International Journal of Innovation, Creativity and Change. www.ijicc.net
Volume 13, Issue 7, 2020

# STEM Project-Based Learning in Chemistry: Opportunities and Challenges to Enhance Students' Chemical Literacy

**Yuli Rahmawati[a*], Fransisca Dushita Andanswari[b], Achmad Ridwan[c], Robyn Gillies[d], Peter Charles Taylor[e],** [a,b,c]Universitas Negeri Jakarta, Indonesia, [d]University of Queensland, Australia, eMurdoch University, Australia, Email: [a*]yrahmawati@unj.ac.id

This study explored how a Science, Technology, Engineering and Mathematics (STEM) project-based learning (PBL) approach was integrated into a Year 10 chemistry curriculum to develop students' chemical literacy. The STEM PBL approach involved the application of the topics of 'redox' and 'electrolysis' to the process of chemical etching. The development of students' chemical literacy was demonstrated by the evidence of general scientific ideas, characteristics of chemistry, chemistry in context, higher order thinking skills, and affective aspects. The study employed the data collection techniques of interview, reflective journal, fieldnotes, and a chemical literacy test. The research was conducted in a private secondary school with 15 students in Year 10. The data was analysed using the chemical literacy criteria of mastery, competent, developing, emerging, and absent. The results indicate that the project stimulated students' curiosity in exploring scientific concepts and developed their conceptual understanding in chemistry, critical thinking, and collaborative skills. Students enthusiastic engagement in this novel STEM PBL approach enhanced their development of chemical literacy.

**Keywords:** *STEM, Chemistry learning, Chemical literacy, Project-based learning.*

## Introduction

Chemistry deals with the natural phenomena associated with molecular structures, physical and chemical properties, and energy changes, all of which give an abstract characteristic to the discipline. In chemistry education, this characteristic has been addressed by a pedagogical model that focusses on the relationship between the macro, submicro, and symbolic types of representations (Gilbert & Treagust, 2009b; Talanquer, 2011). However, this approach does not necessarily make chemistry learning attractive to students. To be able to cope with today's rapid and complex world of scientific change and technological development, students need more than a basic understanding of abstract chemistry. For many students, mere chemistry without exposure to anything that can be found in their everyday lives lessens the sense of purpose of learning. The traditional pedagogical emphasis on overloading students with isolated facts, rote learning, and a lack of perceived relevance of what they are learning, is challenging teachers to re-evaluate the goals of teaching and to make significant changes by emphasising 'chemical literacy' (Gilbert, 2007; Shwartz et al., 2005).

Tsaparlis (2000) argues that chemical literacy — understanding chemistry and the ability to apply it in daily life — needs to be instilled at school. People who are chemically literate can communicate a general understanding of chemistry, perform scientific investigations, and draw conclusions using this knowledge to explain an event. A chemically literate person is able to understand the main ideas of chemistry, demonstrate higher order thinking, seek answers to questions raised during investigations, and demonstrate an interest in matters involving chemistry. Recently, a multidisciplinary perspective has been advocated as a means of engaging students in developing their chemistry literacy.

This STEM perspective integrates the disciplines of Science, Technology, Engineering and Mathematics for the purpose of solving everyday science-related problems. Roehrig, Moore, Wang and Park (2012) proposed integrating the four disciplines to gain a deeper understanding of science, broaden understanding of science by relating it to technology and engineering, and develop students' interest in STEM-related professions. Teaching using a STEM perspective is a strategy aimed at improving the academic achievement of learners, as well as introducing them to skills that are important for future jobs. It is anticipated that there will be at least three million jobs in STEM-related fields by 2020.

For this study, a STEM perspective was used in conjunction with a Project-based learning (PBL) approach to provide opportunities for students to develop their chemical literacy. In PBL, students direct their own learning, develop creativity, and work together to solve problems (Ergül & Kargın, 2014). The experience gained in completing projects can make learning more meaningful and relevant to students' current and future lives. The theoretical framework for this study was adapted from the chemical literacy model developed by Shwartz, Ben Zvi and Hofstein (2005, 2006). The impact on students' chemical literacy development was assessed through five components: (1) ability to conduct a scientific investigation and draw conclusions (*general scientific ideas*); (2) ability to explain macroscopic phenomena in terms of microscopic structure of matter (*characteristic of chemistry*); (3) knowing the relevance of chemistry in the context of related concepts (*chemistry in context*); (4) ability to ask questions and look for related information (*higherorder thinking skills*); and (5) demonstrated interest in chemistry (*affective aspect*).

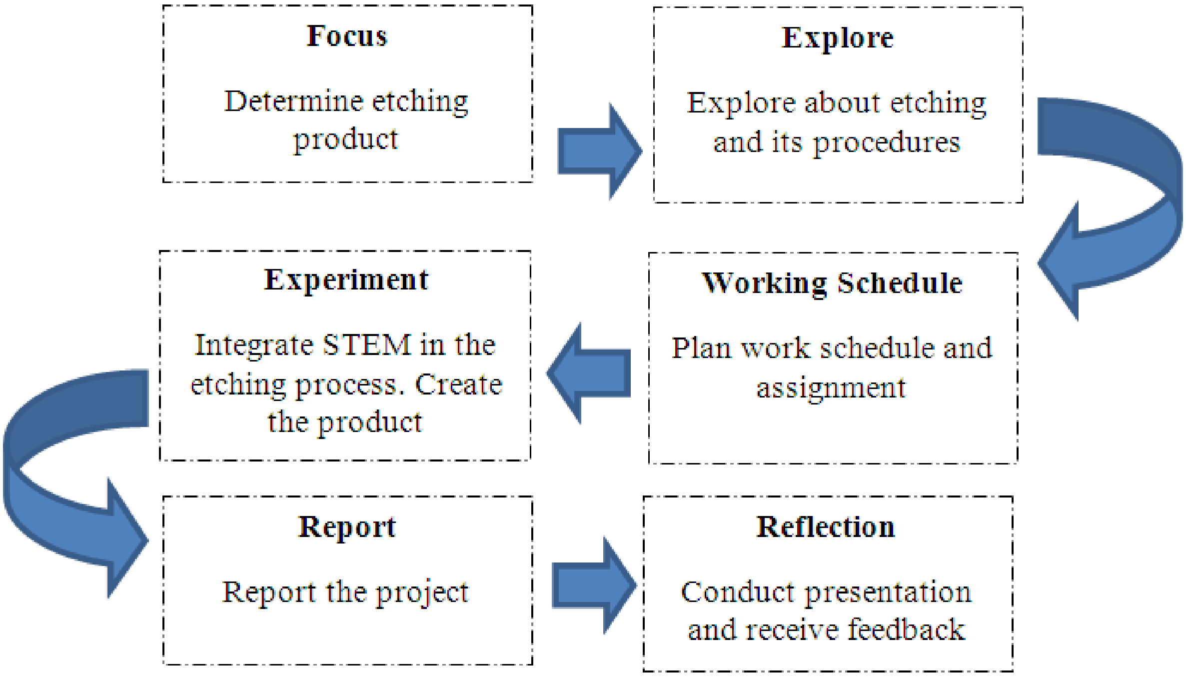
## Purpose of the Research

In 2013, Indonesia's Ministry of Education and Culture (2016) renewed the national curriculum with the aim of fostering character development, skills, and knowledge that result in more productive, creative, innovative, and knowledgeable learners for the twenty-first century. This study was designed to broadly assist Indonesian chemistry teachers to develop the ability to successfully implement the new curriculum goals. Recent research has revealed the common constraints throughout Indonesian schools that need to be overcome in order to implement the new curriculum, namely, linking abstract chemistry concepts to students' daily lives, and accommodating students' individual learning characteristics (Rahmawati, 2013; Rahmawati & Ridwan, 2017). On the other hand, recent studies on the application of STEM education in Indonesian chemistry classrooms have shown promise for developing students' interest and confidence in studying science, raising curiosity and increasing achievement, developing twenty-first century skills, and illuminating how a career in STEM can drive economic growth in developing countries (Sheffield, Koul, Fitriani, Rahmawati & Resekc, 2018). Therefore, given the shifting nature and needs of Indonesia's national curriculum, the purpose of this study was to investigate the feasibility of a project-based approach to STEM education for developing Indonesian students' chemical literacy.

## Research Methodology

The STEM PBL activities were conducted eight times during a four-week period. The study employed a 'mixed methods' research approach (Cresswell, 2005) that involved preparation of a project timeline, students' project guide, a chemical literacy test, and interview protocol. The six-step STEM PBL pedagogical process is illustrated in **Figure 1**.

**Figure 1.** Six Steps of STEM PBL




**Participants**

The main participants of the study were 15, Grade 10 students enrolled in an international school in Jakarta. Nine male and six female students participated in the study. The students were placed in three groups, comprising five students per group.

**Data Sources and Data Production**

Sources of data included a chemical literacy test, semi-structured interviews, fieldnotes, and a reflective journal. The chemical literacy test was based on a rubric developed by Shwartz et al. (2006) and was content validated by three chemistry lecturers and two chemistry teachers. The quantitative part of the test comprised a five-point response scale: *mastery*, *competent*, *developing*, *emerging*, and *absent*. Students' chemical literacy was assessed qualitatively by presenting a vignette that stimulated them to identify questions and the sources of their information.

The data was produced during three distinct phases of the study. In the preliminary phase, the researchers interviewed the chemistry teacher and observed the culture of the class. In the implementation phase, the classroom observations and reflective journal focussed on how the project-based learning activities were implemented and developed students' chemical literacy. In the post-implementation phase, semi-structured interviews were conducted using open-ended questions to elicit information on students' learning experiences and the chemical literacy development. The interviews were conducted outside of the classroom, and took 10–15 minutes per student.

**Data Analysis**

The data was coded and analysed using both deductive and inductive approaches (Pope et al., 2000). The deductive approach was used to code the quantitative data generated by the chemistry literacy test and in accordance with the criteria identified by Shwartz et al. (2006), meanwhile an inductive approach was used to code the qualitative data obtained from the interviews, field notes, and reflective journal. The data were reduced by grouping, selecting, focussing, removing unnecessary items, and reorganising the data. The grouping of data was based on the Shwartz et al. (2006) components of chemical literacy. The data analyses are presented in tables, graphs, and narrative texts.

**Results and Discussion**

The STEM PBL approach was integrated in the normal allotted lesson time for teaching the topics of redox and electrolysis. The teacher provided the students with structured guidance, as this was their first experience with a STEM PBL approach. The following vignette illustrates the high level of engagement observed by the students during the whole STEM PBL process:

**Engaging Exploration**

An exploration activity was conducted in the class on the fourth meeting. I was happy seeing all group leaders able to manage their discussions — all of them seemed engaged in the activity. Group 1 used a white board to facilitate discussion; the leader sketched their ideas on the white board and designed the drawing for the etching process on the tumble. When I approached to monitor their activity, one student was excited to explain their design. Group 3 discussed how the etching process will take place and what product they will make. They shared their ideas with each other and sometimes asked for confirmation from the teacher. Student 1 asked "Ms, may we use two metal plates? We want to put the two metal plates side by side together so we will get a bigger size than this". I answered, "Yes, you may, but how will you stick them together? What will you use?". I left them with that question for their further thinking. After going around the class monitoring another group, I came back to them and asked, "So how?", and they replied, "No Ms, we cancelled that idea. It is impossible to stick the metal together with glue. We decided to just use this size and make a licence plate". They were busy measuring the metal plate and designing their sticker (Fieldnotes, F1).

This vignette demonstrates how the STEM PBL created engaging opportunities for students who had previously mostly only listened to their teacher's explanation of chemistry concepts.

Students enthusiastically took responsibility for creating and managing their own learning experiences, in negotiating how to achieve the project goal. Classroom observations indicated that the students generally enjoyed engaging in the STEM PBL activity from the outset.

In this study, students were encouraged to integrate the STEM principles in the etching project. The integration of STEM is shown in the following Table 1.

**Table 1:** Disciplinary Components of the STEM PBL Approach

| Discipline | Disciplinary Components |
|---|---|
| Science | - Understanding of redox and electrochemistry concepts<br>- Inquiry skills in applying scientific investigation |
| Technology | - Etching materials, process, and products<br>- Application of chemistry knowledge |
| Engineering | - Design of etching process<br>- Design thinking |
| Mathematics | - Calculating concentration of solutions, numbering, measurement, and geometrical shape<br>- Logical reasoning |

Working in groups, the students collaboratively designed and made three products, as follows:

***An Etched Tumbler***

Group 1 students applied the etching process to create a customised design on a metal tumbler (see **Figure 2**). The poster explains how the stainless steel tumbler was etched and that in everyday life, etchings can be applied to metal jewellery and to marking metal tools, such as a stainless steel ruler. In the presentation, they gave a chemical explanation about the electro-etching process.

**Figure 2**. Etching a Tumbler


### *Etching a Decorative Plate*

Group 2 used the volta series principle to etch a metal plate and create a beautiful pattern on its surface (see **Figure 3**). Their poster accurately explains etching as "a form of intaglio printing, where an image was created by cutting or engraving into a surface, but this time the ink is pushed into the cut lines". The poster further mentions the chemical reaction with $FeCl_3$ to create the decorative pattern on the metal, and they stated that in the real-world, etching can be used to create stamps with various artistic patterns.

**Figure 3.** Etching a Decorative Plate

***Etching a Mini Car Licence Plate***

Group 3 applied the principle of electrolysis to design and produce a mini car licence plate (see **Figure 4**). The image was designed using a computer and was printed on water durable adhesive paper, which served as a template for the etching process. The group presentation suggested that the etching process can be applied to design jewellery accessories, as a profitable small business.

**Figure 4.** Etching a Mini Car Licence Plate

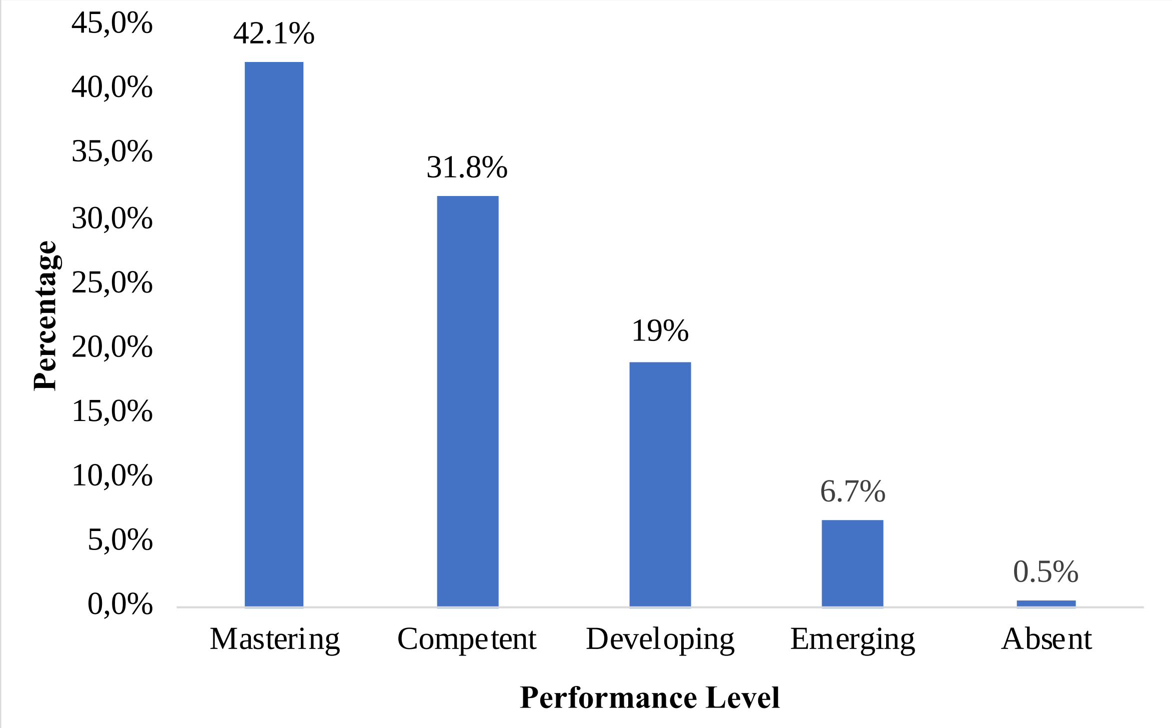

***Development of Chemical Literacy***

A chemical literacy test based on the five criterion was administered to determine how students' chemical literacy developed as a consequence of their participation in the project. The test result is tabulated below (see **Table 2**) and is presented on the graph (see **Figure 6**).

**Table 2:** Students' Chemical Literacy Development

| Performance Level | Percentage |
|---|---|
| Mastering | 42.1 |
| Competent | 31.8 |
| Developing | 19.0 |
| Emerging | 6.7 |
| Absent | 0.5 |

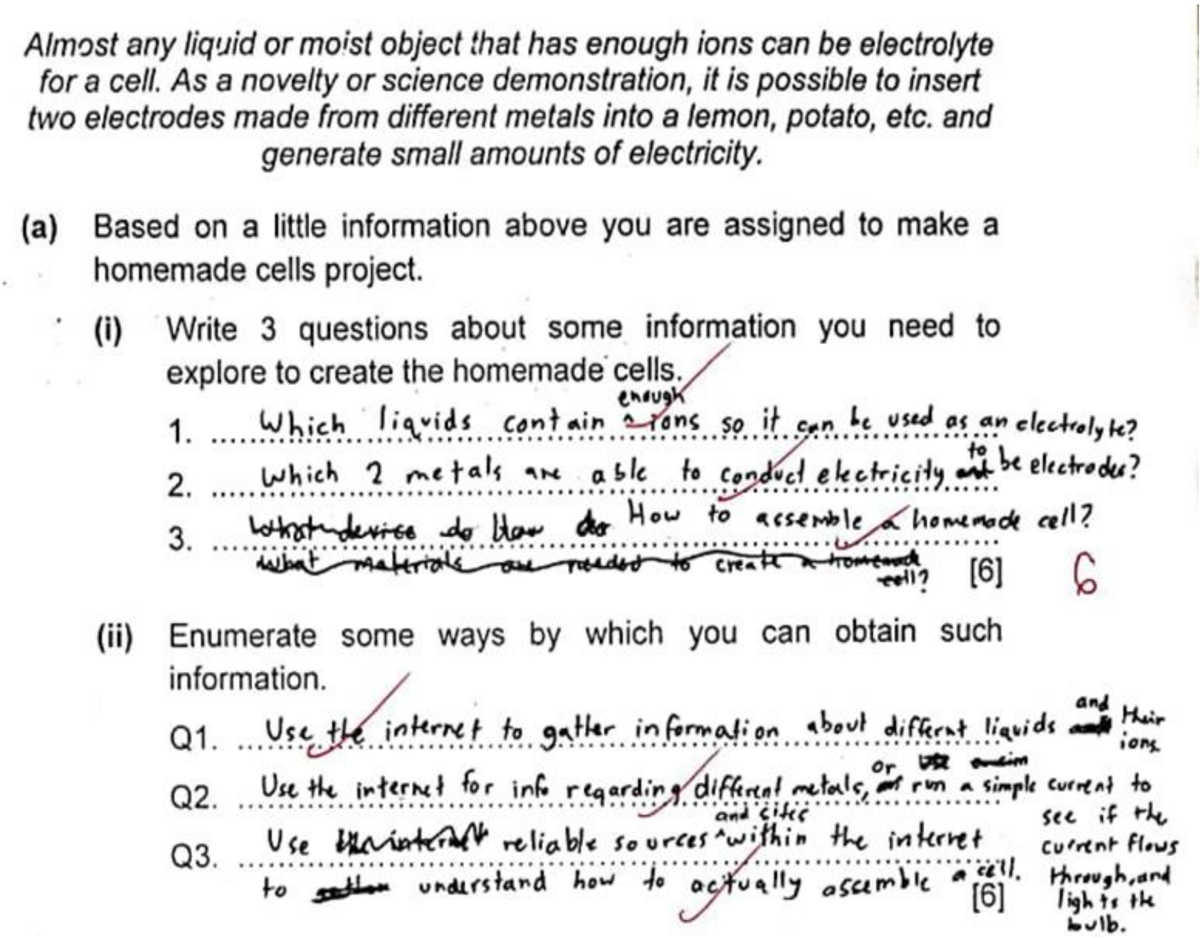
**Figure 6**. Students' Chemical Literacy Development




Analysis of the chemical literacy (see **Figure 6**) showed that nearly three-quarters (73.9 per cent) of the students' answers indicated a very good level of chemical literacy (42.1 per cent mastery, and 31.8 per cent competent). Most students were able to correctly answer questions, they could define electrolysis, and predict the product formed at the cathode and anode. Nevertheless, some could not use the definition they had memorised to identify the electrochemical cell used in industry diagrams, given as an electrolytic cell. Students also found difficulty in determining the use of pure copper at a particular electrode. In the question about predicting the observation result, few students were able to use their knowledge to explain macroscopic phenomena (ion transfer from anode to cathode, half-reaction, and concentration of the solution). Some students could predict the observation result correctly, but incompletely explained what happened in microscopic phenomena terms. Some attempted to explain the microscopic phenomena but because they did not have a solid understanding of the phenomena, failed to predict the observation result correctly.

In the chemistry in context questions, many students were able to see the use of redox and electrolysis and its consequences in both economic and environmental contexts. Higher order learning skills at the mastery level were evident with most students being able to generate thought-provoking questions to help them find the information needed to create homemade cells. They also knew where to look for the information, as illustrated in **Figure 7**.

**Figure 7.** Student Answer Showing Higher Order Learning Skill*s*


*Almost any liquid or moist object that has enough ions can be electrolyte for a cell. As a novelty or science demonstration, it is possible to insert two electrodes made from different metals into a lemon, potato, etc. and generate small amounts of electricity.*

(a) Based on a little information above you are assigned to make a homemade cells project.

(i) Write 3 questions about some information you need to explore to create the homemade cells.

1. Which liquids contain enough ions so it can be used as an electrolyte?
2. Which 2 metals are able to conduct electricity ~~and~~ to be electrodes?
3. ~~What devices do~~ ~~How do~~ How to assemble a homemade cell? ~~what materials are needed to create a homemade cell?~~ [6] 6

(ii) Enumerate some ways by which you can obtain such information.

Q1. Use the internet to gather information about different liquids ~~and~~ and their ions
Q2. Use the internet for info regarding different metals, or ~~use~~ run a simple current to see if the current flows through, and lights the bulb.
Q3. Use ~~the internet~~ reliable sources and sites within the internet to ~~settle~~ understand how to actually assemble a cell. [6]

Finally, the integration of the STEM helped students in understanding the chemistry concepts through hands-on learning. The teacher confirmed that students benefited from this STEM PBL experience, and furthermore, some weaker students were improving through this novel approach to learning:

"*I could see they learnt and enjoy a lot of their STEM PBL. The low achiever students got good marks, one of them is student 9. I am glad other low achiever students are making an improvement*" (Teacher interview, TW1).

The five components of chemistry literacy were also explored through each theme, which was analysed as discussed below.

### *General Scientific Ideas*

The students' initiative to conduct a scientific inquiry and draw conclusions are indicators of the General Scientific Ideas component of chemical literacy:

*"The electrolyte has to be able to conduct electricity so the present ions may get discharged. You can change the salt water into vinegar because it can ionise"* (Student Interview, Student 6).

Student 6 has explored the chemical issues of etching and is able to examine the importance of performing etching through an electrolyte aid. He knows etching will work if he uses another good electrolyte.

*"We used two types of metal — the theory (given activity guidance) only used one metal. We can actually understand the reactivity series between the two metals; copper is slower than aluminum"* (Student Interview, Student 15).

Student 15 conducted his scientific inquiry and proved the metal reactivity theory. The following is an excerpt of a dialogue between student 15 and the teacher during the exploration activities:

*Student 15:* *"Ms, may I ask [for] another metal plate for a further experiment?".*
*Teacher:* *"What is this for?".*
*Student 15:* *"I want to see its reaction and compare the result with Aluminium".*
*Teacher:* *"We have several kinds of metal. Here is zinc, copper, and lead. Which one do you want to try?".*
*Student 15:* *"Copper, Ms".*

In this dialogue, it can be seen that the STEM PBL stimulates the student's curiosity to explore further in order to improve his understanding. This is in line with Herro and Quigley (2016), who disclose that the transdisciplinary principle in PBL can lead students to a deeper understanding and enable them to solve complex problems in the real world. Generally, students asked questions and searched for information, did the experiment, and found appropriate answers. Students found that copper reacts more slowly with $FeCl_3$ than aluminum reacts with $FeCl_3$, and therefore, copper takes a longer reaction time to obtain the desired etching result. A similar understanding is evident in the reflective journal of student 7 (in Group 3):

*"I learned how to do electrolysis. I learned that [the] higher the voltage of the electricity, the faster the reaction will take place, but it does not have to be set up at the highest voltage. That lack of knowledge gives bad experience so the experiment was at first — we waited for a long time and nothing happened. After a few moments, we realised the cable was broken. The good experience was that finally our problem was solved, the experiment worked, and the product was satisfying"* (Student Reflective Journal, Student 7).

Group 3 set up the experiment and started the etching process straight away. They tried a variation of the voltage required for the process, gradually starting from a low voltage of 3V, then they raised it to 6V, and 9V. A moment later, they found that the bubbles did not appear as before. They observed once again ensuring to realise there was no reaction occurring. Student 7 and his group analysed the problem by trying to replace the power supply and cable. They concluded that even though the reaction speed was directly proportional to the applied voltage, the etching process should not always be performed at a high voltage, due to the cable's endurance that can exceed its maximum limit. Thus, they were able to conduct a scientific investigation, resolve the issue, and draw conclusions.

**Characteristics of Chemistry**

Students who recognised the characteristics of chemistry were able to use their own chemical knowledge to explain macroscopic phenomena through microscopic and symbolic terms in understanding chemistry concepts. Students were happy to work on the project but sometimes found difficulties in drawing connections to chemistry concepts:

*"In the beginning, I did not really get the link between [the] chemistry I have learnt in class with the etching project. After having hands-on [experience] of this etching and sharing knowledge within the group, I kind a got it how the redox reaction takes place with the aid of salt water as electrolyte"* (Student Interview, Student 2).

Understanding the microscopic in chemistry representations was challenging for students, therefore it is important for the teacher to facilitate students' understanding by making connections between the macroscopic and microscopic world. A student who had little understanding of the etching project was able to discuss the macroscopic phenomena of her group project after having had a brief introduction to the topic, and the opportunity to work on the etching project with her group:

*"Doing the project is important because it gives us other point of view of what we are learning. We experienced seeing the bubbles and the engraving, so we are not only seeing it from pictures. The oxidation reaction of the metal resulted in the engraving and the reduction of hydrogen ions forming hydrogen gas"* (Student Interview, Student 3).

Student 3 was able to write down the redox reaction that occurs in the etching process using Aluminum metal and a $FeCl_3$ solution when she saw the changes on the metal surface and the bubbles. Chemically literate students know that chemical knowledge is needed to explain the phenomena that occurs in life. This includes the principle that chemistry teaching is designed to promote understanding about macroscopic phenomena through microscopic and symbolic understanding (Shwartz et al., 2005). In the classroom, it is usually a significant learning challenge to develop a correlation between these three chemical representations. Students usually understand the symbol in chemistry reactions with a limited understanding of microscopic representation and observation of the macroscopic representation, as illustrated below.

Group 3 has set up the experiment and let the electrolysis reaction occur for a while.

*Student 1: "Guys, is there [a] reaction?".*
*Student 10: "Yes, it is".*
*Students were observing the dipped metal in the electrolyte.*
*Student 7: "Wait... I don't think the reaction is going on".*
*Student 10: "There were bubbles [a] few minutes ago".*
*Student 7: "Not anymore. There is no change in temperature either".*
*Student 1: "Yes, there are no bubbles anymore. What is going wrong here?".*
*Student rechecked the experiment setup to figure out the error.*

The students in Group 3 remembered the evidence of a chemical reaction, such as the formation of bubbles, temperature change, and so on. They were able to make use of related pre-knowledge in doing their project, which they used to explain the macroscopic phenomena that identifies an improper process.

**Chemistry in Context**

Knowing chemistry in context means that students are able to see the relevance of chemical knowledge and its usefulness in everyday contexts. It is an important process for developing chemical literacy and creating meaningful learning experiences. Etching as a topic of PBL motivated the students to investigate.

*"Etching doesn't require a lot of materials, you can just find at home, such as a battery, wires, saltwater solution. You can like etch your name onto it if you own it. Etching is different from just writing it down because etching is more concrete, more clean, and it won't go away. Unlike if you just write use a marker, it's probably gonna go away soon but etching won't"* (Student Interview, Student 6).

Student 6 understood etching very well, so he could see how it could be applied in a different situation.

*"The use of [a] sponge was for the physical protection — how we did not let the metal be dipped in the solution — by letting it float and cover the backside of the metal. If we dipped*

*the metal into the solution, it will etch the whole metal unless we needed to shade the whole backside of the metal with permanent marker. For the side of the metal, we taped and traced it with permanent marker, so it did not get etched from the side, and for the design we drew with permanent marker — only the area without the design that got etched by ferric chloride"* (Student Interview, Student 15).

Chemical reactions occur on the surface of metal plates exposed to chemical solutions. Student 15 understood that principle very well by using permanent markers that could physically protect the metal from being etched by chemical solutions, and used a sponge that was taped on one side of the metal, that allowed the metal to float, and made sure that the chemical reaction only occurred on one side. Their chemical knowledge was applicable in designing the decoration of the plate. The adding of a colourful painting resulted in a beautiful pattern on the metal.

*"A deeper knowledge about the application of chemistry is very useful. This is easy to do. I love it. I can try making creative accessories too at home. That will be good for my small business idea"* (Student Interview, Student 5).

Student 5 and her group explored etching and its procedure. They found some examples of etching on plates in daily life and thought of it creatively, as something that can be made into a business.

Cigdemoglu and Geban (2015) state that providing students with the knowledge of chemistry in various contexts of everyday life can develop their chemical literacy. Student 15 understood the usefulness of the electrochemical series in chemical reactions that can be applied to produce products that are useful for everyday life. The application of STEM PBL not only contributed to the development of students' chemical literacy, but was also a solution to the problem of the chemistry curriculum, which generally only discusses abstract theory and shows a lack of relevance, as revealed by Gilbert (2007).

*Students were gathered to discuss how to set up the experiment.*

*Student 3: "Hey, we can use this sponge to let the metal float so only one metal's side [is] dipped in the solution".*
*Student 15: "Yes, that's right. Student 9, you cut this sponge into halves!".*
*Student 9 cut the sponge.*
*Student 3 took the half-pieces of sponge and placed it on the back side of designed metal.*
*Student 3: "Student 15, help me tape this on the metal. Tape the side of the metal too for protection".*

This dialogue illustrates how students learned to work together in constructing knowledge through hands-on learning, problem-solving, and discussion.

**Higher Order Learning Skills**

Higher order learning is an ability to deal with new challenges. This ability is marked by learners becoming more active and flexible in their approach to learning, as they learn to ask questions and explore answers through different ways of learning, and as these students' statements demonstrate:

*"I explored deeper on electrolysis. I went to many resources to find out about the experiment setup, its duration, and the voltage needed. I made use of Google and YouTube to find articles and related videos"* (Student Interview, Student 1).

*"I explored more about the given task to find out about etching. I wanted to know what etching is, and how it works in chemistry reactions. I searched articles and also found out its procedures and required materials from YouTube"* (Student Interview, Student 15).

Student 1 was challenged to find out more about electrolysis and investigated the processes involved in how to run the electrolysis to make the licence plate. Meanwhile, student 15 was able to understand the concept of the etching process and how to apply it to the product that their group chose. STEM education encourages students to adopt logical and scientific thinking that stimulates and enriches their learning experiences (Bybee, 2010). STEM education develops curiosity and improves students' learning motivation. Students explored various ideas in their STEM PBL that led them to emphasise the use of logical reasoning, mathematics skills, experimental skills, and deep scientific thinking.

Higher order learning skills can also be seen through the students' ability to evaluate the problems encountered and to find solutions, as illustrated in one student's reflective journal comments:

*"The metal plate can be covered with the (permanent) marker. We drew our design and its result was good. In future, I will use a thicker metal plate with a longer time for the process, so the pop out part would be more visible"* (Student Reflective Journal, Student 15).

Student 15's group met an obstacle — their design could not be printed on the sticky paper. However, because they had understood the principle of the etching process, they were able to find instant solutions by using a permanent marker in lieu of their design on the sticky paper. At the end of the experiment, they found that the etching results did not 'pop out' enough, so the quality of the decoration on the plate was less satisfactory. They then suggested to allow for a longer reaction time for future experiments.

Group 1 also demonstrated higher order thinking skills, as recorded in the following first researcher's fieldnotes:

*"After group 1 finished their presentation, the teacher asked about any improvement that could be done in the future. Student 6 answered that it is better to use a better sticky paper as the stencil; it should not absorb water easily, so the etching result would be neater and will give the design look that is supposed to be"* (Fieldnote, F2).

Group 1 has just finished doing the presentation.

*Observer 3:* *"Please evaluate and reflect on your work".*
*Student:* *"We think we are able do this etching project pretty well. The process ran smooth, not many difficulties. It is just the drawing on the tumbler that is still not that excellent".*
*Observer 3:* *"What thing can you improve to have a better one next time?".*
*Student:* *"We can improve on the sticky paper we use. It must be high quality so the drawing on the metal would be neat and perfect".*

Group 1's etching results were not satisfactory compared to their design plan. They were able to evaluate the etching results by looking at how the process was conducted before. They asked questions, suggested what caused it, and found solutions to use an adhesive paper that is more water resistant.

**Affective Aspects**

Affective aspects were demonstrated through the students' general interest, curiosity, and motivation in chemistry learning. Students enjoyed the hands-on experience with the problem compared to what they had read previously. They also developed collaboration and communication skills as they worked together.

*"It is fun when I did the project because I can see instead of just reading from the book. It is more understandable. I also learned to work with others in developing the project"* (I15).

*"I don't get chemistry that easily. I think if we do more experiments, I will like chemistry more because practical activity teach[es] skill. I like science in general"* (I5).

All students expressed excitement when they were successful in completing the project. They enjoyed the activities that reflected the theories found in their textbooks. Wheeler, Whitworth, and Gonczi (2014) suggest that STEM PBL attracts students' interest and they become excited when they are trying to succeed. Learning activities also become fun as students realise the benefits of working together to solve problems that challenge their thinking. In short, what they experience is more memorable than what they just read in textbooks.

*"I love doing practical work because you actually do it. I like theory, I like explaining but it is better to practically do it so you get like the sense of "ooh this how you do it", and communicate with others, and "this is what is gonna happen in real life". It is so fun. It's better if you do it first-hand, like you experience it instead of just watching someone else do it"* (I6).

An integrated STEM PBL approach can enhance motivation and involvement in learning (Henrkisen et al., 2015) with students learning to actively engage deeply in their learning. Smith and Karr-Kidwell (2000) state that the application of an integrated STEM approach aims to provide complete learning, connecting various disciplines so that learning becomes meaningful and relevant to everyday life.

## Conclusion

The results of this study indicate that integrated STEM PBL in chemistry learning stimulated the affective aspects of developing chemical literacy, and bringing students to a deeper conceptual understanding through their experience of practising what has been previously learned only from textbooks. By means of engaging in multidisciplinary hands-on experiments, students were able to better see the relevance and importance of chemistry in daily life (i.e., chemistry in context). They found that an enjoyment of learning motivated them to further study chemistry, as it stimulated their curiosity and creativity. Their newfound curiosity prompted them to raise questions and encouraged them to look for new information, and to undertake scientific inquiry to find their own answers (i.e., higher order learning skills). Furthermore, they also developed collaboration and communication skills as they worked together to investigate the phenomena.

Based on the students' responses, it can be inferred that the project helped to cultivate the seeds of chemical literacy. However, while the findings of this study shed light on how students' chemical literacy can be enhanced through a well-planned STEM PBL method, the small number of participants in this study limits the generalisation of these findings. Future research is needed to explore the application of STEM PBL to enhance the chemical literacy of all students.

**Acknowledgements**

We would like to thank the Ministry of Education and Culture, Indonesia for the research grant, and the Universitas Negeri Jakarta, and the school for their support.

**REFERENCES**

American Association for the Advancement of Science. (1989). *Project 2061. Science for all Americans,* Washington, DC: American Association for the Advancement of Science.

Brady, J. E. (2009). *Chemistry: matter and its changes*. Hoboken: John Wiley & Sons.

BouJaoude, S. (2010). Balance of scientific literacy themes in science curricula: The case of Lebanon. *International Journal of Science Education*, *24*(2), 139–156.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*,*70*(1), 30-35.

Chittleborough, G. (2014). *Learning with Understanding in the Chemistry Classroom. The Development of Theoretical Frameworks for Understanding the Learning of Chemistry*. Dordrecht, Netherlands: Springer Science+Business Media B.V.

Cigdemoglu, C. & Geban, O. (2015). Improving Students' Chemical Literacy Levels on Thermochemical and Thermodynamics Concepts through a Context-Based Approach. *Chemistry Education Research and Practice*, *16*(2), 302-317.

Connor, A. M., Karmokar, S. & Whittington, C. (2015). From STEM to STEAM: strategies for enhancing engineering & technology education. *International Journal of Engineering Pedagogy*, *5*(2), 37–47.

Cresswell, J. W. (2005). Educational reserach: Planning, conducting, and evaluating quantitative and qualitative research (second edition ed.). New Jersey: Pearson Education, Inc.

Ergül, N. R. & Kargın, E. K. (2014). The Effect of Project Based Learning on Students' Science Success. *Procedia - Social and Behavioral Sciences*, 136, 537–541.

Firman, H. (2016). Pendidikan STEM sebagai kerangka inovasi pembelajaran kimia untuk meningkatkan daya saing bangsa dalam era masyarakat ekonomi ASEAN. *In Proceedings Seminar Nasional Kimia dan Pembelajarannya*, 1–7.

Gabel, D. L. (1998). The complexity of chemistry and implications for teaching. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 233–248). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gilbert, J. K. (2005). Chemical Literacy: An Approach Through Models and Modelling. *In Proceedings 7th ECRICE 3rd ECCE Ljubljana, Slovenia*, 15-29.

Gilbert, J. K. (2007). On the nature of "Context" in Chemical Education. *International Journal of Science Education*, *28*(9), 957–976.

Gilbert, J. K. & Treagust, D. F. (2009a). Introduction: Macro, Submicro and Symbolic Representations and The Relationship Between Them: Key Models in Chemical Education, Multiple Representations in Chemical Education. In: Gilbert J.K., Treagust D. (eds) *Multiple Representations in Chemical Education. Models and Modeling in Science Education*, vol 4. Dordrecht, Netherlands: Springer.

Gilbert, J. K. & Treagust, D. (Eds.). (2009b). Multiple Representations in Chemical Education. Dordrecht, The Netherlands: Springer.

Gültekin, M. (2007). The Effect of Project Based Learning on Learning Outcomes in the Fifth-Grade Science Education. *Elementary Education Online*, *6*(1), 93-112.

Hadinugrahaningsih, T., Rahmawati, Y., & Ridwan, A. (2017). Developing 21st century skills in chemistry classrooms: Opportunities and challenges of STEAM integration. *AIP Conference Proceedings*, 1868. https://doi.org/10.1063/1.4995107.

Henrkisen, D., DeSchryver, M., Mishra, P., Deep-Play Research Group (2015). Rethinking technology & creativity in the 21st century transform and transcend: synthesis as a trans-disciplinary approach to thinking and learning. *TechTrends*, *59*(4), 5-9.

Herro, D., & Quigley, C. (2016). Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. *Professional Development in Education. 43*(3), 416-438.

Kloppenborg, T. J. & Baucus, M. S. (2004). Project Management in Local Non Profit Organizations: Engaging Students in Problem Based Learning. *Journal of Management Education*, *28*, 610-630.

Ministry of Education and Culture. (2016). *Lampiran Peraturan Menteri Pendidikan Dan Kebudayaan Nomor 20 Tahun 2016 Tentang Standar Kompetensi Lulusan Pendidikan Dasar Dan Menengah Bab. 2016*. [Attachment of Regulation of the Minister of Education and Culture No. 20 of 2016 on Competency Standards of Primary and Secondary

Education Graduates Chapter. 2016]. http://bsnp-indonesia.org/wp-content/uploads/2009/04/Permendikbud_Tahun2016_Nomor020_Lampiran.pdf.

National Research Council. (1996). *National Science Education Standards*. Washington, DC: The National Academies Press.

OECD. (2006). *Assessing scientific, reading and mathematical literacy: a framework for PISA 2006*, Paris: OECD Publishing.

Osborne, J., Dillon, J., & Nuffield Foundation. (2008). *Science education in Europe: Critical reflections: a report to the Nuffield Foundation*. Retrieved from

Oxtoby, D.W., Nachtrieb, N. H., & Gillis, H. P. (2001). *Principles of modern chemistry*. London: Brooks Cole.

Pangesti, K. I., Yulianti, D., & Sugianto. (2017). Bahan Ajar Berbasis STEM (Science, Technology, Engineering, and Mathematics) untuk Meningkatkan Penguasaan Konsep Siswa SMA. Unnes *Physics, Education Journal*, *6*(3), 53-58.

Pertiwi, R. S., Abdurrahman, & Rosidin, U. (2017). Efektivitas LKS STEM Untuk Melatih Keterampilan Berpikir Kreatif Siswa. *Jurnal Pembelajaran Fisika*, *1*(1), 11–19.

Pfundt, H. & Duit, R. (2000). *Bibliography: student's alternative frameworks and science education*. Kiel: University of Kiel.

Pope, C., Ziebland, M., & Mays, N. (2000). *Analysing Qualitative Data: In: Qualitative Research in Health Care*. *320*(7227), 114-116.

Rahmawati, Y. (2013). *Revealing and reconceptualising teaching identity through the landscapes of culture, religion, transformative learning, and sustainability education: a transformation journey of a science educator: PhD thesis.* Bentley: Curtin University.

Rahmawati, Y. & Koul, R. (2016). Fieldwork, co-teaching and cogenerative dialogue in lower secondary school environmental science. *Issues in Educational Research*, *26*(1), 147-164.

Rahmawati, Y. & Ridwan, A. (2017). Empowering students' chemistry learning: The integration of ethnochemistry in culturally responsive teaching. *Chemistry: Bulgarian Journal of Science Education*, *26*(6), 813-830.

Roehrig, G. H., Moore, T. J., Wang, H.-H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44.

Septiani, A., & Rustaman, N. Y. (2017). Implementation of Performance Assessment in STEM (Science, Technology, Engineering, Mathematics) Education to Detect Science Process Skill. In *Journal of Physics*: Conference Series, 9, 3–10.

Shwartz, Y., Ben-Zvi, R., & Hofstein A. (2005). The importance of involving high-school chemistry teachers in the process of defining the operational meaning of 'chemical literacy'. *International Journal of Science Education*, *27*, 323-344.

Shwartz, Y., Ben-Zvi, R., & Hofstein, A. (2006). Chemical Literacy: What Does This Mean to Scientists and School Teachers? *Journal of Chemical Education*, *83*(10), 1557-1561.

Sheffield. R. Koul, R., Blackley, S., Fitriani, E. Rahmawati, Y., & Resekc, D. (2018). Transnational Examination of STEM Education. International Journal of Innovation in Science and Mathematics Education, *26*(8), 67–80.

Smith, J. & Karr-Kidwell, P. (2000). The interdisciplinary curriculum: A literary review and a manual for administrators and teachers. *Retrieved from ERIC database*. (ED443172).

Suprapto, N. (2016). Students' attitudes towards STEM education: Voices from Indonesian junior high schools. *Journal of Turkish Science Education*, *13*(Special Issue), 75–87.

Suwarma, I. R. (2014). A Research on STEM Education Theory and Practices Method in Japan and Indonesia Using Multiple Intelligences Approach. Shizuoka University. Retrieved from http://jairo.nii.ac.jp/0063/00007768/en.

Taber, K. S. (2002). *Alternative Conceptions in Chemistry: Prevention, Diagnosis and Cure?* London: The Royal Society of Chemistry.

Talanquer, V. (2011). Macro, Submicro, and Symbolic: The many faces of the chemistry 'triplet'. *International Journal of Science Education*, *33*(2), 15, 179–195.

Trilling, B. & Fadel, C. (2009). *21st century skills learning for life in our times*. San Francisco, CA: John Wiley & Sons.

Tsaparlis, G. (2000). The States-of-Matter Approach (SOMA) to Introductory Chemistry. *Chemistry Education Research and Practice*, *1*(1), 161-168.

Wheeler, L, Whitworth, B dan Gonczi, A. (2014). Engineering Design Challenge: Building a Voltaic Cell in The High School Chemistry Classroom. *The Science Teacher*, *81*(9), 30-36.

Winterman B, Malacinski G. M. (2015) Teaching evidence-based innovation (EBI) as a transdisciplinary professional skill in an undergraduate biology writing workshop. *International Journal of Arts and Sciences*, *8*(2), 423-439.

Wisudawati, A. W. (2018). Science Technology Engineering and Mathematics (STEM) education approach against a microscopic representation skills in atom and molecule concept, *International Journal of Chemistry Education Research*, *2*(February), 2–6.

Wright, et al. (2016). Both Theory and Practice: Science Literacy Instruction and Theories of Reading. *International Journal of Science and Mathematics Education*, *14*, 1275–1292.