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THE INTEGRATION OF GREEN CHEMISTRY PRINCIPLES INTO SMALL SCALE CHEMISTRY PRACTICUM FOR SENIOR HIGH SCHOOL STUDENTS

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ABSTRACT

Implementation of Principles of Green Chemistry in teaching chemistry can become an essential approach to enhance students' awareness of environmental problem. In contrast with the goal of sustainability, chemistry practicum normally deals with chemicals and waste management which contribute to environmental problem. A shift toward more sustainable and economical experiments is essential to maintain the existence of the practicum in senior high curriculum. Small Scale Chemistry (SSC) practicum is one of the approaches to promote sustainability in chemistry practicum by using smaller scale and safer apparatus. It is expected to produce less waste. It is also safer and more economical chemistry experiment. This research aims to study the integration of principles of green chemistry in chemistry practicum by using SSC experiment. This study investigates two main topics in senior high school chemistry subject: electrochemistry and acid-base indicator. This study has shown the practice of integration of the principles of green chemistry approach into senior high school chemistry practicum through SSC. The experiments demonstrated in this study enable us to integrate Principles of Green Chemistry in terms of preventing waste, using less hazardous chemical, and conducting safer experiments which can be implemented in senior high school chemistry practicum.

Keywords: small scale chemistry (SSC), senior high school chemistry practicum, green chemistry

INTRODUCTION

Society today should be more alert with environmental issues such as waste pollution and energy consumption. Students as a part of society should be aware of environmental issues so they can contribute to the development of the present and future society. It is important to expose the students with environmental problems to improve their awareness of environmental issues. The aforementioned idea is in line with the goal of sustainable development. Sustainable development addresses global challenge related to inequality in education, climate, environmental degradation, prosperity, peace, and justice. Sustainable development ascertains that people now and in the future can live in a sustainable and harmonious life (UNESCO, 2017; Owens, 2017).

Universities act as one agent to promote sustainability. Universities need to prepare the students way of thinking and acting to become sustainability change-makers. Thus, chemistry

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education should take part in promoting sustainability for today and future society (Burmeister & Eilks, 2013; Hamidah et al., 2017). Sustainability in the university can be implemented by integrating it into curriculum and practice. Green Chemistry can be used as an approach to promote students' literacy toward environmental issues.

Green Chemistry, also known as sustainable chemistry was proposed around twenty years ago (Anastas & Warner, 1998). Green Chemistry provides twelve principles for designing the chemistry process with the goal of inherently of less risk to human health and the environment. Green chemistry supports the goal of sustainability and covers a bigger scope including teaching, research laboratory, as well as chemical industries. Green Chemistry has 12 principles, namely: "(1) prevention; (2) atom economy; (3) less hazardous chemical syntheses, (4) designing safer chemicals; (5) safer solvents and auxiliaries; (6) design for energy efficiency, (7) use of renewable feedstock; (8) reduce derivatives; (9) catalysis; (10) design for degradation; (11) real-time analysis for pollution prevention; and (12) inherently safer chemistry for accident prevention" (Anastas & Warner, 1998; Nurbaity et al., 2016).

It is important to promote Green Chemistry as a mindset in teaching and working at the laboratory. The integration of Green Chemistry in university has been explicitly taught through a course in the level of undergraduate or graduate program (Gross, 2012; Haley et al., 2018; Kennedy, 2015). Green Chemistry is also implemented in chemistry teaching with integration in organic chemistry or basic general chemistry (Mitarlis & Yonata, 2018; Timmer et al., 2018).

A research shows that the effect of teaching and learning is through laboratory work (Andraos & Dicks, 2012). In reality, chemistry learning cannot be separated from practical work or laboratory work. Practical work allows the students to improve the conceptual understanding, master the practical laboratory skill, and gain learning motivation (Ural, 2016; Tesfamariam et al., 2017). Practical work in chemistry gives students opportunities to gain laboratory skills through scientific investigations and hands-on activities Thus, practical work enhances learning and development of conceptual understanding (Abdullah et al., 2009). However, practical work sometimes is excluded from chemistry because of the lack of resources. Theoretical class integrated with experimental works is a good holistic experience in learning chemistry.

Learning chemistry integrated with practical work is vital. despite the expensive cost in equipment and chemicals. Chemistry experiment in school and universities are generally related to the big size of glassware and toxic chemicals. In contrast with the goal of sustainability, chemistry experiments normally deal with chemicals; product disposal, excess reagents, solvent and waste production which contribute to environmental problem. Another challenge is the health hazard in the laboratory for the students, teacher, and laboratory staff. A shift toward a more sustainable and more economical experiment is needed.

These challenges can be solved by using Green Chemistry principles. A direct application of Green Chemistry can be seen clearly in laboratory work by minimizing the production of waste, replacing toxic, dangerous, and nonrenewable material. It makes sense to "greening" the experiment and moving toward more sustainable and economical experiments. In addition, Small Scale Chemistry (SSC) is introduced as a solution to tackle the shortage and high cost of laboratory facilities problems.

Small Scale Chemistry (SSC) or microscale chemistry is an approach of conducting chemistry experiments using a reduced scale using small quantities of chemicals and often, but not always, simple equipment along with a change of the glassware materials to plastic materials (Mafumiko et al., 2013; Sattsangi, 2010; Singh et al., 1999; Tesfamariam et al., 2014). SSC promotes cost saving, health safety, pollution prevention, and environmental friendliness by using smaller glassware with reduced amount of chemicals. The experiments can be done hands-on by each individual to enhance the students to endeavor as well as experience in chemistry (Zakaria et al., 2012). In addition to its great advantages in environmental, economic, and safety, SSC suggests a deeper benefit in pedagogy (Mafumiko et al., 2013) including: (1) promoting students' engagement and collaborative learning in hands-on learning experiences; (2) gaining students' courage in dealing with small amounts of chemicals; (3) carried out in faster time thus students can accomplish more in the laboratory; (4) obtaining enjoyment in class by the reduced laboratory work; and (5) promoting students' work ethics in material conservation.

The advantages of SSC are improving students' laboratory skill and boosting their confidence by conducting experiments in smaller quantity of chemicals. By dealing with smaller quantity of material, students can save their time for further discussion and reflection. Besides, SSC promotes students' conscience by preserving chemicals. In brief, SSC supports the goal of sustainability in education. In Indonesia, presumably Green Chemistry principles and SSC with their relation to sustainability in chemistry education are still not widely known to university and senior high school students (Hamidah et al., 2017; Listyarini, 2019). Green chemistry and SSC have the same purpose of minimizing the destructive effect of chemistry in the environment and human health (Duarte et al., 2017; Rojanarata et al., 2011). Therefore, Green Chemistry and SSC approach can be used together for pedagogy.

An attempt to study the integration of Green Chemistry principles in chemistry education needs to be made. The integration of Green Chemistry and SSC into senior high school practicum is expected to promote "green" pedagogies and sustainability in education. This study aims to investigate the possibility of integration of Green chemistry and SSC approach as an alternative way of learning chemistry experiments in Indonesia. This research examines Green chemistry and SSC approach in two main topics: electrochemistry and acid-base indicator for senior high school practicum. As a part of the collaboration between Sanata Dharma University and Sogang University, Korea, this study strives to make Green Chemistry and SSC become widely known in Indonesia to support the goal of sustainability in chemistry education.

METHODS

This research used the approach of Development research with 4D development model (Define, Design, Development, and Disseminate), limited to Development stage. The method of data collection includes literature review, experiment, and questionnaires. Data collection was conducted to answer the possibility of integration of Green Chemistry principles into senior high school practicum. Literature reviews were used for determining topic for experiments that are designed to be developed. Experiments in this study were carried out using SSC kit obtained from Sciencemarket Korea. SSC kit consists of several pieces of equipment which can be used to conduct basic chemistry experiments in class. Experiments that have been designed were tested on Chemistry Education study program students (34 students) of Sanata Dharma University in July 2018 and January 2019. The questionnaire was used to investigate the students' perception related to the possibility of integration of Green chemistry principles and SSC approach in electrochemistry and acid-base indicator experiments.

(a) (b)

Figure 1. (a) SSC Kit; (b) Several Pieces of Equipment inside SSC Kit

RESULTS AND DISCUSSION

The early stage of this study was determining the topic for experiments to be developed. Literature reviews were used to deciding the topic for experiments. The experiment covers the two main topics which are electrochemistry, in particular, making Daniell cell and acid-base indicator. Electrochemistry is one of the topics taught in senior high school chemistry subject and general/physical chemistry at undergraduate level studies. Understanding oxidation-reduction or redox reaction in electrochemistry is important because it explains daily phenomena for instance battery and combustion reaction. Contextual learning related to daily life or local context is one of the goals of education for sustainability (UNESCO, 2017; Owens, 2017). However, "electrochemistry is one of the most difficult curriculum domains taught and learned in secondary school chemistry ranked by teachers and students" (Ahmad & Lah, 2013; Eggen, 2010; Supasorn, 2015). The students must deal with complicated reaction and concepts. One of the sources to improve the understanding and motivation of students in learning electrochemistry topic is by using experiments, therefore, this topic was chosen. Practical work in learning chemistry promotes enjoyment and interest in the mastery of chemistry topics.

Daniell Cell Experiment

The common model of galvanic works with a salt bridge connecting the anode electrode of a zinc sulfate solution and an immersed zinc plate as well as the cathode electrode of a copper sulfate solution (Dong et al., 2014; Eggen, 2010). The representation of Daniell cell is presented in Figure 2.

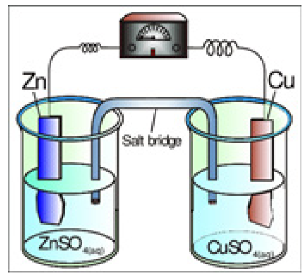

Figure 2. Daniell Cell (Dikmenli et al., 2015)

The electrochemical cells produce current to run a LED (Eggen, 2010). The chemical reaction taking place in anode zinc is oxidation as follows:

$$Zn_{(s)} \rightarrow Zn^{2+}(aq) + 2e^{-}$$

Cathode copper will be reduced as follows:

$$Cu^{2+}_{(s)} + 2e^{-} \rightarrow Cu(aq)$$

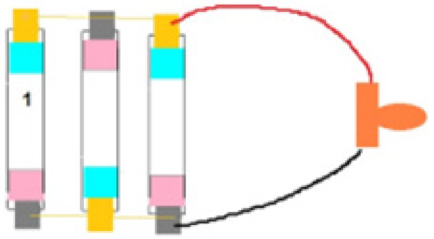

Figure 3. Daniell Cell Design Using SSC Approach

The modification of Daniell cell had been rebuilt in the previous studies, for instance, using Li-ion exchange film (Dong et al., 2014); using separated small homemade clay container for copper and zinc plates (Eggen, 2010), and using small bottle containing copper and zinc plates (Khattiyavong et al., 2014; Supasorn, 2015).

In this study, SSC approach was used to reconstruct the Daniell cell. The design of Daniel cell using SSC approach was presented in Figure 3. One straw is prepared and divided into three small pieces. Copper plate (yellow) was covered with a small blue flannel and placed inside a small piece of straw. $CuSO_4$ solution was dripped into blue flannel and covered the copper plate. The straw was put in a reversed direction filled with resin and Na_2SO_4 solution (white part in the middle straw, 1). Na_2SO_4 solution is used as salt bridge. Zinc plate (grey) covered with pink flannel is put at the other end of the straw. $ZnSO_4$ solution was dripped into blue flannel and covered the silver plate. The three small straws filled with zinc-copper plate and electrolyte solution were arranged in series and connected to a small LED lamp. The current produced by Daniell cell was used for running the LED lamp. This attempt was successfully conducted and proved in Figure 4.

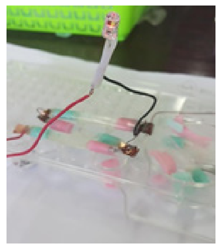

Figure 4. Daniell Cell Produces Current to Run LED Lamp

Daniell cell presented in this study is smaller in terms of the amount of solution and material used compared with the Daniell cell designed by Khattiyavong et al. (2014). It needed only a couple drops of electrolyte $CuSO_4$ and $ZnSO_4$ solution. The size of the copper and zinc plate is relatively small around 5 mm, the same as the radius of a small straw. The design of Daniell cell experiment was integrated with Green Chemistry. The integration of Green Chemistry in the Daniell cell experiment is presented in Table 1. The experiment of Daniell cell employs at least two principles of Green Chemistry in terms of prevention of waste and safety for accident prevention. In terms of prevention of waste, Daniell cell with SSC approach uses a small copper and zinc plate as electrode, uses small amount of electrolyte solution, and produces small amount of waste. In terms of safety for accident prevention, Daniell cell uses SSC kit equipment which consists of plastic equipment. The other advantages of this Daniell cell are the little amount of effort and time needed to construct the cell. The new reconstruction of Daniell cell using SSC approach is expected to be feasibly implemented in senior high school chemistry practicum.

Acid-Base Indicator

Another interesting topic in senior high school chemistry experiment is acid-base indicator. Acid-base indicator can be described as halochromic chemical agents which are added in small amount to a solution to determine the pH (acidity or basicity) of the solution visually and change the color with variation in pH (Khalid et al., 2015; Sharma et al., 2013; Vyas et al., 2012). Acid-base indicator is usually weak base or acid which partly dissociates in water. Several plants and flowers contain a possible compound which can act as an acid-base indicator.

Anthocyanins are found in the flower and fruits of natural plants as secondary metabolites. The structure of anthocyanins is provided in Figure 5. Because of their color change in different pH and broad color spectrum, anthocyanins can be used as a pH indicator (Choi et al., 2017; Prietto et al., 2017). Anthocyanins are highly unstable and easily degraded. The stability is affected by pH, temperature, light, and concentration (Khan & Farooqui, 2011). The structure of anthocyanins changes under different pH conditions. Oxonium ion becomes colorless when H^+content is decreased and eventually becomes blue under basic condition. Anthocyanin naturally occurs for instance in red cabbage which is easily obtained from the market. This study used the anthocyanins from the red cabbages as an acid-base indicator.

Table 1. Integration of Green Chemistry in SSC Experiment

Experiments	Principles of Green Chemistry	Integration in the experiment
Daniel Cell experiment	Prevention	Using a small piece of copper and zinc plate as electrode Using a small amount of electrolyte solution Producing a small amount of waste
	Inherently safer chemistry for accident prevention	Using SSC kit made of plastic material
Acid-Base indicator	Prevention	Using small amount of solution Producing small amount of waste
	Use of renewable feedstock	Using alginate and red cabbage as ingredients
	Inherently safer chemistry for accident prevention	Using SSC kit made of plastic material

Acid-base indicator experiment using natural compounds is usually made using only the solution or paper/film. This study attempts to develop acid-base indicator more interestingly by using alginate ball.

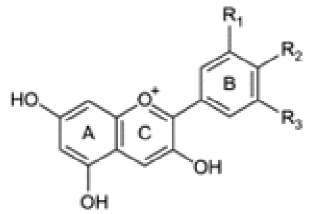

Figure 5. Structure of Anthocyanins (Valavanidis & Vlachogianni, 2013)

Alginate is a natural polysaccharide obtained from brown algae and is generally used as an emulsifier and thickening agent in food. The first attempt to use alginate bubbles as acid-base indicator was named "Chameleon bubbles" (Biswas et al., 2012). Dittmar et al. (2016) designed inquiry experiments with alginate bubbles. In this study, it was attempted to make alginate ball using SSC approach. Red cabbage extract was obtained from a fresh red cabbage in the market. The red cabbage extract was mixed with alginate powder and heated around 40 °C.

In a small plastic cube, calcium chloride solution was prepared. The alginate red cabbage mixture was added at a dropwise using plastic pipette into calcium chloride solution at room temperature. The shape and color of the balls were presented in Figure 5. The balls were collected and washed with water, and they were ready to be used as an acid-base indicator.

Figure 5. Red Cabbage Alginate Ball

Several samples, for instance vinegar, lime juice, HCl solution, CaO solution, ammonia solution and fruit juice, were prepared in each of the small wells. The balls were put in a different sample and the change in the colors of the balls can be seen in Figure 6.

Figure 6. Red Cabbage Alginate Balls Color in Different Sample (Left to Right: Vinegar, Lime, HCl, CaO, Ammonia, Fruit Juice)

The color of red cabbage alginate ball changed to a different sample. The color becomes red in acid solution such as vinegar, HCl solution, and fruit juice. The color becomes green in a basic condition such as CaO solution and ammonia solution. The color change for red cabbage indicator can be described using the chart in Figure 7.

Figure 7. Color Change Chart Bar of Red Cabbage (Taken from https://warwick.ac.uk)

Red cabbage alginate balls were prepared using SSC approach. The amount of red cabbage alginate solution, calcium chloride was reduced. The equipment used for making red cabbage alginate balls were made from plastic; for instance, plastic pipettes, plastic glass, plastic petri dish, except for mixing red cabbage and alginate powder that used a beaker glass.

The design of red cabbage alginate balls was integrated with Green Chemistry. The integration of Green Chemistry was presented in Table 1. The experiment of red cabbage alginate balls employed at least three principles of Green Chemistry in terms of using the renewable feedstock, prevention of waste, and safety for accident prevention. In terms of using renewable feedstock, this acid-base indicator used red cabbage and alginate as the main ingredients. Both of these ingredients are renewable sources which are environmentally friendly and easy to degrade. In terms of prevention waste, the amount of solution used in this reaction was reduced, no excess waste was produced. In terms of safety for accident prevention, red cabbage alginate balls used SSC kit consisting of plastic equipment.

The students' perception related to the integration of Green chemistry principles and SSC approach in electrochemistry and acid-base indicator experiments was investigated using a questionnaire. Prior to these experiments, the students had taken Green Chemistry Principles course (2 credits) in the preceding semester. The students strongly agree (55.8%) that Green Chemistry principles can be integrated with SSC approach into chemistry practicum as presented in Figure 8. The results are also supported by statements from the students.

P6: "I strongly agree because Green Chemistry principles are principles that apply the use of chemicals that are easily renewable and non-detrimental and of course when balanced with SSC it will be very efficient in its application."

P10: "Green Chemistry principles suggest the production of less waste, using harmless material that can be renewed or easily obtained. It is better to use a more efficient, more practical, and safer way when conducting an experiment to minimize accidents. This can be achieved by using smaller amount of chemicals and equipments with SSC approach."

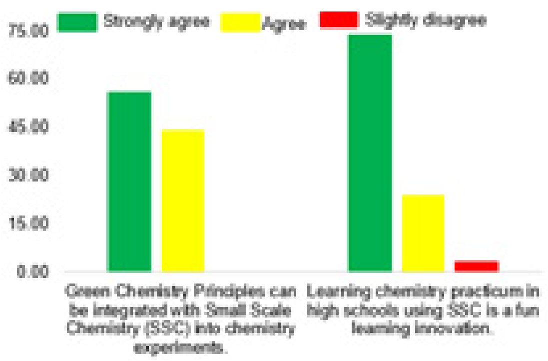

Figure 8. Students' Perception Related to Integration of Green Chemistry Principles and SSC Approach in Electrochemistry and Acid-Base Indicator Experiments

In addition, the students strongly agree (75.33%) that SSC approach can be used as a learning innovation in senior high school chemistry practicum. This statement is also supported by the statements from the students.

P1: "By applying the principles of Green Chemistry and SSC approach, students will better understand the material of practicum and be more creative in learning"

P17: "I feel that this innovation is very good for learning chemistry. On the one hand, I can study chemistry through SSC and I can also take care of the environment with the principles of green chemistry."

The results indicate that the integration of Green Chemistry principles and SSC approach in developing and reconstructing senior high school chemistry practicum was practicable and achievable.

CONCLUSION

The experiment conducted shows that SSC approach can be used for studying chemistry such as electrochemistry, in particular, Daniell cell and acid-base indicators. SSC approach can be used for reconstructing Daniell cell. The integration of Green Chemistry principles is in terms of waste prevention and conducting safer chemistry for accident prevention by using SSC kit. Also, SSC approach can be used for creating alginate ball acid-base indicators. The integration of Green Chemistry principles is in terms of using renewable feedstock, preventing waste, and conducting safer chemistry experiments by using SSC approach.This study has shown that Green Chemistry principles complement the SSC approach. It is practicable to use both approaches by integrating Green Chemistry principles into senior high school chemistry practicum through SSC experiments. This study provides an alternative way of learning chemistry experiment in Indonesia.

This study is expected to make Green Chemistry principles and SSC become widely known in Indonesia. The findings of this study are supposed to help educators and students to reach sustainability goal in chemistry education by creating less waste, using less hazardous chemical, and conducting safer experiments.

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