Pertanika J. Soc. Sci. & Hum. 25 (S): 41 - 50 (2017)

PERTANIKA JOURNALS

SOCIAL SCIENCES & HUMANITIES

Journal homepage: http://www.pertanika.upm.edu.my/

Development of the Science Skills of Lower Secondary Students in a Chemistry Laboratory Experiment

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ABSTRACT

The aim of this study is to determine the existence of science process skills (SPS) on the topic of reaction rate. The research design used survey as the methodology. The sample contained 40 students from Grade 11 at one senior high school in Karanganyar, Indonesia. The science process skills of the students were assessed using a performance assessment and observation sheets. The instrument used for performance assessment is a rubric that consists of descriptions of four levels of performance, comprising low, medium, high and very high. The science process skills assessed were observing, data recording, communicating, inferring, experimenting and data interpreting. Results showed that the highest value for science process skills was achieved in communication and the lowest in data recording.

Keywords: Chemistry, problem solving, reaction rate, science process skills

INTRODUCTION

The chemistry curriculum generally combines numerous abstract concepts, and they are the centre of learning Chemistry and any other fields of study (Taber, 2002). These concepts are very important since advanced Chemistry, science concepts or science theories are not easy to understand if the underlying concepts are not really comprehensible for the students (Ayas & Demirbaş, 1997; Nakhleh, 1992; Nicoll, 2001; Zoller, 1990). Chemical characteristics that are abstract indicate that learning chemistry requires a high level of critical thinking skills (Fensham, 1988). The constant interaction between the macroscopic and microscopic levels

ARTICLE INFO

Article history:
Received: 01 December 2016
Accepted: 23 August 2017

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ISSN: 0128-7702

of thinking is considered important with respect to the chemical characteristics that are a challenge for those who are beginning to learn Chemistry (Bradley & Brand, 1985). The language of the chemists can be a barrier to the understanding of chemical because the language is symbolic and alphabetic (Sliwka, 2003). The characteristics of chemistry are conceptual, and frequently obtained from rote learning (reflected from recall, which is efficient for exam). Understanding requires a conceptual comprehension to be achieved in a meaningful way. Therefore, students demonstrated their understanding in their answer sheet, while the researchers found misunderstandings; they have learned by memorising certain parts of basic chemistry that they do not understand at every level (Johnstone, 1984).

Johnstone (1991) states three levels of chemistry that should be learnt explicitly; sub-microscopics, macroscopics and symbolics, and the relationship among those levels which should also be learnt, as shown in Figure 1. Moreover, the interactions and distinctions between them are important characteristics in Chemistry and are necessary to understand the concepts.

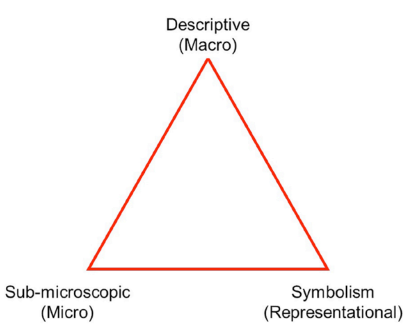

Figure 1. The Chemistry Triangle (Johnstone, 1991)

Therefore, the difficulties found by the students at a certain level will affect the other levels as well. Johnstone (1984) and Sirhan (2007) explained that the students would find it difficult to learn the concepts' characteristics in Chemistry, along with the represented concepts (macroscopic, microscopic, or representative). As a result, the method used by the learners potentially contradicts the nature of science and influences the teacher's use of the traditional method (Johnstone, 1980).

Science process skills can be developed using appropriate educational activities since it requires the students to perform critical thinking and scientific enquiry. In order to broaden their knowledge, the students should be accustomed to finding out 'how to know' instead of 'what to know' as early as possible, even when they are still in elementary school. Laboratory experience allows students to develop their problem solving and science process skills to provide conceptual development and promote a scientific attitude and scientific enquiry. The process skills play a role in the emergence of these skills; moreover, the mastery of operational outcomes should be considered as the foundation of their understanding of science. The cardinal philosophy guiding the science educational scenario is built by a strong belief and practice during the teaching and learning process. This research deals with the conceptual details of science process skills combined with the indicators, and it purposely addresses the challenges leading to global excellence in education (Sheeba, 2013).

The accumulated and systematised body of knowledge, which is the 'product' of science, has a dynamic counterpart, method of inquiry, which is the 'processes' of science. It means that the combination of processes and products create the science, and they are related each other.

Process skill is commonly defined as the cognitive process by which the learners are engaged during the learning process. Meanwhile, the product skill is created by the use of the process skills by the learners. The learners emphasise process skills in science, and, as a result, it is called process skills in science. Furthermore, it is also defined as the reflection of the method used while producing information on science; this is divided into intellectual skills, associated psychomotor skills and effective skills focusing on the all aspects of learning science. The skills pertain to several domains, including the cognitive domain, and include comparing, communicating, inferring, predicting, using number relations and time/space relations, and making operational definitions, framing hypotheses, controlling variables, interpreting data, generalising, raising questions, applying, quantifying, evaluating, designing investigations, and finding relationships and patterns.

Akinbobola and Afolabi (2010) view science process skills as the cognitive and psychomotor skills used in problem solving, problem identification, data gathering, transformation, interpretation and communication. According to Ozgelen (2012), science process skills are the thinking skills that scientists use to construct knowledge during problem solving and result development. This indicates that the skills are integral and natural to scientists. They are the instrument for the study and generation of scientific knowledge; whereby science learning and development of science process skills are integrated activities. The science process skills, along with the knowledge those skills produce and scientific values and habits of mind, define the nature of science (Funk, Fiel, Okey, Jaus, & Sprague, 1995).

The literature review illustrates that science process skills can be developed by the students in authentic learning (Keys & Bryan, 2001). The teachers need to adopt an enquiry-based approach to teach science as part of the teaching and learning process. Remziye, Yeter, Sevgül, Zehra and Meral (2001) found that the use of an enquiry-based approach significantly improve students' science process skills and behaviour. Bilgin (2006) explained that the students would more successfully achieve science process skills and have a more positive behaviour regarding the science itself, compared with the ones experiencing the traditional method when the teaching-and-learning activities and practice process are conducted at once. Burak (2009) investigated the relation between science process skills and the use of a laboratory that is efficient and the science in Chemistry.

SAPA categorises the science process skills into two kinds, which are basic and integrated. Basic skills that provide the foundation for learning are used particularly for basic cognitive function in elementary school. Moreover, these skills also build the foundation for the advanced skills and problem solving abilities. They represent the foundation of scientific reasoning that learners are required to master before acquiring and mastering the advanced, integrated science process skills. The basic science process skills are interdependent. This indicates that investigators may display and apply more than one of these skills in any single activity (Akinbobola & Afolabi, 2010; Funk et al., 1995). The basic science process skills, which are defined by the American Association for the Advancement of Science (AAAS), are observing, classifying, measuring using time/space relations, using number inferring, communicating and predicting.

The integrated science process skills used in problem solving cover several skills such as identifying variables, constructing tables of data and graphs, describing relationships between variables, acquiring and processing data, analysing investigations, constructing hypotheses, operationally defining variables, designing investigations and experimenting (Funk et al., 1995). Integrated contextually means that the learners are told to combine the basic process skills for greater expertise and flexibility to design the tools during the phenomena investigation, which leads to the realisation and achievement of integrated science process skills.

In fact, some teachers have limited time to implement laboratory experiments. This leads to students having difficulties when performing laboratory experiments (Utami, Saputro, Ashadi, Masykuri, & Aminah, 2016). Science process skills not only need to be achieved by scientists but by every individual, otherwise it is difficult to be successful in life (Rillero, 1998). Many students fail to understand that the results of the reaction and reaction rate are different concepts (Kousathana & Tsaparlis, 2002). Demircioglu and Yadigaroglu (2011) conducted a study to determine the effects of the use of laboratory methods on students' understanding of the rate of chemical reactions showing significant differences in students' achievement at the level of chemical reactions between experimental groups taught by teaching laboratory methods and control groups taught by traditional approaches. Scientific enquiry activities effectively enhance students' learning achievements and integrated science process skills (Lati, Suparson, & Promarak, 2012).

In learning about the chemical reaction rate, students conduct experiments in a laboratory on the factors that affect the rate of reaction. The students observe the effects of surface width and concentration affecting the reaction rate. While conducting an experiment, an assessment regarding the science process skills is conducted including observation, communicating, inferring, experimenting and interpreting data. This study is guided by the objective to determine the science process skills included in the chemistry practical examinations on the factors influencing the rate of reaction.

METHODS

Science process skills can be acquired and developed through activities in the practical chemistry sessions on factors that affect the rate of reaction. In practical work, an opportunity to test the application of scientific procedures, manipulative abilities and scientific skills is available. This research used the survey method. The population was 40 students of a Grade 11 class at one senior high school in Karanganyar, Indonesia. As for the students' characters during the learning process, they were found to get easily bored while learning, with most of them did not pay attention in the period of learning, and they lacked the ability to repeat the material that was submitted by the teachers. The observation illustrated that the level of students' activity in learning was also low, which could be clearly seen when discussions were taking place, whereby only a few students asked questions or indicated his/her mind, and there was little work at the time of the discussion.

The science process skills were assessed using performance assessment. Performance assessment uses a rubric consisting of descriptions of four levels of performance for a given standard, each of which is assigned a score ranging from low to high. The performance assessment of the science process skills includes observation, recording data, communicating, inferring, experimenting and interpreting data (Marzano, Pickering, & McTighe, 1993). The rubric for the science process skills can be seen in Table 1.

Table 1
Rubric of the science process skills

Science Process Skills	Criteria		Score
Observation and recording data	1.	There are graphs and tables	4 = If 5 indicators appear
	2.	Labelled correctly	3 = If 4 indicators appear
	3.	The results and data are recorded clearly	2 = If 3 indicators appear
	4.	Organized so it is easy for the reader to see trend	1 = If 2 indicators appear
	5.	There is a written description of the data	4 = If 5 indicators appear
Communicating	1.	They always listen to the explanations of friends who are presenting	3 = If 4 indicators appear
	2.	They always appreciate the opinions of friends in discussions, whether received or unacceptable	2 = If 3 indicators appear
	3.	The students communicate (greet each other) politely to all their group of friends	1 = If 2 indicators appear
	4.	The students have discussions with all their group mates	
	5.	They always accept criticism and suggestions from friends in discussions	

Table 1 *(continue)*

Science Process Skills		Criteria	Score
Inferring	1.	The important data used to explain the conclusions is summarized	4 = If 4 indicators appear
	2.	The conclusions follow the data	3 = If 3 indicators appear
	3.	They discuss experimental applications (connecting with 'the real world')	2 = If 2 indicators appear
	4.	Hypotheses are restated, and rejected or received on the basis of the data	1 = If 1 indicators appear
Experimenting	1.	They prepare the practical tools	4 = If 5 indicators appear
	2.	They measure the weight of empty petri dishes	3 = If 4 indicators appear
	3.	They measure the weight of a petri dish containing an eggshell	2 = If 3 indicators appear
	4.	They measure the volume of the solution	1 = If 2 indicators appear
	5.	They record time with a stopwatch	
Interpreting data	1.	The analysis is appropriate, complete and correct	4
	2.	The analysis is appropriate, but it contains minor errors or omissions	3
	3.	An attempt is made to analyse the data, but it is either seriously flawed or inappropriate	2
	4.	No attempt is made to analyse the data	1

RESULTS AND DISCUSSION

The purpose of the experiment on the factors that influence the reaction rate in this study is that students can determine the effects of concentration on the reaction rate and the effect of surface area on the reaction rate.

Effect of concentration

The students conducted experiments on the effect of concentration on the rate of reaction by mixing two solutions; sodium thiosulphate ($Na_2S_2O_3$) and hydrochloric acid (HCl). The solution of sodium thiosulphate was given in various concentrations. Then, the glass beaker was placed on a paper with a large cross mark based on their size. The students recorded the reaction time of the solution, i.e. how long it takes or the time taken for the mixture to turn turbid and for the cross mark on the paper to no longer be visible. Based on their observation and record of data, students would take note of the time required for the reaction.

Then the students determine the faster reaction, as well as the low or high concentration of sodium thiosulphate. In this case, it is the high concentration of sodium thiosulphate. This is because substances that contain large concentrations have a greater number of particles, so the particles are arranged more densely than in the low concentration substances. The particles have a more dense structure, and would often collide with the particles arrangement than tenuous, so there is the possibility of a greater reaction.

Influence of Surface Area

In the experiment on the effect of surface area, students mixed eggshell/calcium carbonate ($CaCO_3$) with a solution of hydrochloric acid (HCl) in a container that was covered by a balloon. The reaction produced a gas that expand and filled up the space in the balloon. The time taken for the balloon to become upright was recorded for the variations, which were for the crushed eggshells and those in an intact form. From this experiment, the students identified the reaction rate to see which of the two had a faster reaction, the eggshells that had been crushed and those in the intact form. The substance reacts faster in powder form than when the substance is in the form of chips. This is because the substance in powder form has a touch wider field so that collisions are more likely to occur. The total surface area of a substance is enhanced when it is in pieces of a reduced size. The more refined a substance is, the greater the rate of reaction will be because the reacting surface area is even greater.

From the experiments, it is understood that (1) students were not able to discuss the results of the laboratory work as intended, and (2) students were not able to conclude the experiment done exactly as intended. Based on the interview of the students, it should be noted that the students did not have enough time to answer the questions and analyse the answers completely. If there was any discrepancy with the theory, the students were not able to provide a critical analysis. The theory included in the report is still not appropriate to the purpose of the laboratory experiment (too wide or too little). The chemical reaction that occurs still has a lot of mistakes.

In the laboratory, the students actively performed the experiments and cooperated with their friends in the group. The results showed that the average yield of the science process skills obtained by the students are as follows: observation and recording data (63.8%), communication (92%), and inference (71.8%), experiment (63.8%) and interpretation of data (65%). Some students still find it difficult to conduct the experiment. Figure 2 indicates the students' science process skills results based on the rubric.

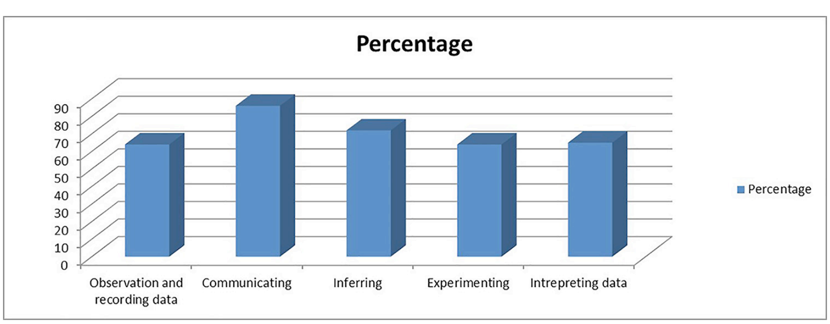

Figure 2. Students' science process skills results based on the rubric

For the observation of the obstacles encountered by the students during the experiment, the students were given observation sheets. From the observation sheets, it was clear that the students did not understand how to write a hypothesis in the lab report. In writing the report, there were students who did not describe their observations. As for the indicator of the students who were able to answer questions to analyse the experiment properly, they did not have enough time to open any book to add to the answers and analyse them.

According to Siska, Kurnia and Sunarya (2013), the application of an enquiry model on a reaction rate can significantly improve science process skills, with an average result of 71.9%. The highest score was achieved on the prediction skills, while the lowest score was on communication skills. According to Harlen (1999), the mastery of science process skills allows students to have a deeper concept and know the content, and equips them for acquiring content knowledge later on. Content knowledge is efficiently acquired and understood when it is obtained through enquiry using science process skills. A science curriculum emphasising science process skills could potentially enable the students to improve critical thinking skills, creative thinking and decision making. These skills can be transferred to other disciplines (Halim & Meeran, 2012).

According to Rauf, Mansor, Rasul, Otman and Lyndon (2013), the process of teaching and learning science has additional advantages, providing chances for the inculcation of the science process skills. It also provides students with the opportunity to learn independently when acquiring some of the skills. The use of various teaching approaches is in juxtaposition with each other. The science teaching-and-learning process is a dynamic process, in which movement from one teaching approach to another occurs and does not necessarily always occur in an orderly sequence. Hence, the use of various teaching approaches in a single lesson can create more opportunities for the inculcation and acquisition of science process skills in the classroom. Ong, Tuang, Yassin, Baharom and Yahaya (2013) concluded that students' mastery levels do not reach the two-thirds standard for overall science process skills, basic and integrated science process skills, as well as for each of the particular 12 science process skills, namely the skills of: (1) observing; (2) classifying; (3) measuring and using numbers; (4) inferring; (5) predicting; (6) communicating; (7) using space-time relationship; (8) interpreting data; (9) defining operationally; (10) controlling variables; (11) hypothesising; and (12) experimenting.

CONCLUSION

A laboratory chemistry experiment on the topic of reaction rate can enhance the science process skills that help students to learn to understand the concept of the effect of concentration and surface area on the reaction rate. Students discover knowledge with measures such as scientists, and it makes the students active and helps to improve their observation and record of data observation, experimentation, interpretation of the data, as well as communication and inference of the experiment results. The results showed that the highest value of science process skills is for communication skills and the lowest is for the collected data. The acquisition of science process skills allows students to learn through investigations and empowers them to act on information to generate solutions to problems.

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