

A Study on Teaching Gases to Prospective Primary Science Teachers Through Problem-Based Learning

Erdal Senocak · Yavuz Taskesenligil · Mustafa Sozibilir

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Abstract The aim of this study was to compare the achievement of prospective primary science teachers in a problem-based curriculum with those in a conventional primary science teacher preparation program with regard to success in learning about gases and developing positive attitudes towards chemistry. The subjects of the study were 101 first year undergraduate students, who were in two different classes and who were taught by the same lecturer. One of the classes was randomly selected as the intervention group in which problem-based learning (PBL) was used, and the other as the control in which conventional teaching methods were used. The data were obtained through use of the gases diagnostic test (GDT), the chemistry attitude scale (CAS), and scales specific to students' evaluation of PBL such as the peer evaluation scale (PES), self evaluation scale (SES), tutor's performance evaluation scale (TPES) and students' evaluation of PBL scale (SEPBLs). Data were analysed using SPSS 10.0 (Statistical Package for Social Sciences). In order to find out the effect of the intervention (PBL) on students' learning of gases, independent sample *t*-tests and ANCOVA (analysis of co-variance) were used. The results obtained from the study showed that there was a statistically significant difference between the experimental and control groups in terms of students' GDT total mean scores and, their attitude towards chemistry, as well as PBL has a significant effect on the development of students' skills such as self-directed learning, cooperative learning and critical thinking.

Key words problem-based learning · self-directed learning · conventional teaching · gases · attitudes · chemistry · science teacher education

E. Senocak
Faculty of Education, Department of Primary Science Education,
Gaziosmanpasa University, Tokat, Turkey
e-mail: esenocak@gop.edu.tr

Y. Taskesenligil · M. Sozibilir (✉)
Kazim Karabekir Education Faculty, Department of Secondary Science
and Mathematics Education, Atatürk University, 25240 Erzurum, Turkey
e-mail: sozibilir@atauni.edu.tr

Y. Taskesenligil
e-mail: ytaskes@atauni.edu.tr

Introduction

Education systems are changing their instructional approaches. Although educationalists use different terms, emphasise different elements and claim the uniqueness of their approach, the similarities of the approaches suggested are more impressive than their differences (Boud & Feletti, 1991). Frequently used terms include life-long learning, situated learning, authentic learning, open-discovery learning, collaborative learning and self-directed learning. These educational approaches propose a more constructivist view to teaching and learning, in which the emphasis shifts from the rather absolute knowledge offered by the teacher to the learner's active participation in the construction of knowledge. The common feature of these educational approaches is a shift from the teacher-centred approach towards an emerging student-centred and life-long learning approach where self-directed learning, the ability to apply knowledge and skills in more authentic problem oriented situations, and group and teamwork are essential components (Driessen & Van Der Vleuten, 2000).

Problem-based learning (PBL) is an instructional approach originally developed in medical school programs over 40 years ago (Barrows & Tamblyn, 1980), and later adapted for use in elementary and high schools (Delisle, 1997). In PBL, problems act as the stimulus and focus for student activity and learning (Boud & Feletti, 1991). Learning in this way is purposeful and self-motivating as the student learns while searching for solutions to the problems. Students are actively involved and learn in the context in which knowledge is to be used (Chin & Chia, 2004). PBL is also a learning approach that embodies most of the principles that improve learning, such as being active and cooperative learners, receiving prompt feedback, teaching which is tailored to students' learning preferences and promoting student empowerment and accountability. It aims to help students develop higher order thinking skills and a substantial disciplinary knowledge base by placing students in the active role of practitioners confronted with a situation (an ill-structured problem) that reflects the real world. Ill-structured problems are those where (a) the initial situation lacks all the information necessary to develop a solution, (b) there is no single right way to approach the task of the problem-solving, (c) as new information is gathered, the problem definition changes, and (d) students will never be completely sure that they have made an acceptable selection of solution options (Gallagher, Stepien, Sher, & Workman, 1995; Greenwald, 2000). Rather than focussing on facts, PBL encourages active learning and self-directed learning, is context-based using real life situations; focuses on thinking skills (problem-solving, decision making, and critical thinking), requires integration of interdisciplinary knowledge, skills or behaviours and develops lifelong learning skills (Yuzhi, 2003). Teachers in PBL, as meta-cognitive coaches, help students understand the questions to ask during problem definition, information location, analysis and synthesis, and helping students to sort through potential interpretations and/or resolutions (Gallagher et al., 1995).

PBL is an educational approach that has increasingly become spread across educational levels and areas of teaching, from medical education (Albanese & Mitchell, 1993; Barrows, 1986), nursing (Creedy, Horsfall, & Hand, 1992), pharmacy (Miller, 2003), law (Driessen & Van Der Vleuten, 2000), engineering and basic sciences (Polonco, Calderon, & Delgado, 2004), to science education (Gallagher et al., 1995; Peterson & Treagust, 1998; Soderberg & Price, 2003; West, 1992; Ying, 2003; Yuzhi, 2003).

Although PBL is an old and well established approach in medical and nursing education, its application in science education could be considered as quite new. In recent years,

studies emerged about the use of PBL in science teacher education. For example, there have been studies of PBL in science teacher training (Gallagher et al., 1995; Peterson & Treagust, 1998), teaching chemistry (Ram, 1999; West, 1992), biochemistry (Jaleel, Rahman, & Huda, 2001), analytical chemistry (Cancilla, 2001; Yuzhi, 2003), electrochemistry (Ying, 2003), and biology (Soderberg & Price, 2003).

One of the few studies of the application of PBL in chemistry teaching is by Yuzhi (2003). That study aimed to teach some analytical chemistry concepts such as chemical analysis and instrumental analysis through PBL. The students' performances were subject to the reports they prepared after the study and examinations at the end of the trial. It was found that students in the trial group were much more successful in the use of laboratory equipment, producing solutions to the problems, self-efficacy and theory production. However, while there was no statistically significant difference between the students' performance on the written examinations. In addition, Yuzhi argued that students developed positive attitudes towards chemistry when they were taught through PBL. Similar studies in analytical chemistry were conducted by Ram (1999) and Ying (2003). The results of these studies showed that PBL prepares students in tackling everyday life problems and engages students in learning information.

Peterson and Treagust (1998) carried out a PBL study that would enable pre-service teachers to develop both their knowledge base for primary science teaching, and the ability to make reasoned judgements about their teaching. The results of the study indicated that a PBL approach helped the students to develop their knowledge base for teaching and pedagogical reasoning ability, and also help participants to consider these two areas together when resolving a problem. As Peterson and Treagust pointed out, in a teacher education context, PBL could focus on the development of a knowledge base for teaching, which could be extended beyond the development of science content knowledge in a primary science situation, and allow for knowledge from a range of sources such as curriculum knowledge and knowledge of how students learn to be considered when working on the problem.

Researchers in science education showed an overwhelming interest in identifying and cataloguing students' misconceptions in a wide range of science concepts. Some of these concepts are gases and concepts related to gases such as temperature, pressure, kinetic molecular theory, diffusion (Barker, 1995; Benson, Wittrock, & Baur, 1993; Krnel, Watson, & Glazar, 1998; Novick & Nussbaum, 1978, 1981; Stavy, 1988). "Gas is a formal concept that has no visible attributes available to children" (Stavy, 1988, p. 553). It is a difficult idea for students to grasp that all matter is made of discrete particles. Frequently, students are not able to imagine the behaviour of the gas molecules in a container and a considerable proportion of the students think that gas molecules in a container are in a continuous phase. As prospective primary science teachers have access to a very limited number of gases in their everyday life and, therefore, their knowledge of gases, prior to instruction, was expected to be very poor (Stavy, 1988) and this view was supported by follow up researchers (Barker, 1995; Benson et al., 1993).

As an instructional approach, PBL has high potential in promoting inquiry in science classrooms (Boud & Feletti, 1991). However, the use of this approach is relatively new in schools and not much research has been done in the area of science education. There is no research reported in teaching concepts of gases through PBL. The purpose of this study was to compare the achievement of prospective primary science teachers exposed to a problem-based curriculum with those in a conventional primary science teacher preparation program

regarding learning concepts of gases. Their attitudes towards chemistry were also examined and compared. The specific research questions were:

1. Is there a statistically significant difference between students' performances when learning about concepts of gases through PBL compared to a conventional teaching approach?
2. Is there a statistically significant effect of PBL compared to a conventional teaching approach in terms of students' attitudes towards chemistry?

Materials and Method

Sample

The sample of the study was composed of total of 101 first year undergraduate students (from two parallel classes) enrolled in a General Chemistry-II course (4 hours per week and 14 weeks in a semester) at the Department of Primary Science Education of Atatürk University in Turkey in the second semester of the 2003–2004 academic year. The Primary Science Education Department has two classes at each level. There are 50 and 51 students in each class. All students in the class took part in the study. Before determining control and experimental groups, a gases diagnostic test (GDT) was applied as pre-test. An independent sample *t*-test was carried out and no statistically significant difference was found between the two classrooms ($t(99)=0.840$; $p>.05$). Classes were randomly assigned as experimental (Class 1) and control (Class 2) group.

Data Collection Instruments

Data were gathered through three types of tools. These were *gases diagnostic test*, *chemistry attitudes scale*, and *scales specific to students' evaluation of PBL*. These data collection tools are described below.

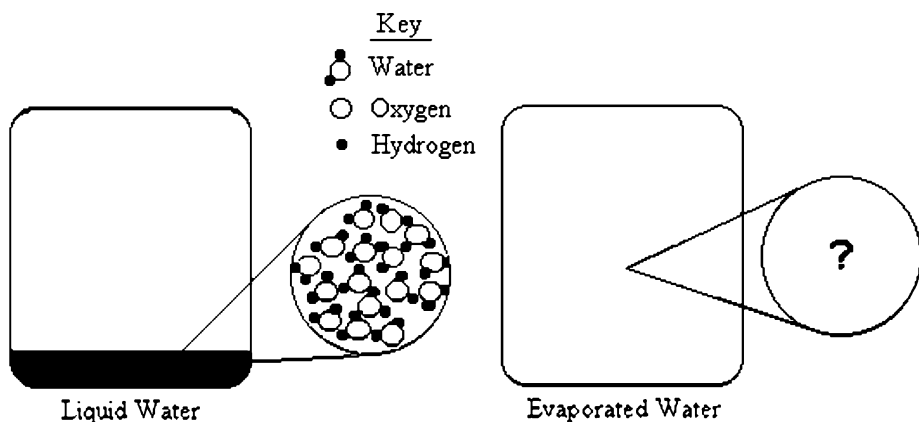
Gases Diagnostic Test (GDT) A diagnostic test composed of 22 multiple choice questions was developed in the light of the students' learning difficulties and misconceptions identified in the literature. The questions covered all aspects of gases including gas pressure, gas laws, ideal gas equation and its applications, gases in chemical reactions, gas mixtures, kinetic theory of gases and non-ideal (real) gases. The GDT was piloted with a group of students from the Department of Chemistry Education who took General Chemistry-II course and modifications were made in terms of language and design of the test. The validity of the test was ascertained by consulting two Chemistry professors in the Department of Secondary Science and Mathematics Education. With respect to reliability, GDT was administered to a group of 42 third year students from the Department of Primary Science Education who took General Chemistry-II course the year before. The Kuder–Richardson formula was used for determining the reliability of the GDT (reliability coefficient, .65). This level of reliability coefficient for an achievement test indicates that the test could be considered satisfactorily reliable (McMillan & Schumacher, 2001, p. 243). Two sample questions can be seen in Figure 1.

Chemistry Attitudes Scale (CAS) An attitude scale originally developed for Turkish chemistry students by Ertepinar and Geban (1996) was used in order to measure the

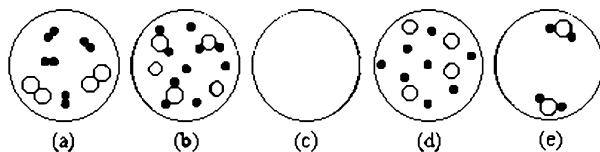
students' attitudes towards chemistry. CAS was composed of 15 Likert type items on a 5-point scale ranging from 1 (not satisfied) to 5 (very satisfied). The reliability of the CAS was found to be high ($\alpha=.83$) by Ertepinar and Geban. An individual could score a maximum of 75 and minimum of 15 from the CAS. CAS was administered pre- and post-intervention.

Scales specific to students' evaluation of PBL Three different scales were developed to determine the students' evaluation of PBL. These scales were the *peer evaluation scale (PES)*, in which students evaluated their groupmates' performances during the PBL application; *self evaluation scale (SES)*, in which students evaluated their performance during PBL sessions; *tutor's performance evaluation scale (TPES)*, in which students evaluated their tutor's performance during the PBL sessions; and *students' evaluation of PBL scale (SEPBLs)*, in which students evaluate the effectiveness of the PBL approach. All these scales included 7 to 10 Likert type items on a 3-point scale ranged from 1 (disagree), 2 (neutral) to 3 (agree), and also each scale had an open-ended part in order to give students

Question 22. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.



What would the magnified view show after the water evaporates?



Question 7. In which of the following cases does a constant amount of X gas get closest to an ideal gas at the given pressure and temperature?

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>
P(atm)	1	1	2	0,5	2
T(°C)	123	23	23	546	273

Figure 1 Two sample questions used in GDT Retrieved October 23, 2003, from http://jchemed.chem.wisc.edu/JCEDLib/QBank/collection/CQandChP/CQs/ConceptsInventory/Concepts_Inventory.html

a chance to write their opinions. Each of these scales was completed by the PBL groups at the end of the trial.

Problem Cases (Scenarios)

A crucial aspect of PBL is the actual design of the problem to be solved. Most basically, PBL should enhance and promote the goal of a course, not serve as a digression in curriculum and pedagogy. The problem should promote student knowledge and skills that have been clearly defined as intended course outcomes. In this study, 10 problem cases (scenarios) were developed covering different aspects of the gas phases of matter. Basically, two aspects were considered in designing problem cases. These were the educational purpose of the problem in terms of covering particularly gas phases of matter, and being a part of or close to real life situations and arousing students' attention. All problem cases were supported with a picture that illustrates the case, and also problems were designed with a degree of difficulty that ensured they could be solved in a four-week period of time. A sample problem case is shown in Figure 2.

Grouping and Stages of Implementation

Intervention involved a total of 16 lecture hours over four weeks (four lecture hours per week). The experimental and control group was taught by the same person, the first author. In the control group, conventional instruction approaches were used. The conventional

CONFUSION OF AN ENGINEER



A chemical engineer wanted to carry out an experiment. For this experiment he needed nitrogen gas which had 135 atm pressure and 92.4 kg weight. The engineer had a vessel with 1m^3 in which he could store the gas. But the engineer had 92.4 kg of nitrogen gas at 81 atm pressure at 300 K temperature. The engineer wonders how he could increase the pressure of gas to 135 atm without changing

the volume and the amount of gas. In order to solve this problem, he conducted some mathematical calculations assuming that nitrogen behaving as an ideal gas. He found that if he heats up the gas to 500 K, the pressure of gas will reach to 135 atm. Once he heated the gas up to 500 K, the pressure of gas reached to 140 atm instead of 135 atm. The engineer confused and started to think about what was the mistake he made. What do you think about this case? Why the pressure of the gas become 140 atm instead of 135 atm at 500 K? (Assume that the engineer did not make any mathematical calculation mistake.)

Figure 2 A sample problem case used in PBL

instruction approach was mainly dominated by lecturing, and included in-class discussions and problem solving. In the experimental group where PBL was administered, firstly students were informed about PBL and its processes. Then the students were grouped, five students in nine groups and six students in one group.

The students went through five consecutive stages in the experimental group during PBL the trial: (1) presenting the problem case to the groups, (2) identifications of the problem to be investigated by the students, (3) carrying out scientific inquiry, (4) putting the information together, and (5) presenting the findings.

In Stage 1, the students were given a problem case in class and told to carefully read it and were encouraged to write their ideas about the problem case. In Stage 2, the students identified learning issues related to the problem case and organised them around three focus questions (Gallagher et al., 1995) using a ‘need-to-know’ worksheet. The questions were as follows: (a) What do you know? (b) What do you need to know? (c) How can you find out what you need to know? The students recorded their ideas and questions onto this worksheet regularly as a group. In this way, the need-to-know worksheets served as “a central focus point for the unit and represented the continuing cycle of problem definition, information gathering, analysis and synthesis of information, and problem redefinition” (Gallagher et al., 1995, p. 141). In Stage 3, the students gathered data to answer their own questions. Some of the students used the science laboratory to carry out their investigations, some looked up information from print and electronic resources using both library research and the Internet, and others consulted expert professionals. In Stage 4, the students reported on what they had done, and prepared a report for the presentation to the classroom. In Stage 5, each group gave a 5–10 min oral presentation on what they had learned about their problem case. The students also submitted a group report which documented the group’s findings and details of the inquiry process. The lecturer evaluated the groups based on criteria related to both the process and the products of the project work, including the oral presentation. After the trial, the GDT was administered as post-test to both experimental and control groups.

Data Analysis

Data were analysed by using SPSS 10.0 (Statistical Package for Social Sciences). The significance level was set to .05. In order to find out the effect of the intervention (PBL) on students’ learning concepts of gases, both the independent sample *t*-test and ANCOVA (analysis of co-variance) were used. ANCOVA gives the pre-test as a true co-variant rather than a focus of interest in itself (Dugard & Todman, 1995). For the purpose of determining the effect of PBL on the students’ attitudes towards chemistry, an independent sample *t*-test was used.

Results

Comparisons of GDT Mean Scores

Descriptive statistics related to total mean scores of pre-test and post-test and corrected means for post-test after ANCOVA are presented in Table 1.

The experimental group post-test total mean scores (\bar{X} =17.02, SD=2.30) were higher than that of the control group (\bar{X} =15.98, SD=2.93) while their pre-test total mean scores were \bar{X} =14.45 (SD=2.59) and \bar{X} =13.89 (SD=2.75) respectively. Students performed better in the experimental group compared to the control group. An independent sample *t*-test result

Table 1 GDT Descriptive Statistics (Pre-Test and Post-Test).

Group	Number	Pre-test		Post-test		Corrected means of post-test after ANCOVA
		Mean	SD	Mean	SD	
Experimental (PBL)	51	14.45	2.59	17.02	2.30	16.92
Control (conventional)	50	13.89	2.75	15.98	2.93	15.83

also confirms that there is a statistically significant difference between students' total mean scores in the post-test ($t(99)=2.046$; $p<.05$), although there was no statistically significant difference between the pre-test total mean scores of experimental and control group ($t=0.840$; $p>.05$). ANCOVA (analysis of co-variance) results (see Table 2) also confirms the independent sample t -test result suggesting that there is a statistically significant difference between the corrected total mean scores of students in the experimental group (16.92) where PBL was trialed compared to the control group students (15.83) where a conventional teaching approach was used [$F(1, 101)=4.893$; $p<.05$; $\eta^2=0.68$]. These results provide an indicator of difference in student understanding of gases and related concepts. Regarding the Research Question 1, therefore, it could be said that there was a statistically significant difference in favour of PBL students over conventional teaching approach students. When it comes to the practical implication of the result, η^2 values given in Table 1 indicate that the results, have medium and large practical implications.

Comparison of Students' Attitudes Towards Chemistry

Students' attitudes towards chemistry were determined by the CAS. The total mean scores of CAS for pre-intervention were 47.40 and 46.54 for the experimental and control groups. An independent sample t -test indicates that there was no statistically difference between the students' attitudes towards chemistry before the intervention ($t(99)=0.929$; $p>.05$). After the intervention, the CAS was re-administered and the total mean scores were found as $\bar{X}=48.80$ (SD=3.65) and $\bar{X}=46.87$ (SD=4.08) for experimental and control groups respectively. An independent sample t -test suggested that there was a statistically significant difference between the total CAS mean scores after the intervention in favour of the

Table 2 Summary of ANCOVA Results.

Source	Df	Mean square	F	p	η^2
Corrected model	4	66.988	11.171	.000	.189
Intercept	1	415.757	69.334	.000	.419
Group (control–experimental)	1	29.339	4.893	.029*	.068
Pre-test	1	92.800	15.476	.000	.139
Error	97	5.996			
Total	101				
Corrected total	101				

$R^2 = .189$

Adjusted $R^2 = .172$

*Significant at .05 level

Table 3 Total Mean Scores of Scales Specific to Students' Self Evaluation of PBL ($n=51$).

PES (min 7–max 21)	SES (min 7–max 21)	TPES (min 10–max 30)	SEPBLs (min 10–max 30)
17.64	17.85	27.19	26.89

PES Peer evaluation scale; *SES* self evaluation scale; *TPES* tutor's performance evaluation scale; *SEPBLs* students' evaluation of PBL scale

experimental group where PBL was administered ($t(99)=2.556$; $p<.05$). This result provides an answer to Research Question 2: There was a statistically significant difference in positive attitudes towards chemistry in favour of PBL students compared to conventional students.

Students' Evaluation of PBL

Four different scales were developed in order to determine the experimental group students' evaluation of PBL (see Table 3). All scores are close to the maximum indicating that students were happy from the PBL approach and liked it.

Data gathered from the open-ended sections of each scale supported above interpretation indicating that students mostly were satisfied with the PBL approach. Responses indicated that this was the first time they had encountered such an approach and they were motivated to study as they realised that they could do something themselves. The PBL approach also helped students to realise that chemistry is a real part of the everyday life.

My research skills are improved. I look to the events happening around with a different view. For example, when I look to a hot air balloon, I start to think about how it works, how it flies?

Learning through PBL helped us to learn what to do when come across with a problem cases and how to find a solution to the problems in real life.

In addition, PBL helped students to learn working in groups. The quote below supports this view.

Working in groups helped us to get responsibility and learned how to work in groups. I have benefited from our group members. Discussions opportunities helped me to learn better.

Moreover, students stated their satisfaction with PBL that it was an approach that they were expecting at an undergraduate level. This could be seen from the following quote:

This way of learning is totally different from than what we have seen so far. I went to the classroom with enthusiasm. In fact, I have found what I was expecting from a university course which is more different than high school.

These quotes also indicate that the students had developed the necessary skills, such as self-directed learning, critical thinking and problem solving, working through PBL.

Conclusions and Discussion

This study aimed to compare learning of prospective primary science teachers in a problem-based curriculum with those in a conventional primary science teacher preparation program

in the context of learning about the concepts of gases. The attitudes of these students towards chemistry were also compared. It is argued that in a PBL learning environment learners either attained slightly higher scores than learners in a conventional approach or attained at least similar scores (Miller, 2003; Rideout et al., 2002). Our results also confirm this view. Although a statistically significant difference between the total means scores of PBL and conventional learners was found, this was not a large difference (see Table 1). However, these data indicate that PBL may be at least as effective an approach of teaching chemistry to primary science training students in conventional lectures' discussions and problem solving. Moreover, it is also argued that the significant effect of the PBL appears to be the students' satisfaction with the learning environment. Almost all PBL trials reported that students perceived their learning environments to be more positive than their counterparts in conventional programmes (Miller, 2003; Rideout et al., 2002; Soderberg & Price, 2003; Yuzhi, 2003). The PBL approach is viewed positively by learners, who describe it as enjoyable, interactive, relevant, practical and holistic. Students in our PBL groups showed more positive attitudes towards chemistry after PBL intervention than students in the control group, and also they reported that PBL was the type of teaching approach that they were expecting in a university curriculum. Relatively high PES ($\bar{X}=17.64$, $SD=2.55$) and SES ($\bar{X}=17.85$, $SD=2.79$) mean cores indicate that students experienced a constructivist environment and they had the opportunity to develop inter-personal skills through PBL. The role of the tutor is very different from the usual teacher's role in PBL. Rather than being a 'content expert' who provides the facts, the tutor is a facilitator, responsible for guiding students to identify the key issues in each case and to find ways to learn those areas in appropriate breadth and depth. However, it is reported that tutors who were experts on subject matter were more able to fulfil the tutor's role in PBL (Das, Mpofu, Hasan, & Stewart, 2002). The high TPES score ($\bar{X}=27.19$, $SD=2.61$) suggests that the tutor was perceived to be effective in their study. Another important indicator of the effectiveness of an approach used in a classroom is the students' evaluation of the method. In this case students also evaluated the effectiveness of PBL. The high SEPBL score ($\bar{X}=26.89$, $SD=2.29$) suggests that students were happy with the PBL approach. We believe that the students had developed the necessary skills, such as self-directed learning, critical thinking, literature researching and problem solving, working through PBL activities.

Implications

PBL has two distinctive goals: to learn a required set of competencies or objectives and to develop problem-solving skills that are necessary for life long learning (Ward & Lee, 2002). Given the small sample size, caution is advised with respect to generalising the findings. The result of this study indicates that PBL may be at least as effective a method of teaching basic science concepts to prospective teachers in teacher training faculties as is conventional lecturing. This study provides evidence that PBL has a significant effect on the development of students' skills (self-directed learning, cooperative learning, critical thinking etc.) and slightly improved attitudes towards chemistry. If students are given an authentic problem that is challenging and real, they will be even more motivated to learn and to enjoy the learning process immensely.

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