An Appraisal of Engineering Students' Critical Thinking and Science Process Skills using Problem-Based Learning Approach

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Abstract

Problem-Based Learning approach (PBLA) promotes motivation and maximizes the potential of students through their acquired science process skills (SPS) and critical thinking skills (CTS). Most of the researches about PBLA focus solely on the SPS or CTS of the students. The study examined the effect of PBLA on both skills of the first-year engineering students in chemistry laboratory subject. Through convenience sampling, the study was carried out on one intact class of Bachelor of Science in Electronics Communication Engineering students enrolled at a state university in Manila during the 2nd semester of SY 2015-2016. Students were motivated through PBL laboratory activities and were facilitated to design their own procedures. Quantitative data was obtained using the Science Process Skills Test and Critical Thinking Appraisal. The results revealed that majority of the students' SPS was enhanced and developed. There was significant progress on their CTS after exposure to PBLA. Likewise, qualitative data was obtained based on the Students Experience Survey piloted to them. Findings show that some of the attributes of the PBL were demonstrated and, the negative and positive experiences of students towards the PBLA. This study recommends the implementation of PBLA in teaching and learning to improve students' manifestation of SPS and CTS. Future studies are recommended to put more emphasis on qualitative analysis to identify other intervening variables that influence students' engagement in PBLA and the rate of development of their SPS and CTS.

Keywords

appraisal**,** attributes, critical thinking skills, problem-based learning approach, science process skills

Introduction

Science education attempts and keeps on improving the learning engagement of students and the teaching strategy of science teachers to produce skillful students who will contribute to the progress and development of the country. Student engagement in chemistry laboratory class, which uses "cookbook" procedure during experiments inhibit them from thinking about the larger purpose of their investigation, thus, it prevents them to exhibit their creativity, organization and data interpretation. Since the activities are predetermined, students uncritically follow the directions and get a little experience of problem-solving and are not concerned with matching their learnings in the laboratory to previous experience or are not able to ask questions from the answers. Teaching and learning in the chemistry laboratory may be a way of concretely strengthening theories of investigation that may help individuals to develop effective SPS and CTS. Through PBL, students can learn independently by utilizing their acquired skills to find a strategic solution to solve a problem. This student-centered approach is responsible for discovering, evaluating and extracting information and ideas in a collective manner. Also, it helps to conceptualize their previous knowledge to solve the present problem. Being exposed to PBL activities, they need to work cooperatively and think critically as a significant training for a collaboration workforce.

Problem-Based Learning (PBL)

Constructivism (Bhattacharjee, 2015) is a theory of learning used to explain how individuals create their own information. It suggests that people conceptualize knowledge and meaning from their experiences because learning is an active and constructive process by nature. It is an inquiry-based approach which aims to ask questions, investigate a topic, and find solutions and answers. Likewise, it is also collaborative in nature, as students review and reflects on their prior knowledge and experience. Moreover, constructivism helps a teacher to transform students from being passive to active, and the classroom setting to student-centered rather than teacher-centered.

PBL is one of the many forms of constructing knowledge and is a student-centered and independent learning approach that commences with a problem, which is directed by a facilitator. A good problem affords feedback that allows students to evaluate the effectiveness of their knowledge, reasoning, and learning strategies. This problem needs a facilitator for effective execution of PBL. The facilitator guides the development of higher-order thinking skills (HOTS) by encouraging students to justify their thinking and externalizes self-reflection by directing appropriate questions to individuals. This approach is important considering that higher education mandates on giving emphasis to students' development and active learning.

Surif, Ibrahim and Mokhtar (2013) identifies the impact of PBL as a teaching strategy in the process of teaching and learning in higher education institutions towards the development of students. Students could solve problems using group activities, lecturer guidance and independent learning. Moreover, Fatokun and Fatokun (2013) presents the application of PBL in the tertiary education as a functional tool for learning Chemistry using life situations or simulated scenario. Furthermore, instead of using 'recipe-style' laboratory teaching method, Mc Donnell, O'Connor, and Seery (2007) implements a PBL mini-project as an alternative to the traditional method of laboratory teaching. This PBL mini-project is found to be successful in increasing class participation and engagement. Additionally, using PBL in the laboratory can provide instructors with teaching scheme entirely different from cookbook. PBL module as utilized by Hicks and Bevsek (2011) uses approach for students to devise their own flowcharts before engaging in the analysis. Similarly, Kelly and Finlayson (2007), tries to implement the PBL laboratory-based module for first-year undergraduate chemistry with the intention of developing the students' skills and scientific understanding. The PBL module also encourages students to prepare for their laboratory session in an active and collaborative manner through pre-lab exercises. Likewise, Laredo (2011) considers changing the first – year Chemistry Laboratory Manual to implement a PBL approach for the improvement of students' engagement who are not taking science as major subjects. Lastly, Capinding (2015) investigates the effects on students' performance in Chemistry class using a strategy parallel to PBL, known as the Open-Ended Inquiry-Based Laboratory Activities (OEIBLA). This approached is used by third-year BS Physical Therapy students where engagement in chemistry laboratory class has greater value and importance.

Science Process Skills (SPS)

Science process skills or SPS are described as set of mostly manageable abilities, appropriate to many science disciplines and tools that students use to scrutinize the world around them, specifically, in the construction of scientific concepts. It is a process for the acquisition of scientific knowledge, and is responsible in the assessment, analysis and in finding a solution to a problem. These skills are given importance in the case study in Jambi, Indonesia by Sukarno, Permanasari and Hamidah (2013) where they encourage the government to consider various measures to develop and improve the acquired SPS of students while still in junior high school in preparation for their college. It is not only important to those pursuing careers in science, but also most jobs in this new millennium involve using these skills. Thus, it is a necessary tool to think scientifically, to understand and solve the problems encountered in daily life. This is supported by Ostlund (1992) as cited by Ergül, Simsekli, Calis, Özdelik, Göcmencelebi and Sanli (2011) which stated that SPS is the building blocks of critical thinking and inquiry in science.

Critical Thinking Skills (CTS)

Critical thinking is the ability to logically and rationally consider information, which is essential as a tool of inquiry. It is described as the ability to engage in reflective and independent thinking. It requires using one's ability to reason. It is about being an active learner rather than a passive recipient of information. Facione (2015) emphasizes that critical thinking is purposeful, self-regulatory judgment which results interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, and contextual considerations upon, which judgment is based. This means that it is the individuals' intellectual skills that enable him to verify that the data and all other information because of experimentation, e.g., chemistry laboratory test and evaluation.

Since PBL is a student-centered approach that increases the participation and engagement of students, McKinley (2012) investigates the incorporation of PBL and Guided Inquiry to improve student achievement in an acid-base unit for high school chemistry. The activities and laboratory involves in the unit are modified to be centered on the problem. Students who also participates in guided inquiry laboratory improve their CTS and increase the amount of solved problems in the classroom. Zhou, *et al.* (2013) investigate the effect of Task-Based Learning approach on students' critical thinking skills. The findings provide an effective way for chemistry teachers to improve students' critical thinking and analyticity skills. Like PBL, TBL puts emphasis on the capacity of students to act and think like scientists through investigation, planning, implementing, consolidating, and evaluating their observation. The teacher, as facilitator, motivates by posing questions that drive the students to process their learning and thinking capacities. Further, Sada, *and colleagues* (2016) support the idea that PBL builds the CTS of students by integrating it into all areas of learnings and even to the student's entire life. According to them, PBL approach can enable students to demonstrate an enhanced ability to use CTS in their activities, considering that an effective critical thinker knows how to think reasonably and reflectively likewise, can decide what to believe or do, and knows how to stimulate thinking process to deal with uniqueness of any given phenomena. With the capability to adapt and select interactions within the environment, students can recognize how to examine facts and arguments while injecting queries.

This study analyzes the process of PBL that can be an effective method of engaging student in inquiry because there have been some studies about effectiveness of the PBLA on students' CTS or SPS in the field of medicine, mathematics, business, engineering, and sciences. It is one of the studies about the effectiveness of PBLA on students' both SPS and CTS particularly in chemistry laboratory in tertiary level. PBLA helps the teacher transfer the knowledge thru scaffolding until the learner is no longer dependent that leads to enhancing his/her performance. The teacher could use this approach to monitoring, asks and challenges how to think, and manages the group dynamics by keeping students involved during the process.

This paper is based on several related studies on problem-based learning approach. These include, among others, the effects of using PBL towards chemistry (Mataka 2014), PBL laboratory-based module for first-year undergraduate chemistry (Kelly and Finlayson (2007), implementation of PBL in Higher Education Institutions (HEIs) and its impact on students' learning (Surif, *et al*. 2013) promoting engagement, improving comprehension and enhancing retention of content to students (Amador & Gorres, 2004), effects of SPS in learning chemistry (Almo, 2002), and improving CTS and attitude towards chemistry (Marasigan & Espinosa, 2014).

Given the relevant of thought provided in previous studies, researchers examine the effects of PBLA on the SPS and CTS among first-year engineering students in an inorganic chemistry laboratory setting. Specifically, this study tries to investigate the performance, the manifested SPS, and the level of CTS of the students before and after their exposure to PBLA. The researchers also try to recognize the effects of students' experiences on the application of PBLA in chemistry laboratory engagement.

As educators, considering the needs of learners, the goal is to promote students' competency, who, as confident adults, will find solutions to the problems of the future and keep the country heading in the 21st century. This study aimed to examine the effect of PBLA on students' SPS and CTS using quantitative and qualitative analysis.

Statement of the Problem

The purpose of this study is to determine the effects of Problem-Based Learning (PBL) approach on the science process skills and critical thinking skills of first year engineering students in inorganic chemistry. Specifically, it sought to answers the following questions:

1. What is the performance of the students in the science process skills test (SPST) before and after the use of PBL approach?
2. Is there a difference between the pretest and posttest mean scores of the students in the science process skills test before and after their exposure to PBL approach?
3. What are the students' science process skills before and after their exposure to PBL approach?
4. What are the students' levels of critical thinking skills before and after their exposure to PBL approach?
5. Is there a difference between the students' pretest and posttest mean scores in the critical thinking skills appraisal (CTA) before and after their exposure to PBL approach?
6. What are the students' experiences on the use of PBL approach?

Methodology

The study applied both qualitative and quantitative research designs. The quantitative approach was used to examine the effect of PBL on students' SPS and CTS. The qualitative approach was applied to interpret and understand the experiences of the participants on the use of PBL in their chemistry laboratory activities. Elihayu (2014) differentiate quantitative and qualitative approaches in research. Quantitative approach focuses on describing a phenomenon across a larger number of participants thereby providing the possibility of summarizing characteristics across groups or relationships. This approach applies statistical techniques to recognize overall patterns in the relations of processes while, the qualitative focuses on describing a phenomenon in a deep comprehensive manner. This is generally done in interviews or open-ended questions.

Participants

Through convenience sampling, one section was involved in the study composed of one intact class consisting of 50 students (30 males and 20 females) of BS Electronics Communication Engineering enrolled during the second semester SY 2015-2016. The class has six groups based on their preliminary grades in Chemistry laboratory. The composition of each group was heterogeneous consisting of above average (AA), average (A), and below average (BA) students.

Since human subjects are involved in this study, ethical considerations are given priority. The participation of the students as a subject of the study is permitted by the Dean and has been approved by the panel. All consideration of students' confidentiality and informed comment are well addressed.

The Instrument

Problem-Based Learning Laboratory Activities

Five PBL laboratory activities (Appendix A) were adapted and used covering acid, base and salts; hydrolysis and acid-base titration. These activities were used as intervention for nine weeks. The activities were based on the laboratory manual used in the Chemistry Department of the College of Science and from the websites of Royal Society of Chemistry, www.rsc.org/learn-chemistry. Modification of activities was made upon consultation with fellow chemistry teachers, availability of chemicals, materials, and apparatus. The following were PBL laboratory activities:

Activity #1 - Colors of the Solution

Activity #2 - Reactions of Acids to Metal and Carbonate compound

Activity #3 - Neutralization

Activity #4 - pH of Salts

Activity #5 - What is the Acidity of your Vinegar?

Science Process Skills Test (SPST)

This instrument used is a researcher-developed 30 items of SPST with 10 SPS (six basic skills and four integrated skills) that served as the pre-test and post-test. The final instrument has a computed reliability coefficient Kuder-Richardson using Formula 20 (Kr_{20}) of 0.80, which indicates that the test has acceptable internal consistency reliability.

Critical Thinking Skills Appraisal (CTA)

The researcher adopted the Critical Thinking Appraisal from the website of Watson-Glaser, (HoganLovellsCritical Thinking Testand Linklaters Critical Thinking Test, 2014). The instrument consists of 45 multiple choice tests containing five subscales, namely*:* **Inference Making**, a measure of the student's ability to discriminate among degrees of truth or falsity of inferences drawn from given data which consists of 12 items*;* **Recognition of Assumptions**, a measure of the student's ability to recognize unstated assumptions or presuppositions in given statements or assertions and has 10 items; **Deductions**, a measure of the student's ability to determine whether certain conclusions necessarily follow from information in given statements or premises which consists of 6 items**; Interpretation (Induction),**a measure of the student's ability to weigh evidence and decide if generalizations or conclusions based on the given data are warranted which consists of 8 items; **Evaluation of Arguments**, a measure of the student's ability to distinguish between arguments on how strong or weak which consists of 9 items. This was presented to the expert for content validation and computed the over-all reliability using the Kuder-Richardson Formula 20 (Kr_{20}) which is 0.62. The idea of using these 45 items multiple tests instead of using the standard Watson-Glaser Critical Thinking Appraisal (WGCTA) with 80 to 100 items is patterned to the research of Gadzella, Stacks, Stephens and Masten (2005) which investigated the reliability and validity of WGCTA-Forms S consist of 40 items. Researchers felt that the WGCTA, Forms A and B (consisting of 80 to 100 items) were long and time-consuming inventories. As a result, subjects did not complete.

Data Collection

Pre-Intervention

The researcher used a non-treatment laboratory activity to familiarize the students with PBL activities. From this activity, the students learned how to design their own procedure, present their data, and organize the result until they are able to write their application. The prepared and developed research instruments (SPST, CTA PBL activities, SES, Observation Checklist and Evaluation Rubric) were presented to the experts for validation. The pretest in SPST and CTA were administered one at a time before their exposure to PBL activities.

Intervention

To establish the PBL activities, the groups were given the pre-lab questions that served as the problem as is true in PBL approach. Support materials were provided that motivated the groups in designing procedures they should undertake. It was up to them on how they will divide the task. Each student in a group was assigned a specific role to complete the assignment. The six main roles are: **Planner**, tasked to organize the group members, make schedule, and supervise the implementation; **Information collector**, tasked to collect materials assigned to the members ; **Data organizer**, tasked to arranged the information systematically; **Scheme designer**, makes designing scheme, e.g. exploring the fading phenomena of the reaction between acids and bases; **Experiment preparation**, prepared the experimental materials, chemicals, and equipment according to the scheme;

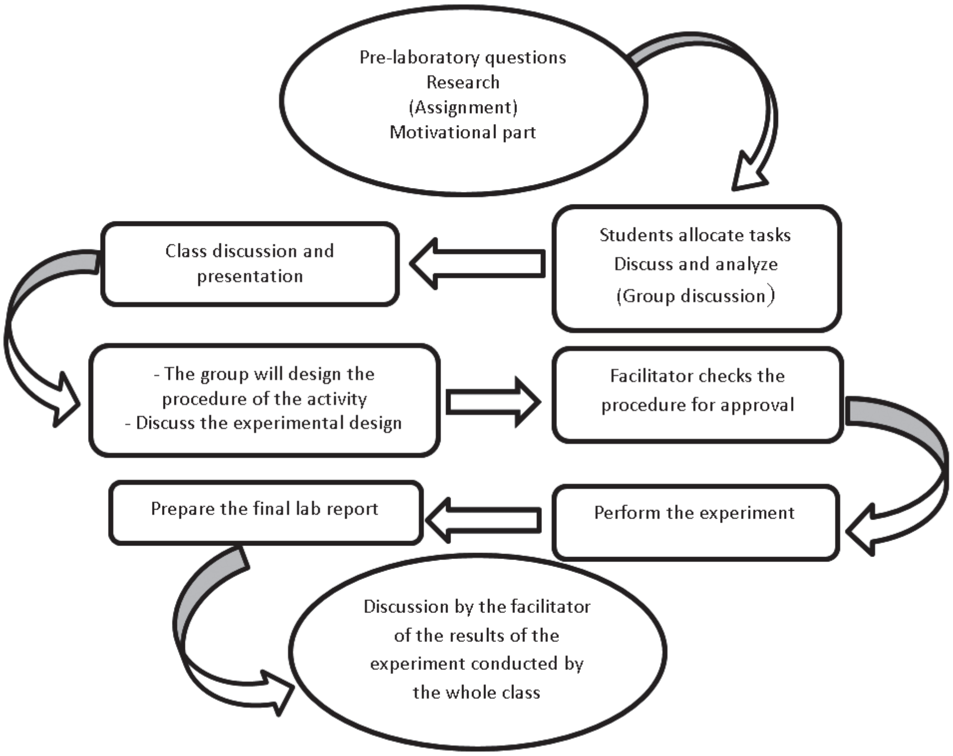

Figure 2. Flowchart of PBL laboratory activities

Presenter, displayed the experiment scheme based on the group members' argument. Participants can do research and discuss among themselves to finalize their output, taking into consideration some information given to them by the facilitator by injecting questions. They can execute their design procedure when approved by the facilitator. A post laboratory report is submitted individually after the experiment and followed by post-lab discussion in the class. The flowchart above summarizes the implementation of the PBL laboratory activities in the class as shown in Figure 2.

Post Intervention

The final stage was the administration of the post-test in SPST and CTA one at a time. The post-test scores in the SPST were used in the computation of final grades. The pre-test and post-test mean scores were analyzed and interpreted. The SES was given also to determine their experiences and opinions about PBLA.

Data Analysis

Participants' responses in the SPST were individually scored and tabulated for the frequency of correct answers in the pre-test and post-test. The mean and standard deviation of the overall scores were determined using paired *t*-test to compare and determine the significance. The frequencies of SPS of each student were classified as to existing, improved and developed skills.

The results in CTA were individually scored and tabulated. The raw scores were ranked from lowest to highest and converted to z-score. The corresponding z-score was converted to stanine and each stanine score has equivalent descriptive interpretation such as1-very poor, 2-poor, 3-considerably below average, 4-slightly below average, 5-average, 6-slightly above average, 7-considerably above average, 8-superior, and 9-very superior. The levels of critical thinking skills were classified with a range of stanine score 7 to 9–Above Average, 4 to 6- Average, and 1 to 3–Below Average.

Table1. The difference in the pre-test and post-test of the participants in the SPST (n=50)

Variable	Pretest		Posttest		*t*-value	df	*p*-value	Remark
	Mean	SD	Mean	SD				
Performance	9.72	3.06	15.58	3.57	-10.52	49	0.000	Significant

p<0.5

SCIENCE PROCESS SKILLS	PRETEST %	POSTTEST %
OBSERVING	46.67	66.67
INTERPRETING	44.00	66.00
EXPERIMENTING	46.67	62.67
INFERRING	45.00	57.00
COMMUNICATING	27.00	55.00
PREDICTING	26.80	54.00
CLASSIFYING	20.40	48.00
QUANTIFYING	20.80	42.00
UNDERSTANDING CAUSE AND EFFECT	28.00	34.00
IDENTIFYING/CONTROLLING VARIABLES	30.00	20.00

The frequency of responses in each item of the SES about their learning experiences on the use of PBLA was evaluated and assessed qualitatively. To interpret the means, a 4-point Likert scale was used, 4-strongly agree, 3-agree, 2-disagree, and 1-strongly disagree. The responses of the students per item were computed.

Findings and Discussion

Science Process Skill

From the test of 50 first-year engineering students of SPST, the performance and manifested skills were recorded and tabulated using descriptive statistics. As presented in Table 1, the result has higher post-test mean and standard deviation ($\bar{x}$=15.58; SD= 3.57) than the pre-test ($\bar{x}$=9.72; SD=3.06), a difference that is statistically significant ($p<0.05$). This indicates that the PBL approach has a positive effect in enhancing the students' performance in chemistry. The use of this approach in different science process skills stimulates the students to become more creative, active, team player, artistic and attentive in performing the laboratory activities.

The SPS of the students before and after the use of PBL laboratory activities were obtained using the developed SPST incorporating the 10 science process skills both basic and integrated skills. The frequencies of students' SPS are also tabulated showing the students' SPS before and after their exposure to PBLA.

The table above illustrates the SPS manifested by students before and after exposure to PBLA. After exposure to the approach, manifestation of observing skill suggests that students could use their senses between the similarities and differences of the properties of acids, bases, and salt during the activity based on the observed color changes. On the other hand, interpreting skill implies that students are better at considering evidence, evaluating and drawing conclusions by assessing the data. They could find a pattern or other meaning in the gathering of data.

Experimenting skill shows that students could formulate and carry out an experiment by following the directions of the procedure they designed. They systematically plan and execute the procedure in each activity. Meanwhile, on inferring skill, students' formulations of assumptions or possible explanations based on their observations are enhanced which proves that they give the effort to support or provide evidence for a conclusion.

Table 2. The Summary of Developed and Improved SPS (n=50)

SCIENCE PROCESS SKILLS	DEVELOPED SKILLS %	SCIENCE PROCESS SKILLS	IMPROVED SKILLS %
CLASSIFYING	33.05	INFERRING	47.69
PREDICTING	26.27	QUANTIFYING	45.38
QUANTIFYING	25.42	CLASSIFYING	45.38
COMMUNICATING	23.73	OBSERVING	40.00
EXPERIMENTING	14.41	EXPERIMENTING	32.31
INTERPRETING	14.41	PREDICTING	21.54
UNDERSTANDING CAUSE AND EFFECT	12.71	INTERPRETING	18.46
OBSERVING	10.17	COMMUNICATING	10.77
INFERRING	8.47	IDENTIFYING CAUSE AND EFFECT	3.08
IDENTIFYING/CONTROLLING VARIABLES	5.08	IDENTIFYING/CONTROLLING VARIABLES	0.00

Consequently, they present an argument instead of merely providing information.

Communicating skill indicates that they are better in representing observations, ideas, or conclusions by writing, drawing or making physical models while the manifestation of predicting skill, suggests that their skills on forecasting the outcome of the activity based on evidence including justification are developed. Students could use their senses to observe and collect data/information. They can make connections to their knowledge.

These different skills are promoted using student-centered approach like PBL in accordance with the results obtained by Balanay and Roa (2013). Base on their research, students can improve their skills using their ability to observe, ask questions and make predictions. Through student engagement activities, this type of learning environment encourages students to develop their observational and recording skills.

The significance of classifying skill denotes that students are better in grouping their data and results based on categories and characteristics of the activity while quantifying reveals that they are better at identifying, ordering and counting.

On the other hand, table 2 shows the frequency in percentage the developed and improved skills after exposure to PBLA.

The results suggest that the use of the PBL approach in teaching chemistry laboratory tends to have positive impact on the students' performance because of the developed and improved skills indicated. It only means that process skills describe students' thinking ability and reasoning as they understand the concepts when they apply in the experimental process (Kelly and Finlayson 2007). It is also noted that SPS is an essential skills related to laboratory activity that involves student engagement and this is proved by Sindelar (2010) that PBL can be effective strategy in classroom. Students are accountable for their own learning and they are more engaged in the learning process.

In view of this, PBL scenarios demand the use of process skills in making observations to define the issues, conducting researches to collect information, evaluate the data and result and justifying the solutions obtain. These help students construct knowledge.

Critical Thinking Appraisal (CTA)

The CTA is used to identify the level (above average, average or below average) of CTS before and after exposure to PBLA. These raw scores are converted to Stanine score for the classification of critical thinking. Table 3 show the level of CTS of students and the significance of pre-test and post-test.

Table 3. The Frequency of Student's Level of Critical Thinking in CTA's Pre/Posttest using Stanine Score (n=50)

Pretest *f*	Posttest *f*	Interpretation
14 students	22 students	Above Average
22 students	18 students	Average
14 students	10 students	Below Average

Variable	Pretest		Posttest		*t*-value	df	*p*-value	Remark
	Mean	SD	Mean	SD				
Critical Thinking Skills	20.60	3.28	24.58	2.49	11.995	49	0.000	Significant

p<0.5

Table 4. The Frequency and Percentage Distribution of Students' Responses in the SES

Items	Indicator			
	4	3	2	1
1. Problem-Based Learning (PBL) laboratory activities give chance to work in the laboratory as real scientists do.	**29(58%)**	21(42%)	0	0
2. It takes time to devise and design a procedure.	18(36%)	**30(60%)**	2(4%)	0
3. Problem-Based Learning (PBL) helped me to learn how to obtain information from a variety of sources in answering the pre-lab questions.	**26(52%)**	24(48%)	0	0
4. Chemistry laboratory should be about learning to do science through scientific investigations.	**28(56%)**	21(42%)	1(2%)	0
5. I feel most confident when the chemistry lessons are well-structured, and student directed.	**28(56%)**	18(36%)	4(8%)	0
6. I appreciated the chance that the teacher gave me to plan my own activity.	16(32%)	**30(60%)**	4(8%)	0
7. The Problem-Based Learning (PBL) laboratory activities developed my skills in solving a scientific problem.	20(40%)	**30(60%)**	0	0
8. I was comfortable working in groups.	18(36%)	**30(60%)**	2(4%)	0
9. The opportunity given to plan my own experiment was very satisfying.	14(28%)	**33(66%)**	2(4%)	1(2%)
10. If given an opportunity, I would like to take another Problem-Based Learning (PBL) class.	2(4%)	**36(72%)**	12(24%)	0

The result in paired t-test signifies that the student's CTS are better after their exposure to the PBL approach. They can define problems and situations, can identify information needed in decision making, can apply logic and reasoning when analyzing information, can draw an accurate conclusion from information and are able to develop arguments. Through group collaboration, PBL is effective in promoting critical thought because it generally stimulates interest and increases the understanding and knowledge. Sada, *and colleagues* (2016) specify that PBL is the best approach in building CTS, integrating it into all areas of learnings and to the students' entire life. Students demonstrate an enhanced ability to use CTS in their activities especially in learning chemistry because it needs higher level of CTS, since it combines numerous abstract concepts.

Students' Experiences on PBLA

After performing the five laboratory activities, the students' feelings, views, opinions, and thoughts regarding their exposure to PBLA are determined. The first part of the survey is a questionnaire (10-items) using a 4-point Likert scale. For each statement, the frequencies of responses in the four columns are tallied and the results are presented in Table 4.

From the results, the attributes of PBLA are observed in teaching and learning in the chemistry laboratory such as collaboration, improvement of HOTS, planning, motivation, creativity, exploration, and organization. Also, it shows that majority of the respondents are confident about working in groups and would like to take another opportunity to plan their own experiment, even though some students do not agree on working in a group. The data reveal that after experiencing PBL laboratory activities, students have become more aware that the chemistry laboratory class will be more daring and satisfying for every laboratory activity they do than a traditional type of laboratory class. PBL encourages active participation in learning by providing relevant, interesting and challenging learning situations.

The second part of the questionnaire is an interview and their answers are summarized and categorized according to their level of CTS (AA, A, BA). Students under the pool of AA have a positive feedback regarding the use of PBLA in the chemistry laboratory class. Some claim that their thinking skills are enhanced and they gained confidence. They turned out to be independent and cooperative in doing their assigned tasks as part or contribution to the group in designing the procedure. They learned how to think outside the box, do planning, and how to analyze. Students under the pool of average have enjoyed and become excited about doing the experiments because they feel like real scientists whenever they accomplished an activity especially when they apply their previous knowledge in real life situations. They also realized the importance of patience, collaboration, and decision making when doing PBL activities. While students from the pool of BA commented that PBL activities are hard and time limitations. According to some respondents, "…*the most challenging part of PBL is designing a procedure*". Other student said that the problem they encountered with PBL is making the post-laboratory report because they do not know how to organize data and think of an application.

The results of this interviews are validated by Mataka (2014) regarding the aim of PBL. Interview responses showed that the students felt both more confident in chemistry and had a positive view of learning in chemistry after undergoing PBL instruction. Students had higher view of themselves performing within the PBL environment compared to the assistance provided by the instructor despite of students' varying characteristics. As active learners, who show independent study behavior and responsibility for their own learning process, students appreciate the use of PBL in teaching and learning chemistry.

Generally, the results from both qualitative and quantitative data suggest that most of the students' have a positive view of the use of PBLA in chemistry laboratory. Since, chemistry is one of the most important disciplines which enable the students to understand their surroundings, even though they find a little difficulty in learning the subject. This study supports in the research of Surif *and colleagues* (2013) that many students agree with the implementation of PBL and satisfied if PBL continues to be administered in chemistry education. Students become active and could articulate their knowledge. They share ideas, explore the situation (pre-lab questions) and focused on what they can do and contribute (a division of task). Students accepted the challenges that encourage them to think critically. Also, participants are more interested in discovering and exploring the situation that made them to think out-of-the-box.

Conclusion

The focus of this study is to examine the effects of PBLA on students' SPS and CTS after they are exposed to PBL laboratory activities that served as the problem or motivational part of the PBL. The results show that majority of the students acquire the science process skills and their critical thinking skills have improved after the exposure to PBLA. Likewise, this study tries to confirm that PBLA promotes learning through engagement and discovery because the six groups could plan and design their own experiment in a creative manner. Although, there are some of the members of the group commented on the difficulty in finalizing the procedure because of time contrasts. Also, PBLA gives emphasis on active and transferable learning, since the teacher as facilitator, transfers the knowledge by letting the students do the experiment and asking thought provoking question leading the students to find the solution.

Base on the findings of students' experiences, majority of the respondents find it rewarding and satisfying despite some problems they encounter. This suggests that as a teaching strategy in a chemistry laboratory, PBL is a possible approach that can motivate students and converted the class into a student-centered classroom. The teacher can monitor the learners and manages the group by keeping the students involved during the process. However, there are some students who are not convinced nor appreciated the use of PBLA as a teaching strategy in the laboratory, maybe due to a short period of exposure to PBLA.

There is a lot of study on the use of PBLA as pedagogy in higher education but limited in giving emphasis on qualitative side. Further studies are suggested using a greater number of participants with longer exposure to PBL pointing out on the negative and positive experiences of students that would help identify other intervening variables that influence the students' engagement. The future researchers are encouraged to conduct a similar study in other disciplines to confirm the result of the study considering other relevant parameters like gender, attitude, and emotional quotient. Additionally, it is recommended to explore on the possible causes of students' poor critical thinking skills and science process skills.

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References

Almo, M. (2002). Starter experiment-based approach (SEBA) and the science process skills (SPS) of high school chemistry students. Unpublished Thesis. Chemistry Department, College of Science, TUP Manila, October 2002

Amador, J., & Görres, J. (2004). A problem-based learning approach to teaching introductory soil science. *Journal Natural Resources Life Sciences Education.Vol. 33*, pp. 21-27. Retrieved February 13, 2015

Balanay, C., & Roa, E. (2013). Assessment on students' science process skills: a student-centered approach. *International Journal of Biology Education*. *Vol. 3*(1), May 2003. Retrieved October 18, 2014

Capinding, E. S. (2015). Open-ended inquiry-based laboratory activities: effects on students' performance and anxiety in chemistry. Unpublished Thesis. Chemistry Department, College of Science, TUP Manila, February 2015

Case and problem-based learning. Retrieved June 5, 2015 from http://file:///G:/research/Case%20and%20Problem%20Based%20Learning.html,

Chebii, R., Wachanga, S., & Kiboss, J. (2012). Effects of science process skills mastery learning approach on students' acquisition of selected chemistry practical skills in school. *Creative Education*. *Vol. 3* (8), pp.1291-1296. Retrieved June 16, 2015 fromhttp://dx.doi.org/10.4236/ce.2012.38188

Critical Thinking Appraisal. Adopted from Hogan Lovells Critical Thinking Test and Linklaters Critical Thinking test taken from Watson-Glaser Critical Thinking Appraisal. Retrieved September 13, 2014 from talentlens.com

Critical Thinking Skills. Retrieved December 4, 2015 from http://www.skillsyouneed.com/learn/critical-thinking.html.

Drăghicescu, M., Petrescu, A., Cristea, G., Gorghiu L.., & Goghiu, G. (2014). Application of problem-based learning strategy in science lessons-examples of good practice. Procedia – Social and Behavioral Sciences 149 (2014) 297 -301. Retrieved August 19, 2015 fromhttp://www.doi.org/10.1016/j.sbspro.2014.08.245

Elihayu, A. (2014). On Methods: What's the diffrence between qualitative and quantitative approaches? Retieved November 28, 2018 from https://www.evidencebased-mentoring.org/

Ergul*et al.* (2011). Inquiry-based science teaching on elementary school students' science process skills and science attitudes. Uhidag University, Turkey. Bulgarian Journal of Science and Education Policy (BJSEP), Vol 5 No. 1, 2011

Facione, P. Critical Thinking: What it is and why it counts. www.insightassessment.com. Retrieved August 17, 2014 from www.rasmassea.edu/student-life/blogs/main/critical-thinking-skills-you-need-to-master-now/

Fatokun, J., & Fatokun, K. A problem-based learning (PBL) application for the teaching of Mathematics and Chemistry in higher schools and tertiary education: An integrative approach. Academic Journals. *Vol. 8*(11), pp. 663-667, June 10, 2013. Retrieved June 16, 2015

Gadzella, *et al.* (2005). Watson-Glaser Critical Thinking Appraisal, Form -S for education majors. *Journal of Instructional Psychology. Vol. 32* Issue # 1. March 1, 2005

Hicks, R., & Bevsek, H. (2011). Utilizing problem-based learning in qualitative analysis lab experiments. *Journal of Chemical Education*. *Vol. 89*, pp. 254-257, 2012. Retrieved July 25, 2015 fromhttp://dx.doi.org/10.1021/ed1001202.

İnel, D., & Balim, A. (2012). Concept cartoons assisted problem based learning method in science and technology teaching and students' views. *Procedia-Social and Behavioral Sciences 93* (2013) 376-380. Retrieved August 14, 2015 fromhttp://www.doi.org/10.1016/j.sbspro.2013.09.206

Institute for Inquiry. Process Skills: Definitions and examples. Retrieved June 13, 2015 from www.exploratorium.edu/ifi

Kelly, O. and Finlayson, O. (2007). Providing solutions through problem-based learning for the undergraduate 1st year chemistry laboratory. *The Royal Society of Chemistry. Vol. 8*(3), pp. 347-361. Chemistry Education Research and Practice, 2007. Retrieved March 19, 2015

Laredo, T. (2011). Changing the first-year chemistry laboratory manual to implement a problem-based approach that improves student engagement. *Journal of Chemical Education.* Retrieved November 24, 2014 fromhttp://www.doi.org/10.1021/ed300313m

Marasigan, A. and Espinosa A. (2014). Modified useful – learning approach: effects on students' critical thinking skills and attitude towards chemistry. *International Journal of Learning, Teaching and Educational Research. Vol. 1,* No. 1, pp. 35-72*,* January 2014. Retrieved August 23, 2015

Mataka, L. (2014). Problem-based learning (PBL) in the college chemistry laboratory: Students' perceptions of PBL and its relationship with attitude and self-efficacy beliefs. Western Michigan University, Scholar Works at WMU. June 2014. Retrieved August 10, 2015

Mc Donnell, C., O'Connor, C.., & Seery, M. (2007). Developing practical chemistry skills by means of student-driven problem based learning mini-projects. *The Royal Society of Chemistry.Vol. 8*(2), pp. 130-139.

Chemistry Education Research and Practice, 2007. Retrieved April 10, 2015

McKinley, K. (2012). Using problem based learning and guided inquiry in a high school acid-base chemistry unit. Michigan State University. Published thesis, 2012. Retrieved May 9, 2015

Sada, A., Mohd, Z., Adnan, A., & Yusri, K. (2016). Prospects of problem-based learning in building critical thinking skills among technical college students in Nigeria. *Mediterranean Journal of Social Sciences. Vol. 7*, No. 3, May 2016

Silver, C. (2004). Problem-based learning: what and how do students learn? *Educational Psychology Review.Vol. 16*, No. 3, pp. 235-266, September 2004

Sindelar, T. M. (2002). The effectiveness of problem –based learning in the high school science classroom. Published Thesis. Wichita University.

Smith, C. (1995). Features section: problem-based learning. *Biochemical Education.Vol. 23*, No. 3, pp.149-152

Sukarno, Permanasari, A., & Hamidah, I. (2013). The profile of science process skill (SPS) student at secondary high school (case study in jambi). *International Journal of Scientific Engineering and Research.Vol. 1*, Issue 1, pp. 79-83, September 2013, Retrieved September 21, 2015 fromwww.ijser.in

Surif, J., Ibrahim, N., & Mokhtar, M. (2013), Implementation of problem-based learning in higher education institutions and its impact on students' learning. *The 4th International Research Symposium on Problem-Based Learning (IRSPBL),* 2013

Teaching critical thinking through science. Retrieved January 15, 2016 from http://mylearningspringboard.com/teaching-critical-thinking-through-science-process-skills/

Zhou, Q., Huang, Q., & Tian, H. (2013). Developing students' critical thinking skills by task-based learning in chemistry experiment teaching. Creative Education 2013. Vol. 4, No. 12A, pp. 40-45. Retrieved November 26, 2015 from http://dx.doi.org/10.4236/ce.2013.412a1006.

Appendix A

Sample PBL laboratory activity

EXPERIMENT #1: COLORS OF THE SOLUTION

Pre-Lab Questions:

1. Differentiate acids, bases and salts with respect to their properties and observed behavior.
2. What is Arrhenius theory of acids? Bronsted-Lowry acid theory? Lewis acid theory?
3. What is an indicator?
4. What are some organic materials that can be used as indicator?
5. What are some indicators used to determine if the solution is acid, base or salts?
6. How do you know if the substance is an acid, base or salts?
7. Give the reaction of an acid, a base, and a salt in each of the following indicators.

Indicator	Acid	Base	Salt
Red Litmus paper			
Blue Litmus paper			
Phenolphthalein			
Methyl Orange			

Description

Students design and conduct a laboratory process to determine the reactions of acids, bases, and salts to indicators. The observation and analysis of their data will lead students to know the properties of acids, bases and salts.

Learning outcome

1. Plan and implement a laboratory investigation using safe practices.
2. Apply chemistry concepts and process skills to determine the effect of indicators to acids, bases, and salts.
3. Make a comparison between the properties of acids, bases and salts according to its theory.
4. Be able to relate and identify the solutions from household as to acids, bases and salts.

Materials

Chemicals	Apparatus
1M HCl	Spot plate
1M H_2SO_4	Universal indicator paper (blue and red)
1M NaOH	dropper
1M KOH	
1M NaCl	
1M KCl	
Methyl orange	
Phenolphthalein	

Safety

Students will review the laboratory safety precautions based on their plan. They will also identify hazards and safe handling/ disposal of the chemicals.

FORMAT OF POST LAB REPORT

Name:____ **DATE:**______________

CYS: ____________________ **GROUP NO.** ________

Title: ____

Objective: ____

Procedure: (Schematic diagram/outline)

Procedure:

Data:

Discussion of Results:

Conclusion:

Applications: