3.75
	4. Leading questions in the problem are related to learning objectives.	3.48	3.25	3.86	3.59	3.86	4.00
	5. Problem steers me to determine the learning subjects.	3.48	3.47	3.67	3.56	3.86	3.84
	6. Problem encourages me to research.	3.43	3.37	3.48	3.44	3.90	3.78
	7. Problem is more effective than teacher to be successful.	2.38	2.25	3.19	2.94	3.48	3.22
The role of a teacher	8. To be successful, guidance of the teacher is more effective than the problem	2.19	2.50	2.52	2.72	3.10	3.06
	9. To be successful, both the guidance of the teacher and the problem affective.	2.81	2.84	3.14	3.03	3.19	3.18
	10. The teacher act only as a facilitator to enhance the solution of the problem during the PBL process.	3.91	3.84	4.00	3.94	3.91	4.16
	11. The teacher did not answer our questions directly.	3.84	3.90	4.06	4.08	4.19	4.10
	12. Teacher's questions helped us to understand the problem.	3.81	3.81	3.90	3.91	3.95	4.00
	13. The teacher encouraged us to associate our previous knowledge with the problem.	3.67	3.65	3.81	3.75	3.95	3.84
	14. The teacher steered us to use variously sources.	3.43	3.59	3.62	3.68	3.86	3.94
	15. The teacher helped all the students equally.	3.76	3.62	3.95	3.96	4.05	4.03
	16. The teacher encouraged all the students to be active participants during PBL process.	3.91	3.68	3.90	3.87	4.10	4.09
	17. If the guidance of teacher were not, we could not enhance the learning objectives.	1.95	2.03	2.57	2.50	2.90	3.06
The role of a student	18. I am satisfied to be evaluated with my performance during the lesson besides achievement test.	3.38	3.50	3.71	3.59	3.95	3.84
	19. My group mates actively participated to group studies	3.43	3.31	3.48	3.59	3.95	3.81
	20. My group mates performed their tasks.	3.43	3.47	3.71	3.69	3.95	3.91
	21. PBL increased our group solidarity.	3.43	3.16	3.67	3.56	3.86	3.91
	22. PBL improved our abilities to express own ideas.	3.33	3.28	3.67	3.59	3.81	3.84
	23. PBL improved our skills to research.	3.19	3.22	3.81	3.47	3.90	3.91
	24. Working in the PBL group developed our learning skills.	3.19	3.25	3.57	3.50	3.90	3.88
	25. Evaluation of my selves and my group mates helps our developments.	3.33	3.34	3.67	3.69	3.95	3.84
	26. I believe that working in PBL group increase our learning achievements.	3.14	3.13	3.57	3.69	3.90	3.91
	27. I believe that if my experience in PBL, my learning achievement will increase.	3.43	3.34	3.67	3.56	4.00	3.91

Students' answers to the first sub-dimension of the scale underlined that while 40% of the students in the experimental groups believed that -*problem is understandable,* and over 50% of them thought that -*problem steer them to determine the learning subjects* and *research*, this ratio were increased significantly to 70%. While 10% - 19% of the students thought that -*problem is the more affective factor to be successful in PBL than teacher,* these ratios increased significantly during the PBL process and reached to 52%. Students' answers to the second sub-dimension of the scale reflected the reason of this increases, and found that students thought that -*guidance of the teacher is more effective than problem* and -*both the guidance of the teacher and the problem are affective to be successful in PBL* decreased significantly. Students' answers to the third sub-dimension showed development of cooperative skills. While approximately 50% of the students believed that group mates; -*were active participant in the group studies* and -*performed their own tasks* after the first activity, this ratio significantly increased to 70%. It was also obtained that students believes about -*PBL helped to develop group solidarity, searching and learning skills, learning achievement* increased significantly from the first to last PBL activities. The results reflected the effects of PBL on students' social and group working skills as mentioned in the other researches (Albanase & Mitchell 1993; Delisle 1997; De Volder et al 1989; Tarhan & Acar 2007; Vernon & Blake 1993). Although the results showed that students' positive thoughts increased during the PBL process, it was found that students' adaptation to their and teacher's new roles was difficult. Therefore, there were some students who had negative thoughts about PBL process. It was found that they were accustomed to teacher-centred educational system, perceived the teacher as a source of knowledge, and required to be instructed by a teacher. They also thought PBL as a waste of time. In addition, some students underlined that they had difficulties in working in a group, and they had to study more because PBL increased their responsibility. These results draw attention to some minority of students was not ready for PBL.

Conclusions

The most important responsibility of education is to give individuals the abilities to learn reason, think creatively and critically, make decisions, solve problems, and function as part of a team (Felder 1996; Nakhleh 1992; Miller 2003). PBL, where these skills can be acquired, has been used for many years around the world, and educators are increasingly looking at the application of PBL in science education (Albanase & Mitchel 1993; Dods 1996; Groh 2001; Hughes 1993; Wenzel 1995; White 2001; Ram 1999). But there are limited studies on the application of PBL in high school-level chemistry curriculum. For this reason in this study, the effects of PBL on high school students' understanding of *ionization of water* and *acid and base strength* was investigated. Students' beliefs about PBL were also analyzed. This study confirmed that PBL as an active learning approach have positive effects on higher learning achievement, overcoming alternative conceptions, and development some social skills. Therefore, it is suggested that instructional methods promoting high level cognitive processing such as the PBL should be integrated into chemistry curriculum from middle to undergraduate level. The results support that if PBL is used in science classes more widely, it seems students could be achieve the skills that they need to be successful in their life. For this reason, besides some problems with PBL, its advantages should be considered for the success of education. Such studies should be continued and PBL activities should be developed and validated for using chemistry lessons as well as the other science fields. Thus, cognitive learning skills, social skills, critical thinking skills, and cooperative working skills can be developed.

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