Exploring the use of context-based green chemistry experiments in understanding the effects of concentration and catalyst on the rate of reaction

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Received 27 Feb., 2018
Revised 20 Dec., 2018

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Abstract

The abstractness of certain chemistry concepts demands the use of appropriate teaching strategies to enable students to construct mental images of the concepts. The concepts include understanding the effects of concentration and catalyst on the rate of reaction. The reactions at the molecular level are not visible to human eyes and the use of hazardous chemicals to teach the reactions further had made the learning irrelevant to the students. As an alternative to the existing curriculum, through this study, context-based green chemistry experiments (CBGCEs) were introduced as a laboratory curriculum. Teaching using CBGCEs began with unfolding a relevant context and followed with an investigation using benign green chemistry experiments. The qualitative interviews and responses to the issue-based open-ended questions show that students exposed to CBGCEs and existing curriculum attained better understanding about the effects of concentration and catalyst on the rate of reaction. However, the themes emerged from the responses of students learned with CBGCEs portray that this group of students has attained more specific and scientifically adequate understanding. The quantitative findings substantiated the findings obtained from the qualitative data.

Keywords: Context-based Green Chemistry Experiments; Effects of Concentration and Catalyst; Laboratory Chemistry Curriculum; Rate of Reaction; Secondary School Students.

Introduction

Chemistry is acknowledged as a subject that enables students to understand the quality of life. Chemistry forms the basis to understand other sciences including biology, environmental science, physics, and geology. It is known as "central science" (Goldsby & Raymond, 2013). For this reason, children are recommended to be exposed to chemistry from early stage of schooling (Ware, 2001). At the secondary school level, chemistry is perceived difficult because it requires learning concepts which are invisible to human eyes (Taber & Coll, 2002). The abstractness of the concepts demands the use of appropriate teaching strategies to enable students to construct mental images of the concepts. Unfortunately, in doing so, teachers immanently engaged in imparting knowledge on chemistry ignoring the societal consequences of the knowledge. As Hofstein and Yager (1982) once said that contemporary science stresses the advancement of knowledge rather than improving the society.

Green chemistry which reflects on an environmentally responsible way of teaching and learning chemistry when implemented in an educational context, it is well documented that this is a possible mean to educate the students on the knowledge inherent to the environment and society. In the past, green chemistry was used as an approach to contextualizing the learning to the local societies (Eilks & Rauch, 2012). These initiatives resulted in various cognitive and affective outcomes, including, improving understanding of chemistry concepts (Karpudewan, Ismail & Sinniah, 2016; Parrish, 2007); and environmental attitude and motivation (Karpudewan, Ismail & Roth, 2012; Karpudewan, Roth & Ismail, 2015). In terms of enhancing understanding of concepts, there are still many chemistry concepts left uninvestigated due to its abstract nature and difficulty to employ appropriate pedagogy to teach the concepts including teaching the effects of concentration and catalyst on the reaction rate. Mainly, this happens because the concepts were taught using laboratory activities involving hazardous chemicals and the concept was taught in a way that it is indeed foreign (not relevant) to the students' culture.

The harmful materials used in the reactions made the concepts irrelevant to the students, resulting in the concepts not being further investigated (Eddy, 2000). To address this notion, in this study, students learned the effects of concentration and catalyst on the reaction rate using context-based green chemistry experiments. Context-based green chemistry experiments (CBGCEs) is a new initiative introduced through this study in answering the emerging research question: "does the experimental group students taught using CBGCEs have better understanding on the effects of concentration and presence of a catalyst on rate of reaction compare to the control group students taught using the usual conventional curriculum?"

Background of the study

Chemical kinetic involves learning rate of chemical reaction and factors affecting the rate such as concentration, catalyst, size, temperature and pressure, which is very much difficult for the students at the secondary level to comprehend (Kirik & Boz, 2012). Except for non-zero order reaction, concentration is one of the factors that alter the reaction rate whereby an increase in the concentration accelerates the reaction (Turanyi & Toth, 2013). Due to this reason, the concentration of a solution, and its importance has attract the attention of many researchers in eliciting students' understanding (Yalçinkaya et al., 2012).

The effects of concentration are investigated in multiple ways. In Thailand, traditionally reactions between calcium carbonate and hydrochloric acid with different concentration (Chairam et al., 2009) was used to teach about effects of concentration. In Malaysia, collision theory was used to explain the effect of concentration followed by investigating the reaction between sodium thiosulphate solution with various concentrations and sulfuric acid (Curriculum Development Centre, 2006). This traditional way of teaching resulted in the students retaining misconceptions about the influence of concentration (Cakmakci, 2010). Reacting sodium thiosulphate solution and sulfuric acid resulted in the students investigating the reaction and behaviors of the particles at the molecular or submicroscopic level. Learning and understanding the reactions of both substances ends at the molecular level. Misconceptions occur during translation of molecular level knowledge to the concrete, real-life phenomena at the macroscopic level. Teaching using a context-based approach permits expansion of investigation from viewing the behaviors at the molecular to the application into real-life situations.

Another factor that can alter the reaction rate in any chemical reaction is the presence of catalysts. Catalysts are needed to initiate a specific chemical reaction, and it is widely used in industries (Kingir & Geban, 2012). For the students to have an in-depth understanding of the reaction, understanding the role of catalyst in chemical reactions is required. In learning about catalysts, students need to understand the activation energy of the reaction. As mentioned by Tastan, Yalcinkaya, and Boz (2010) any increase or decrease in the activation energy of the reaction depends on the catalyst used. A Swedish chemist, Jöns Jacob for the first time coined the word "catalyst" in 1835 and asserted that catalyst is a substance that increases the rate of a reaction without changing the chemical properties of the substance itself. Catalyst exists as a positive and negative catalyst. A positive catalyst increases the rate of a reaction by lowering the activation energy of the reaction using an alternative path for the reaction to occur while negative catalyst decreases the rate of reaction by increasing the activation energy using an alternative path during the reaction (Haber, 1994). Sima (2015) claimed students developed misconceptions about the properties and functions of the catalyst during teaching and learning process. It was identified that students tend to perceive positive catalyst reduces the activation energy. But in presences of positive catalyst, the reaction is executed in an alternative route with lower activation energy. Similar to the investigation on the effect of concentration on the rate of reaction, students engaged in investigating the effects of the catalyst at the molecular level. Lacking ability to directly connect the molecular level understanding to real-world phenomena prompted the students in developing misconceptions.

Due to the lacking of ability to connect molecular level understanding to macro-level events, misconceptions retained despite teachers embarked in using various initiatives such as using inquiry/analogy (Suparson & Promarak, 2015); laboratory method (Demircioglu et al., 2011); cooperative learning (Kirik & Boz (2012); and 5E-based animation aided instruction model (Kolomuc, 2009). For instance, i n a study involving, Year 12 students, Karpudewan et al., (2015) deliberately reported that students' conceptual understanding on the effects of the catalyst is more on average level in the first measurement and reported to be lower than average in the second measurement.

Green Chemistry and Context-Based Green Chemistry Experiments

Green chemistry which is also known as sustainable chemistry, when the 12 principles of the green chemistry were infused into educational context is a form of chemistry that focuses on the environmentally responsible way of teaching and learning (Anastas &Warner, 1998). The lessons on green chemistry deal with less or no hazardous materials to humans and the environment compared to the traditional polluting chemistry (Hjeresen, Schutt & Boese, 2000). During green chemistry lessons life-cycle analysis of a product was performed (Juntunen & Aksela, 2013, 2014) and discussion on alternative fuels and bioplastics were executed (Mamlok-Naaman et al., 2015). Green chemistry was used to address sustainability in classroom practices (Burmeister et al., 2012). Green chemistry principles have been integrated into specific cases (Kennedy, 2016) as classroom activities (Parrish, 2014; Prescott, 2013) and as laboratory experiments (Purcell et al., 2016). In some instances, green chemistry also implemented as laboratory-based pedagogy (Author et al., 2012). In the examples above lessons solely on green chemistry have been executed. On the contrary, this study explains how context inherent to the effects of concentration and catalyst on the rate of reaction is integrated into green chemistry experiments and presented as CBGCEs.

According to Seery (2015) application of the knowledge could be executed through context-based learning. In the context-based learning platform students are presented with relevant everyday context that emanates from the chemistry content that they are learning. CBGCEs introduced through this study is a kind of context-based learning pedagogy. The learning is contextualized using appropriate examples. For instance, learning about the presence of a catalyst in a reaction was contextualized using rising of the cake or bread when yeast is used as a catalyst. To identify the effects of concentration students recognizes that the taste of orange juice is different when water is added to the orange juice. Alternatively, students were shown bleach (Clorox) functions more effectively in the pure form compare to the diluted form.

Learning based on an issue requires students to understand the issue and to solve the issues using the knowledge that has been taught (Joel, Kamji & Godiya, 2016). Joel et al., (2016) had conducted a study with 100 students on understanding the rate of chemical reaction. A quasi-experiment design was used, and students in both groups were given worksheets, in which they needed to discuss the rate of reaction and explain the rate and reaction using daily life examples. The performance of experimental group student noted to be way better. This probably because the experimental group students' learning was extended to a context where the students had to understand the application of the knowledge. In a different study, Nieswandt, (2001) claimed that learning and understanding chemistry would be much easier when it is related to daily life activities. Nieswandt (2001) had conducted a study with 9th-grade German students who were taught chemistry using everyday life activities. The study was based on two basic chemistry concepts: changes of substances and particles model of matter. The analysis done at six different times showed that students had a better understanding of the chemistry concept when they were taught using daily life activities.

Activity theory is a framework used to discover the complexity of real-world situations in learning, and it is a tool used to understand learning (Engeström, 1987). Particularly, activity theory is instrumental in understanding the connectivity between tacit knowledge and scientific approach (Vygotsky, 1978). CBGCEs implemented is this study could be fundamentally explained using activity theory. To facilitate the implementation, activity theory is presented as consist of six elements: instrument/tool, subject, object, rules, community, and division of labors (Engeström, 1987). During the activity (the basic unit of analysis) the subject (the learner) together with the community (other students and teacher) performed the action assigned to them (a division of labor) adhering to the rules (procedures of the experiments) in achieving the objectives. These objectives are later translated as the outcome of the activity.

Methods

Research Design

In this study, a quasi-experimental design, involving randomly assigned experimental (EG) and control (CG) groups were employed. Both of EG and CG groups were taught the same topic investigating the effects of the presence of catalyst and solutions with different concentrations on the rate of reaction. Both groups were taught by the students' regular chemistry teacher. This teacher has been teaching chemistry for more than 20 years. In this case, the EG was taught on the effect of concentration and catalyst on the rate of reaction using CBGCEs. On the contrary, the CG was taught using the usual curriculum with more polluting and hazardous experiments.

Sample

The sample for this study consisted of 100 17 and 18 years old Form Five (equivalent to grade 11) students from two different intact classes in a school. Students from the two different classes were randomly assigned into two groups: EG consisted of 50 students with 28 female and 22 males, and similarly CG has 50 students with 31 females and 19 males. All the 100 students from both groups participated in the study because the researcher does not have any authority to eliminate any one of them. As such intact group sampling approach was used in this study.

Instruments

The rate of Reaction Test (RORT)

The rate of Reaction Test consisted of 20 multiple choice questions. All the 20 questions assessed students' understanding about the effects of catalyst and effects of concentration on the rate of reactions. Questions 1,2,3,4,6,9,10,17,19 and 20 in the RORT assessed the understanding on the effects of concentration on the rate of reaction while questions 5,7,8,11,12,13,14,15,16 and 18 in RORT tested the understanding on the effects of catalyst on the rate of reaction. The questions in RORT are past years' examination questions. The teachers from different parts of the country gathered in one place and involved in designing the questions. The designing process were closely monitored to ensure the validity and reliability of the questions. For all the questions in RORT, students were provided with four choices. The students were required to choose the best possible answer. The correct choice was awarded 1 point, and the incorrect answer was not given any points. An example of a multiple choice question in RORT is presented in Figure 1.

Figure 1: An example of question in RORT

Issue-Based Questions

Which of the following is **not** a characteristic of a catalyst?

A. Catalysts is specific in its reaction

B. A catalyst influence the quantity of product of a reaction

C. The chemical property of catalysts remains unchanged at the end of the reaction

Issue-based questions are questions that were designed based on everyday issues that deal with concentration and catalyst. A group of five chemistry teachers collaboratively involved in designing the two questions. Firstly, the teachers brainstormed and identified aspects to be assessed in relation to the given context. Upon reaching to an agreement, the questions were formulated. The two questions were further discussed and refined till final questions were designed. For concentration, students required to resolve the issue why Clorox (common name for bleach) without mixing in water, decolorizes the cloth promptly compared to Clorox which is mixed with water (Figure 2). For catalyst, students were given a situation what happens if yeast was not included in baking a cake and they were asked to compare the situation with presences of yeast as shown in Figure 3.

If Clorox is poured directly on the clothes, we noticed that the color of clothes would be bleached. But if Clorox is mixed with water first before we apply on the cloth we noticed it takes longer for the color to wash out. In some instances, if Clorox is too diluted the color on the cloth remains. Explain this phenomenon.

Figure 2: Issue-based question on the effect of concentration

Anuratha was a baking bread. Her elder's daughter, Vikasni observed how her mother (Anuratha) baked the cake, then she tried it on her own. She mixed flour, yeast and sugar in a large bowl, she added salt, milk and butter and stirred it until it turns into a dough, and then she baked the cake. Her other two young sisters Reshmaadhiviyaa and Moniisaa try to bake the cake following their elder sister, but they had forgotten to add yeast to the mixture. After baking the bread, they noticed the cake baked by Vikasni rises and baked in shorter time. But the bread baked by Reshmaadhiviyaa and Moniisaa did not rise and it took a longer time to complete the baking. Explain the observation.

Figure 3: Issue-based question on the effect of catalyst

The questions were given to both experimental and control group students after they performed the experiments.

Interview Questions

The interviews were performed with both experimental and control groups after the treatment. A total of five interview respondents were identified using purposive random sampling method. The interview responses were used to obtain further insights into students' understanding of the effects of concentration and catalysts on the rate of reaction. Each interview session was completed between 45 to 50 minutes. The responses were transcribed in the entity. Following are the interview questions:

What do you know about concentration?

Can you explain how does concentration affects the rate of reaction?

What do you know about catalyst?

Can you explain how does a catalyst affect the rate of reaction?

Pilot Study

A pilot study involving 45 Form Five students and two experienced chemistry teachers from a neighboring secondary school was performed to evaluate the reliability and validity of rate of reaction test (RORT) and issue-based questions and also to validate the CBGCEs. Both the participating teachers have more than twenty years of experiences teaching Form Four and Form Five chemistry. The teachers commented that multiple choice questions in RORT and the open-ended issue-based questions encompass the requirements of curriculum specification. The questions possess reliable content validity. The teachers were also noted that language used was simple, understandable and appropriate to the level to the students. For the multiple choice questions in the RORT, a KR-20 value of 0.968 obtained from the pilot study, indicates that questions in test possess high internal consistency.

The CBGCEs were validated to check on the appropriateness of the experiments, the language used in experiments, availability of the apparatus and materials to conduct the experiments and feasibility to conduct the experiments. The teachers identified that CBGCEs was feasible to be implemented, the materials and apparatus were readily available. The language used in presenting the experiments were clear. The teachers proposed that CBGCEs should be implemented replacing the current polluting and dangerous experiments done by the students.

Treatment

Conventional Curriculum

The entire five lessons for the control group started with the teacher posing questions to retrieve students' prior knowledge. During the first lesson, questions were also asked to ensure that the students have basic ideas about the effect of concentration and catalyst on the rate of reaction. This information was helpful for the teacher to decide on the content of the lessons. Once the prior knowledge has been ruled out, the teacher continued the lessons, asking the students to refer to the textbook and read the steps and procedures involved in performing the experiments. Four different experiments were performed in all the four lessons. During lesson two, the reaction between sodium thiosulphate solutions with different concentration and sulphuric acid was investigated. Subsequently, in lesson three, the reaction between different acids (hydrochloric acids, sulphuric acids and ethanoic acids) with sodium thiosulphate solutions;   lesson four decomposition of hydrogen peroxide with the presence and absence of the catalyst [manganese(IV) oxide] and in the fifth lesson, experiment on decomposition of hydrogen peroxide with different quantity of catalyst [(manganese (IV) oxide] were investigated. The experiments in lesson 2 and 3 focused on learning about the effect of concentration and 4 and 5 on the catalyst. Before allowing the students to conduct the experiments, in each lesson, the teacher warned the students about the harmful effects of the chemicals, and they have to be careful in handling the chemicals. The students performed the experiments closely following the procedures included in the textbook. After completing the experiments, the observations and findings of the experiments were discussed with the teacher dominating the lesson. At the end of the lesson, students were asked to respond to the issue-based questions.

Context-Based Green Chemistry Curriculum

Similar, to the control group, the lessons for the experimental group started with the teacher posing questions to retrieve the students' prior knowledge and to identify the level of students' knowledge on the effect of concentration and catalyst. Upon retrieving the prior knowledge, each lesson began with providing contexts relevant to the chemistry concept embedded in each particular lessons. The contexts which are relevant to the students' everyday activities permitted the students to envision on the practical applications of the concepts. For the first lesson, the teacher used orange juice with different concentrations to explain about concentration. The teacher presented three cups of orange juice with different concentrations; the students were asked to consume the juices and identify the differences in the taste of the juice. The teacher raised the question why do you think the diluted juice tasted lighter? The teacher explained further that the lighter taste is because of a number of particles per volume of juice in lesser in diluted juice. The juice is concentrated because a higher number of particles and the richer taste also results from the higher number of particles. Once the students have internalized the meaning of concentration students were asked to investigate the reactions between the different mass of chalk powder and vinegar. The investigation began with marking sign 'X' on a piece of white paper. Conical flask was placed on top of the 'X' sign. Firstly, 0.02g of chalk powder was placed into the flask, and 10mL of vinegar was mixed to the powder. The time taken for the sign 'X' to disappear was noted. The same investigation was repeated with a different mass of chalk powder. After completing the investigation, students required to write a balanced chemical equation describing the reaction; plotting graph time taken for the sign 'X' to disappear versus the mass of chalk powder; calculate the rate of reaction (g/time taken) and explain how concentration affects the time taken for the sign 'X' to disappear. Based on the explanation given by the teacher about orange juice prior to the investigation, the students explained concentrated chalk powder reacts faster with vinegar because it has a higher number of particles. The teacher explained further when there are more particles; there is more tendency for more collision and effective collision between vinegar and chalk particles. Effective collisions resulted in the reaction.

The second lesson focuses on teaching how the concentration of hydrogen ions in solutions changes the rate of reaction. For this purpose acidity level of 10mL of orange juice, lemon juice and vinegar was tested using red cabbage juice paper. Orange juice, lemon juice, and vinegar were later mixed with baking soda. For this purpose, a burette was filled with water and inverted over a basin containing water. The water level in the burette was adjusted, and the initial burette reading was recorded. 2g of baking soda was added to a conical flask and mixed with 50mL of vinegar. A delivery tube with a rubber stopper was inserted into the mouth of the conical flask, and the end of the delivery tube was inserted below the burette. The drop in the water level of the burette is recorded at 30 seconds intervals. The experiment was repeated replacing vinegar with lemon and orange juice. The differences in the volume of water in burette indicate the volume of carbon dioxide gas released from the experiment. The students were asked to observe the reactions and record the findings. The teacher later explained the concentration of hydrogen ions in these three substances are different. More acidic substances are concentrated with hydrogen ions. In other words, a number of hydrogen ion particles are more in more acidic solutions as such more effective collisions that result in reaction expected to happen.

In the third lesson, in introducing catalyst, the teacher presented two cups filled with the same volume of water added with salt. One of the cups was continuously stirred, and the other one was just left on the table. Teacher-related the action of stirring with the presence of a catalyst. The explanation also includes information on activation energy. Students applied the conceptions about catalyst and investigated the reaction between hydrogen peroxide solution and baking soda without the presence of a catalyst and repeated the experiment with the presence of biodegradable detergent as a catalyst. Similar, to lesson 2, in lesson 3 students prepared a burette filled with water and inverted in a basin. In a conical flask 10ml of hydrogen peroxide was added with 1 drop of detergent solution. Later 5g of baking soda was added to the mixture. A delivery tube was placed at the mouth of the conical flask, and later it was fixed to the bottom of the burette. The drop in the volume of water in the burette was recorded at the interval of 30 seconds. The investigation was repeated with adding detergent. At the end of the lesson, students were asked to write a chemical equation on the decomposition of hydrogen peroxide; plot a graph on volume of gases versus time, and explain how catalyst influences the reaction. In explaining the reaction students able to indicate with the presence of a catalyst the reaction happens in a different pathway with lower activation energy. When the activation energy is lower, more collisions tend to reach the energy required. This resulted in effective collisions for the reaction to happen.

In the fourth week, the teacher presented two cups filled with the same volume of water and sugar. Both cups were stirred. This time, one cup was stirred using one glass rod, and the other cup was stirred using two glass rods. The glass rods presences the catalyst and number of glass rods indicate the quantity of catalyst. Once the students have understood the concept of catalyst, they were asked to investigate the reaction between hydrogen peroxide and baking soda with the presences different quantity of biodegradable detergents. The investigation was performed similarly as in lesson 3. They were asked to plot graph volume versus time for all the three repetitions of the experiment with the different amount of detergent on the same graph; interpret the graph and explain how different amount of catalyst affects the rate.

The four CBGCEs introduced began with a context that students usually encounter in their everyday living. The conceptions of how concentration and catalyst work was forwarded using these contexts. Once the students have clear conceptions of catalyst and concentration than the students performed investigations using experiments developed based on green chemistry principles, in performing these experiments, students learn chemistry inherent to catalyst and concentration on the rate of reaction. In answering the questions provided at the end of the experiments and discussion of the observations and findings of the experiments, provided students a better understanding of the concepts investigated.

Data Analysis

Two different types of data were collected in this research to determine the understanding of students on the effects of concentration and catalyst on the rate of reaction. Qualitative findings were used as the primary data to answer the research question. Quantitative findings were used to substantiate the qualitative outcome. In the next section, the information on how the quantitative and qualitative data were analyzed is provided.

Qualitative data

Qualitative content analysis method was employed to analysis both open-ended issue-based questions and interview responses. Students' answers to the issue-based questions were explicitly examined for certain words and phrases that describe the understanding of the concepts. In Table 1 examples of good and average responses provided for the issue-based question on the effects of concentration are presented. The emerging themes are presented in italic font.

Table 1 Examples of good and average responses for the effects of concentration

Average understanding	**Good understanding**
Adding water will result in dilution of Clorox. The *reaction*	Clorox will be diluted with adding water. The number of *particles per unit*

with diluted Clorox will be *slower* because diluted Clorox is *less concentrated*. The diluted Clorox might remove the color on the cloth, or it will *take longer* for the cloth to be bleached.	*volume* in Clorox without water is higher, and it is more *concentrated* than Clorox with water. It will *react with the color* on the cloth and bleaching happens. The Clorox which added with water does not bleach or bleach slower because a number of *particles per unit volume* are less.

The common themes emerged from both responses above are faster/slower reactions; concentrated/less concentrated; particles per unit volume; bleaching (removing color). Both responses reflect that students have acquired the understanding that concentration influences the rate of reaction as both students indicated that bleaching happens at a different rate in diluted and non-diluted Clorox. However, more specific themes 'particles per unit volume' and 'react with the color' that emerged shows that this particular student acquired an accurate understanding of the concept.

Similar to the open-ended issue-based questions, content analysis was used to examine interview responses to identify specific themes. The themes derived from the responses were: increasing/decreasing rate; frequency/effective collision; positive/negative catalyst. Table 2 shows examples of responses with a good and average understanding of the effects of catalyst on the rate of reaction and the emerging themes are presented in italic.

Table 2 Examples of responses with a good and average understanding of the effects of catalyst

Average understanding	**Good understanding**
Catalyst plays an important role in *increasing* the rate of reaction. It increases the *frequency of collision*, and this automatically increases the rate.	The presence of a catalyst, I mean *positive catalyst* enable the reaction go through an *alternative path* with lower *activation energy*. More collisions could overcome the *lower activation energy*. As such frequency of *effective collisions* increase, and rate of reaction also increases.

Quantitative data

Quantitative data collected were analyzed using SPSS (Statistical Packages for the Social Sciences) with the level of significance at 0.05 ($p>0.05$). The post-test results of the RORT were compared using independent sample t-test to compare the mean of traditional teaching method (control group) and context-based green chemistry experiments (experimental group). Following Trochim's (2006) suggestion, to ensure the students from both EG and CG have a similar level of chemistry knowledge prior to the treatment, an independent t-test was performed using the results of chemistry class test. The findings of the independent t-test analysis revealed that both group students are at the similar level prior to the treatment.

Results

This section begins with illustrating students' understanding of the effects concentration on the rate of reaction using qualitative open-ended and interview responses. Subsequently, students understanding the effects of catalysts will be articulated similarly. Quantitative findings were employed to substantiate the qualitative findings.

Understanding the effects of concentration

The analysis of interview responses

The analysis of interview responses obtained reflect that students from both groups have the knowledge about concentration and how concentration affects the rate of reaction. The differences emerged between these groups are that experimental group able to explain more scientifically. This shows that the experimental group students understand the functions of concentration from the particle level. On the contrary, the control students' responses appeared more like a layman's description of concentration and how it affects the rate. Following are excerpts of interviews responses obtained from control and experimental group students for the question "What do you know about concentration?".

Table 3 Responses to question "what do understand about concentration?" from experimental and control group students

	Control Group Responses		Experimental Group Responses
S1	Concentration is something that can make the reaction happen faster.	S4	Concentration is a number of particles per unit volume in the aqueous solution. A more concentrated solution has more number of particles.
S2	Concentration is the amount of reactant in the solution.	S5	Concentration is the quantity of solute that dissolves in $1dm^3$ of the solution. Like when salt dissolves in water to form a salt solution. Salt is solute and water is solvent. The salt solution is a mixture of water and salt.
S3	Concentration is the	S6	Concentration influences the rate of reaction. It is

	factor that that can change the rate of reaction.		about a number of particles in the solution.

Analysis of responses given by control group student shows that two students (S1 and S3) perceived concentration is something got to do with the rate of reaction. Another student (S2) is in the understanding; concentration is the amount of reactant in a solution. The answer given by S2 seems to be more appropriate than S1. Rather than directly linking concentration with the rate of reaction, S2 said that it is about the amount. However, in indicating the number of particles, S2 simply said an amount of reactant. These findings show that control group students somewhat have conceptualized 'concentration,' however, they have not reached the level of complete understanding. Experimental group students exhibited similar conceptualization about concentration whereby they said that concentration got to do with the rate of reaction. However, prior to linking concentration with faster or slower reaction, they have indicated concentration is the amount of particles per volume. In a concentrated solution, this amount is higher. Thus the reaction would be faster. To further, understand the students' knowledge of concentration and rate of reaction, the students were posed with the question "can you explain how does concentration affects the rate of reaction?" The responses were included in Table 4.

Table 4 Responses to the question "can you explain how does concentration affect the rate of reaction?" from experimental and control group students

	Control Group Responses		**Experimental Group Responses**
S1	When the concentration of the solution is high, it can change the rate of reaction. It makes the reaction fast.	S3	Concentration can affect the rate of reaction. When the concentration of the solution is high, the number of particles per unit volume is more. This will result in a higher frequency of collision between the particles in the solution.
S2	When the concentration of the solution is high, the rate of reaction will be faster. Because it will make the reaction faster and time taken will be shorter because the frequency of effective collision is higher.	S4	When the concentration of the solution is higher, the rate of reaction is also higher because the number of particle per unit volume is more. This makes the frequency of collision between the particles increases; as a result, the frequency of effective collision also increases.

The control group students unable to provide details linking the concentration and rate of reaction. Their understanding seems to be limited as they repetitively mentioned higher concentration would result in a faster reaction. S2 try to explain saying that time taken will be shorter as the frequency of effective collision is higher. However, information on how effective collision is related to rate is not given. The responses of experimental group students reflect that these group of students has the understanding, concentration is about amount particles. Higher amount particles per volume increase the number of collision between the particles. With the increase in the number of the collision, the frequency of effective collations that causes the reaction to happen increases as well.

The analysis of responses to the issue-based question

In Table 5 responses to the issue-based questions on the effects of concentration obtained from control and experimental group, students are presented.

Table 5 Responses of the control and experimental group students for the issue-based questions on the effect of concentration on the rate of reaction

	Control Group		**Experimental Group**
S1	In the Clorox without water, the number of enzymes presented is more compared to the Clorox mixed with water. More enzyme will break down and react to the color of the cloth. The color of the cloth will be bleached. The rate of reaction between the enzyme and the cloth is higher.	S4	Colour of the cloth bleaches when it directly poured because the concentration of Clorox is more compared to the Clorox which was mixed with water. When the concentration of Clorox is high, the number of particles per unit volume is more. So concentrated Clorox used to wash cloth react with the color of the cloth. When Clorox reacts with particles on the cloth, it will remove the color from the cloth.
S2	When Clorox is mixed with water, the concentration of the solution decreases. This causes the bleaching particles per unit volume to decrease. The frequency of collision between particles decreases. The frequency of effective collision also decreases. Thus, the rate of reaction decreases. Highly concentrated Clorox able to bleach due to the higher rate of reaction.	S5	When water is added to any substances, it will decrease the concentration of the solution. So when water is mixed with Clorox, the Clorox is diluted. The number of particles per unit volume is lesser. So when it used to wash cloths, the dirt will be removed at the same time it reacts with the color on the cloths.

Basically, in the responses obtained from the control group students, the themes, such as mixing with water resulted in the Clorox diluted; the concentration of Clorox is lesser when mixed with water; and reaction gets slower with lesser concentration appeared. These themes show that control group students unable to be very specific. They appeared more general in providing their description of the rate of reaction. Control group students acquired the understanding that when Clorox is mixed with water, it gets diluted, as such less concentrated. The experimental group students in their responses exhibited a similar kind of understanding. However, the experimental group students tend to be more specific in their answers. For instance, rather than simply saying concentration is higher or lesser, the students specifically mentioned that concentration in terms of the number of particles per volume. They further said that the particles react with the color of the cloth and thus bleaching happens. The discoloration happens when there is a collision between Clorox and color particles. As in concentrated solutions number of particles per volume is high frequency of collations increases as well.

Understanding the Effects of Catalyst on the Rate of Reaction

The analysis of interview responses.

In Table 6 excerpts of interview responses obtained from control and experimental group students for the question "what do you know about catalyst?" are presented.

Table 6 Responses to question "what do you understand about catalyst?" from experimental and control group students

	Control Group		Experimental Group
S1	The catalyst can make the reaction faster.	S4	The catalyst is a substance used to increase the rate of reaction and catalyst itself does not change chemically.
S2	Is a chemical that we use for faster reaction. At the end of the reaction, catalyst remains.	S5	A catalyst increases the rate, but the catalyst does not change chemically at the end of the reaction.
S3	The catalyst is a process where the reaction happens faster.	S6	The catalyst can make the reaction happen faster.

The responses show that both groups attained the understanding that catalyst is a substance that increases the rate without changing its chemical properties as the themes 'faster reaction' and 'remains the same' appeared in the all the responses. Excerpt of S3 from control group exhibited a misconception saying catalyst is a process. The responses in Table 6 shows that students from both groups have understood what catalyst is. In further probing their understanding of the functions of catalyst the question 'can you explain how catalyst effects the rate of reaction?' was asked. Some of the responses to this question are presented in Table 7.

Table 7 Responses from control and experimental group students to the question "can you explain how catalyst effects the rate of reaction?"

	Control Group		Experimental Group
S1	A catalyst increases the frequency of collisions. Increase in the frequency increases the rate of reaction.	S3	Catalyst creates a new path with a lower activation energy for the reaction to happen. The frequency of effective collation increases. The reactions that overcomes the activation energy is more.
S2	The catalyst causes the reaction to take place in a shorter time. This is because it will make reactants to produce product faster by increasing the frequency of effective collision. So this increases the rate of reaction.	S4	With having an alternative path, the number of particles achieved the lower activation energy will be more and frequency of effective collision increases and rate of reaction also increase.

The theme, 'frequency of collision,' 'frequency of effective collision' and 'faster reaction' appears in the responses given by students from the control and experimental group. Appearances of the themes show that the students have acquired the understanding that in the presences of catalyst, the reaction happens in a shorter period because of more effective collision happens during the reaction. The themes, 'alternative path' and 'activation energy' reflects that experimental group students have attained the understanding that in the case of presence of a catalyst, the reaction occurred using a different pathway with lower activation energy. Experimental group students able to grasp with the alternative path, more effective collisions will result as many collisions manage to overcome the activation energy.

The analysis of the response to the issue-based question

The examples of responses provided by control and experimental group students for the issue-based question on the effects of catalysts on daily life activity is presented in Table 8.

Table 8 The answers provided by the experimental and control group students for the issue-based questions on the effects of catalyst

Control Group	Experimental Group
The bread Vikasni baked contains yeast while the bread baked by her sister does not have yeast. Yeast performs anaerobic respiration in the presences of glucose and produces carbon dioxide, ethanol, and heat. Carbon dioxide occupies the space in the	Yeast as a positive catalyst in the baking of bread produces carbon dioxide. As a living organism, yeast undergoes respiration and releases carbon dioxide gas and heat. It makes the bread bake faster as well. Time taken to bake the bread without yeast is

bread forming air sacs in the bread causing it to rise and become fluffy.	longer. With extra heat, the whole baking reaction took place using a shorter path with less activation energy
This is because of the yeast used by Vikasni. It produces carbon dioxide in the presence of water. The respiration process produces more heat when more carbon dioxide is released. The carbon dioxide occupies the space and the dough rises. The heat causes the cake to bake faster.	Yeast is a catalyst for baking. It produces carbon dioxide gas and heat. Carbon dioxide rises the cake. However, the heat makes the reaction faster. With the yeast, an alternative route with a different pathway was created. This pathway has lower activation energy. More collision expected to overcome the activation energy to result in a reaction.

The analysis of the responses revealed that both group students managed to identify that yeast plays the role as a catalyst in the baking process. Both groups are also able to provide on how yeast functions as a catalyst in the baking process from the themes: carbon dioxide; heat; forming air sacs; and heat causes the bread to bake faster. The experimental group students exhibited scientifically defined understanding on the function of yeast in baking a cake. The themes such as alternative route; lower activation energy; and collision expected to overcome the activation energy emerged from the response reflects that ability of experimental group students to be more explicit in answering the questions.

Quantitative findings

A maximum total score for RORT is 20. The control group's mean score (M_{con}=9.14, SD_{con}=3.47) reported being lower than the experimental group's mean score (M_{exp}=12.90, SD_{exp}=3.13). The differences between the mean scores of both groups are reported to be significant [$t(98)= -5.69$, $p<0.05$]. The results show that the students from the experimental group were able to score higher on the RORT than the control group students. This shows that experimental group students' understanding of the effect of concentration and catalyst on the rate of reaction is far better with the mean differences of 3.76. This finding substantiates the qualitative findings obtained from interview and issue-based open-ended question analysis.

Discussion

The qualitative findings of the study reveal that both experimental and control group students have acquired a better understanding of the effects of concentration and catalyst on the rate of reaction after going through the treatment. The findings show that experimental group students' understanding seems to be more explicit and scientifically acceptable. Further, the quantitative findings substantiated the qualitative outcome. The ability of experimental group students to be more specific in explaining the observations probably is due to the understanding that they have attained from the context provided to them prior to each investigation. The context permitted the students to understand the concept well. When the same concepts were investigated using practical laboratory work the knowledge derived from the context was applied in understanding the observations and findings of the experiments (Seery, 2015). It was noticed that students who graduated from a traditional education environment who does not have any learning related to their real life tend to be confused about their understanding (Ng & Nguyen, 2006). In a different study, context or issue provided at some point forced the students to extend the classroom learning to the application beyond that (Joel et al., 2016). They try to seek the connection between the knowledge obtained in the classroom and how the knowledge is turned into real-life applications. These had resulted rather than simply memorizing the knowledge to reason the validity of the knowledge itself (Kurt & Ayas, 2012). This is another possible reason why the context-based approach encourages better learning among the students.

On the contrary, control group students have understood the concept quite well however their responses portray that they memorized the information and reproduced it in answering the questions posed to them. Memorization happens due to the rhetoric teaching. The usual way of solely performing investigations following a recipe like procedures consequently forced the students into memorizing and recalling of facts. As Bristow (2000) said, this happens because hands-on activities in science made the students have better understanding compared to the students who were taught using lecture base method. Alternatively, it has also been said that context-based pedagogy creates a better learning situation that probably will result in students understanding (de Putter-Smits, Taconis, & Jochems, 2013). Perhaps, the nature of CBGCEs which required the students to investigate the context followed with engaging in hands-on activities explain the reasons for the experimental group students to have a better understanding.

Parrish (2007) asserted that green chemistry experiment encourages students to monitor their own learning experiences. In this study, the integration of a particular context relevant to the green chemistry experiment had further enhanced the properties of green chemistry as suggested by Parrish (2007). The CBGCEs permitted the students do have their own learning experiences by relating to the real-life issue. On the other hand, control group students carried out the experiments based on chemicals available in the laboratory unable to justify the relevance of the experiments that they have engaged. Parrish's (2007) argument about green chemistry was further supported by Prescott (2013). According to Prescott (2013), students were able to connect green chemistry experiments they had learned to the general chemistry concepts. Through having a context prior to the experiment as in CBGCEs substantiate the claim made by Prescott. Cacciatore and Sevian (2006) showed that green chemistry experiments indirectly made students spending more time writing scientific communication and reports. Students who carry out green chemistry experiments spent more time because they can relate the issue to their real-life context. They tend to think far, organize data well and produce good writing. When more time is spent in thinking over and over about an issue made them actively critical of the issue. Similar, students exposed to CBGCEs in this study spent more time pondering over the context. As a result, they were critical of the context.

From the theoretical perspective, constructivist and activity theory which CBGCEs experiments were based on profoundly explains the possibilities of the experimental group students' ability to be more specific. When the students engaged in CBGCEs experiments the six elements of activity theory: subject, objects, rules, instrument, community, a division of labor and outcome were inherently executed. The community of learners (also the subject) collaboratively involved in executing the experiments (objects) adhering to the rules and task assigned based on the division of labors. In which during the execution of the six elements the students at all the points actively participated in the learning. New mental structure of knowledge was constructed from learning involving all the elements of activity theory (Engeström, 1987). According to Engeström (1987), moving from actions to activity expands the learning at the macro level. The expanding of learning made them more focused on the learning process through collaborative networking with students, teachers, and community.

Conclusion

Learning of chemistry concepts predominately have been linked with memorization of the concepts rather than understanding the principles and application of the concepts. This mainly happens due to the use of rhetoric teacher-centered pedagogical strategy that ultimately leads to memorizing rather than understanding. This study suggested CBGCEs as an alternative to the existing pedagogy as in the past it was said that relating to a context allows better understanding (Serry, 2015). In this study, similar findings were found in terms of students' understanding of the effects of concentration and catalyst on the rate of reaction. The study is informative to various stakeholders including the curriculum planners, curriculum writers, researchers and teachers as it introduces an effective alternative way of teaching chemistry. However, the study exhibits several limitations. CBGCEs were identified effective solely based on comparing the findings obtained from two groups from the same school. Even though this method is suggested appropriate (Shadish, Cook, and

Campbell, 2002), the findings are not advisable to be generalized. To improve the generalization of the findings, it is suggested for the study to be repeated with different schools and classes and also involving students with various abilities. Further, in the context where this study was performed, the experimental and control groups have to be from the same school. This is to ensure that both groups were taught by the same teacher so that the teacher effect is nested. However, having the groups in the same environment might leads to diffusion of the treatment. In this study, the diffusions effects were controlled by placing the students in different locations and also the activities were performed at two different times for both groups.

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