THE EFFECTIVENESS OF “PhET INTERACTIVE SIMULATION” IN IMPROVING MULTI-MODE REPRESENTATIONS (MMRs) EMBEDDEDNESS AND TRANSLATION IN LEARNING CHEMICAL EQUILIBRIUM AMONG MATRICULATION STUDENTS

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by

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KEBERKESANAN SIMULASI INTERAKSI PhET DALAM MENINGKATKAN PENYELITAN PELBAGAI MOD PERWAKILAN DAN PEMBELAJARAN KESEIMBANGAN KIMIA DALAM KALANGAN PELAJAR MATRIKULASI

ABSTRAK

Kajian ini dijalankan untuk mengkaji keberkesanan simulasi interaksi "PhET" untuk menggalakkan pelajar Matrikulasi dalam menyelit dan menterjemah pelbagai mod perwakilan, Multi-mode representations. Kajian ini juga dijalankan untuk menilai keberkesanan pelajar dalam menyelit dan menterjemah pelbagai mod perwakilan terhadap miskonsepsi dan pengekalan pengetahuan dalam keseimbangan kimia. Kajian ini turut dijalankan untuk menilai keberkesanan pelajar dalam menyelit dan menterjemah pelbagai mod perwakilan terhadap pengalaman dan penglibatan pelajar dalam pembelajaran kimia. Reka bentuk penyelidikan campuran serentak dijalankan selama empat minggu dengan 140 pelajar Matrikulasi. Ujian menulis subjektif, Chemical Equilibrium Open Ended Questions (CEOEQ) dijalankan dan dinilai untuk mengkaji keberkesanan simulasi interaksi "PhET" terhadap pelajar untuk menyelit dan menterjemah pelbagai mod perwakilan. Chemical Equilibrium Diagnostic Instrument (CEDI) digunakan untuk mengkaji keberkesanan pelajar menyelit dan menterjemah pelbagai mod perwakilan terhadap miskonsepsi dan pengekalan pengetahuan dalam keseimbangan kimia. Students' Flow Experiences Questionnaire (SFEQ) juga mengkaji pengalaman positif pelajar terhadap pembelajaran kimia. Keputusan kajian menunjukkan bahawa simulasi interaksi "PhET" mempunyai perubahan signifikan dalam pelajar menyelit pelbagai mod perwakilan *$(F (1,134)=603.925, P <0.00, n^2 = 0.818)$* dan menterjemah *$(F (1,137) = 473.784,$*

P <0.00, n^2= 0.776).Kebolehan pelajar menyelit dan menterjemah pelbagai mod perwakilan jelas megurangkan miskonsepsi *(F (1,133)= 254.487, P<0.00, n^2 = 0.657)* dan meningkatkan pengekalan pengetahuan *(F (1,139) = 793.384, P<0.00, n^2= 0.605)* terhadap keseimbangan kimia. Kebolehan pelajar menyelit dan menterjemah pelbagai mod perwakilan juga meningkatkan pengalaman positif *(F (1,133) = 267.482, P<0.00, n^2 =0.989)* dan penglibatan *(F (1,137) = 20738.6, P<0.00, n^2 = 0.993)* terhadap pembelajaran kimia. Analysis kandungan penulisan CEOEQ menunjukkan bahawa pelajar menggunakan pelbagai cara untuk menyelit and menterjemah pelbagai mod perwakilan. Analysis tematik melalui temuduga pula menunjukkan bahawa pelajar dapat memberi penerangan yang tepat terhadap konsep keseimbangan kimia yang secara tidak langsung mengurangkan miskonsepsi dalam keseimbangan kimia. Selain itu, pelajar juga telah mempunyai pengalaman positif terhadap pembelajaran kimia.

THE EFFECTIVENESS OF "PhET INTERACTIVE SIMULATION" IN IMPROVING MULTI-MODE REPRESENTATIONS (MMRs) EMBEDDEDNESS AND TRANSLATION IN LEARNING CHEMICAL EQUILIBRIUM AMONG MATRICULATION STUDENTS

ABSTRACT

This study investigated the effectiveness of "PhET" interactive simulations to embed and translate multi-mode representations and effectiveness of embedding and translating multi-mode representations on students' misconceptions and retention of knowledge in chemical equilibrium. This study also investigated students' flow experiences towards learning chemistry. Concurrent embedded mixed method design was employed for four weeks among 140 Matriculation students. The effectiveness of "PhET" interactive simulations to encourage the embedding and translating multi-mode representations measured using Chemical Equilibrium Open Ended Questions (CEOEQ). The Chemical Equilibrium Diagnostic Instrument (CEDI) measured students' misconceptions and retention of knowledge in chemical equilibrium while Students' Flow Experiences Questionnaire (SFEQ) measured students' flow experiences towards learning chemistry. The MANCOVA analysis performed indicates that PhET interactive simulations significantly improved multi-mode representations embeddedness in CEOEQ open ended test *((F (1,134) = 603.925, P <0.00,* n^2 *= 0.818)* and improved translation between multi-mode representations *(F (1,137) = 473.784, P <0.00,* n^2*= 0.776).* Besides that, analysis indicates embedding and translating multi-mode representations reduces the misconceptions in chemical equilibrium *(F (1,133) = 254.487, P<0.00,* n^2 *= 0.657)* and increased students retention of knowledge in chemical equilibrium *(F (1,139) = 793.384, P<0.00,* n^2*=*

0.605). Embedding and translating multi-mode representations also increased students' positive experiences *(F (1,133) = 267.482, P<0.00,* n^2 *=0.989*) and engagement mode *(F (1,137) = 20738.6, P<0.00,* n^2 *= 0.993)* towards learning chemistry. The content analysis performed on students' open ended test indicated that students use many modes to embed and translate between multi-mode representations. The thematic analysis performed on interview responses indicated that students were able to give accurate explanations in chemical equilibrium and reduce their misconceptions. Students also exhibited positive flow experiences towards learning chemistry.

CHAPTER 1

INTRODUCTION

1.0 Introduction

Students' understandings of science concepts are important in order to provide detailed explanation during assessment or examinations. Understanding can be enhanced through writing task with integration of multi-mode representations (Ainsworth, 1999). Some studies revealed that students apply multi-mode representations such as diagrams, chemical equations, tables and graphs to improve their understanding in science concepts (McDermott, 2006; Gunel, Hand & Prain, 2007). Besides including the multi-mode representations, students' conceptual understanding is greatly determined by the ability to embed and translate between the modes (Prain & Hand, 1999). According to McDermott and Hand (2012), translation is indicated when students effectively establish the linking between modes rather than using text for them to experience greater learning. Movement between different modes enhances students' efficiency in retrieval of information, integration of information from various sources and application of information in new contexts (McDermott & Hand, 2012).

Studies has shown that students do not understand many fundamental chemistry concepts and that students hold many misconceptions (Ozmen, 2008; Chu & Hong, 2010). Chemical equilibrium is considered one of the most difficult topics in Chemistry as learning chemical equilibrium requires students to shift between the microscopic, macroscopic and symbolic level of representations (Johnstone, 1988). Inability to seemingly shift between the levels results in students developing misconceptions in chemical equilibrium (Upahi & Ramnarain, 2019). The ability to shift between the three levels of representations denotes understanding of the concepts. Embedding and translating multi-mode representation in writing goes hand in hand with the shifting between three levels of representation depicts the understanding of the concept. This scenario is reflected in learning about chemical equilibrium concepts whereby the students were required using chemical equations, graph and symbols representing a dynamic equilibrium to show rate of forward and backward reaction. The multi-mode representations are essential for representing the macroscopic formation of products and reactants. Meanwhile, a symbol representing the molecules in the reactants and products implies the submicroscopic level (Taber, 2013). Few studies reported that chemical equilibrium was not researched much and students had misconceptions due to the abstract concepts of chemical equilibrium (Ozmen, 2008; Karpudewan, Treagust, Mocerino, Won & Chandrasegaran, 2015). Since, the use of multi-mode representations allow the learning of complex concepts in science (Yore & Hand, 2010; McDermott, 2009), the multi-mode representations in learning chemical equilibrium predicted to reduce students' misconceptions and increase retention of students' knowledge in chemical equilibrium.

In order to encourage students to embed and translate between modes, a specific teaching strategy is required rather than traditional teaching method (McDermott & Hand, 2012). Some studies recommended using technology (digital) assisted tool as a strategy to encourage embedding and translating of multi-mode representations (Prain & Waldrip, 2006; Hand, Gunel & Ulu, 2009; Tytler & Prain, 2010). Computer animations enable deeper coding and more expert-like mental models of the particulate nature of matter compared to static visuals such as text book pictures and chalk diagrams (Williamson & Abraham, 1995). Study conducted by Wu, Krajcik and Soloway (2001) suggested that computer visualizing tool, *echem* act as a vehicle for generating mental images and help the students to construct knowledge and translate representations. Another research by Moore, Chamberlain, Parson and Perkins (2014) asserted that a Physics Education Technology (PhET's) interactive simulation is an effective tool for understanding of many chemistry concepts. This probably because PhET inherently involves learning using multi-mode representations. However concrete evident associating PhET and student's ability of using multi-mode representations particularly in learning chemical equilibrium is infantile.

In using computer simulation, flow experiences and engagement encountered by the students is the integral factor that determines the effectiveness of the learning (Osman & Bakar, 2012; Bressler, 2014). Research has showed that the implementation of computer simulations in class increase students positive experiences and academic performance (Ketamo & Kili, 2010; Amory, 2010). In this study, PhET an interactive simulation was employed to encourage embedding and translating multi-mode representation. The action of embedding and translating using PhET simulations expected to affect the students flow experiences comprises of enjoyment, concentration, control and challenge and engagement.

1.1 Background of the Study

Matriculation programme is a one year pre university programme offered by the Matriculation division under the Malaysian Ministry of Education beginning from the year of 2000.The Matriculation programme consist of two semesters. The Matriculation programme is generally offered to high achievers of secondary schools who have completed their Sijil Pelajaran Malaysia (SPM). In order to qualify for the Matriculation programme, the students must obtain A's in all subjects including science subjects offered at the upper secondary level examinations. After completing their studies at Matriculation level, the students will have an opportunity to enter internationally recognized public universities. The students will be offered relevant university courses according to their Matriculation results. (http://www.moe.gov.my/)

Chemistry, mathematics and physics are compulsory subjects at the Matriculation level and biology is optional. In the Matriculation curriculum, the students are taught physical and inorganic chemistry in the first semester and organic chemistry in the second semester. Under the Matriculation chemistry curriculum, the topic of chemical equilibrium occupies a central place and it is taught in semester one. The chemical equilibrium topic covers dynamic equilibrium, reversible reactions, equilibrium constant, homogeneous and heterogeneous equilibrium, salt and solubility and Le Chatelier's principle (http://www.moe.gov.my/). Besides Matriculation, the chemical equilibrium topic is also taught in the Form Six education, A-level programme and other pre- university programmes in Malaysia. Currently, traditional teaching method is used to teach chemical equilibrium (http://www.moe.gov.my/). The lesson is teacher centred and guided by PowerPoint notes and textbook.

The topic of chemical equilibrium is widely emphasized in secondary schools and tertiary curriculum (Ozmen, 2008; Cheung, Ma & Yang 2009). The topic of chemical equilibrium in chemistry is the pre-requisites to understanding many other concepts such as solubility, phase changes, redox reactions and acid base properties (Van Driel & Graber, 2002). However, students find it difficult to understand chemical equilibrium because they are unable to associate chemical reactions with macroscopic observable changes such as evolution of gases, precipitate formation, color changes and heat changes (Karpudewan, Treagust, Mocerino, Won & Chandrasegaran, 2015). These difficulties have further led to several misconceptions. For instance, study conducted by Erdemir, Geban and Uzuntiryaki (2000) using 143 middle east freshman students from a general chemistry course in education during the spring semester of 1998-1999 asserted that 80% of the students failed to differentiate between reaction rate (how fast) and reaction extent. In another study by Demircioglu and Yadigaroglu (2013) involving 97 chemistry student teachers from department of secondary science education of Fatih Faculty of Education in Turkey reported that 46.3% of student teachers possessed misconceptions that at equilibrium state reaction does not occur; 41.2% student teacher thought that concentration of reactants and products are equal at equilibrium and 37.1% student teachers categorized rate of forward reactions as not equal to reverse reactions at equilibrium state. Apart from that, other misconceptions related to chemical equilibrium reported are equilibrium constant will increase with constant temperature (Ozmen, 2008); equilibrium is an oscillation of pendulum (Van Driel, De Vos , Verloop & Dekkers, 1998); there is an effect of catalyst at equilibrium (Griffiths, 1994); and concentration of reactants and products remain constant with increasing pressure (Banerjee, 1991). According to Demircioglu and Yadigaroglu (2013), chemical equilibrium is one of the abstract topic in chemistry and research of teaching and learning of chemical equilibrium is somewhat lacking in literature.

One of the approaches suggested in the literature to improve students learning and understanding of science concepts is through writing (Prain, 2006). This phenomenon is more explicit when the students use various modes in presenting their writing (McDermott & Hand, 2012). However, the students commonly present their understanding using a unimode which is in the form of a text. Unimode representation prevents the students from clearly expressing their understanding particularly in chemistry concepts which is abstract (Johnstone, 1991). According to Gunel, Hand and McDermott (2009) using multi-mode representation such as graphs, equations, concept maps and diagrams in writing to learn task improve students' conceptual understanding. McDermott and Hand (2013) in their study using quasi experimental regression and correlation data deduced that there is a positive relationship between embeddedness of multi-mode representations and students understanding. However, when the students were introduced to multi modes they must be able to understand the modes, translate between the modes and integrate the mode as a part of learning science concepts (Ainsworth, 1999; Dolin, 2001; Prain & Waldrip, 2006). For instance, research done by Prain and Waldrip (2006) involving upper primary students and teachers (years 4-6) in Australia using multi-mode representations in teaching and learning of electric circuit reported that most of the students learnt effectively using multi-mode and were able to see translation between modes.

Using multi-mode representations only to learn science concepts is not sufficient to form a conceptual understanding among students (Gunel, 2006). A student requires embedding multi-mode representations rather than using multi-mode representations (McDermott & Hand, 2013, 2016). The ability to embed multi-mode representations is measured in term of text production, modes representations and average embeddedness (McDermott & Hand, 2010). Text Production Score (TPS) particular interest was whether the text covered required topics from assignment, was accurate, was complete and was grammatically correct (McDermott & Hand, 2010). . Modes Representation Score (MRS) measured the overall number of modes outside of text appropriately utilized and the number of science topics that were addressed through utilization of these modes (McDermott & Hand, 2010). Average Embeddedness Score (AES) was determined for each piece of multimodal writing by assessing each use of a mode outside of text in the student writing individually with a checklist of several key factors. The key factors assessed included whether or not the multi-mode representation were accurate (no scientific inaccuracies), complete (did not leave out information), next to the text that referred to it, referenced in the written text (used a phrase such as "see Fig.1"), contained a caption, or were an original item created by author and not copied form another source (such as cutting and pasting on a computer) (McDermott & Hand, 2010).

Translating between modes happens when the text able to interconnect various modes such graph, equation, notation or symbols effectively to describe particular concepts (Ainsworth, 2009; McDermott, 2006). Translation between modes were measured using cohesiveness scores (McDermott & Hand, 2010). . The cohesiveness score (CS) is used to measure how well the students interconnect the modes. Cohesiveness scores assessed seven specific components which included placement of modes outside of text next to appropriate text, the presence and absence of a caption, the originality of modes outside text in text, the reference to modes outside of text in the text, necessity of modes for explanation, the scientific accuracy of the information of the modes outside of text and conceptual connection of the modes outside the text to the information in the text (McDermott & Hand, 2010).

Previous researches indicated that digital technology including simulations, animation, models and games as effective pedagogical tools that can enhance students' understanding in visualizing science concepts (Nakhleh & Krajcik, 1994). A qualitative research conducted by Stieff and Wilensky (2003) involving 6 undergraduate students using interactive simulations to teach equilibrium found that students showed better understanding in chemical equilibrium concepts such as characterization of factors affecting equilibrium; in defining equilibrium and understanding the translation between macro, sub micro and symbolic levels. This happens because using multi-mode representations students seeming shifted between the three levels of presentations in chemistry by constructing mental visualization to make an abstract concepts perceptible (Kozma & Russell, 2005).This could help the students to create correct mental images of chemical phenomena to gain a meaningful understanding (Gkitzia, Salta & Tzougraki, 2011).

Suitable teaching strategies required to encourage embedding and translating multi-mode representations. Hand, McDermott and Prain (2016) proposed technological tools as effective pedagogical tool to encourage students to embed and translate multi-mode representations. A study conducted by Hand, McDermott and Prain (2016) found out that students who used PowerPoint presentation format with multi-mode representations were greatly engaged with multi-mode representations than students used the report format. In addition, a study conducted by Karpudewan and Balasundram (2019) revealed that the students who used 'Popplet' applications resulted in more cohesive and organized written product by embedding and translating multi-mode representation on transition metals.

Physics education technology (PhET) is a project affiliated with University of Colorado that created research based science simulation which is accessible to everyone. There are various topics available for the field of chemistry ranging from subatomic particles and chemical dynamics. PhET simulations consist of 130 simulations on various aspects of science and mathematics integrated with classroom activities, mini lab activity and teacher resources. The three simulations namely reversible reactions, reaction and rates and salt and solubility used to cover the topics of reversible reactions, rate constant, equilibrium constant and Le chatelier's principle.

The PhET interactive simulations can be used to organize writing in a science classroom. For instance, students can conduct virtual experiments to describe dynamic equilibrium concepts. This enables students to use various modes in their writing and allow them to organize their writing effectively. Organizing writing allow students to embed and translate multi-mode representations fluently to describe concepts in science including chemical equilibrium. Hence, the use of PhET interactive simulations expected to encourage embedding and translating multi-mode representations.

Digital technology as a medium of instruction helps the students to retain more information. According to Hameed, Hackling and Garnett (1993), students may change their misconceptions for a while following intervention but may revert back to the original misconceptions after some time. A study conducted by Hameed, Hackling and Garnett (1993) among 30 Year 12 chemistry students revealed that digital tools are better compared to traditional teaching methods for students' memory. This is because old misconceptions have been superseded by new science concepts and accommodation of new information has occurred. This allows students to embed and translate multi-mode representation fluently to describe the concepts. In addition, a 4 weeks delayed study conducted by Tanel and Erol (2008) using jigsaw game reported that post-test and delayed test mean scores of jigsaw game group were retained nearly 98% of their knowledge on delayed post-test compare to control group students retained nearly 80%.

Flow experiences and engagement encountered during the lesson is an important determinant of the learning (Csiksznthmilhalyi, 1997; Winberg & Hedman, 2006). “Flow” is an intensely rewarding experience when a person is deeply focused on performing an activity (Csiksztntmilhalyi, 1990). Ghani and Deshpande (1994) highlighted five important components of flow: enjoyment, concentration, control, exploration and challenge. In this study, since the PhET interactive simulations focused on cognitive rather than training, it did not give much importance for exploration (testing different ways of operation). This flow component did not emerge as important in the model (Winberg & Hedman, 2006) and exploration components were excluded in the questionnaire. Engagement mode explains how people use different ways to involve themselves with a task or activity (Hedman & Sharafi, 2004). Engagement mode consist of three positive modes namely enjoyment/ acceptance; efficiency/ proficiency; curiosity/ ambition and two negative modes namely frustration/ anxiety and hesitation/ avoidance. Since, engagement modes were assumed to influence students’ performance when using computer simulations (Hedman & Sharafi, 2004), engagement modes were assessed as one of the component in the flow experiences. Flows experiences and engagement mode assessment includes components namely enjoyment, concentration, control, challenge and engagement.

Frequently, students expressed positive view on the flow experience and engagement in the lessons which employed computer simulations (Winberg & Hedman, 2006). For instance, in a study conducted by Bressler and Bodzin (2013) to teach chemistry concepts for 68 urban middle school students found that on students’ flow experiences and engagement mode revealed that students exhibited interest to learn science and improved their collaborative skills. Most of the research done indicated that the students’ flow experiences and engagement towards teaching instructions became more favorable when they were taught using new technology based instructions (Csiksczntmilhalyi, 1999; Kozma & Russsell, 2005). For instance, a quasi-experimental study was conducted by Susskind (2005) among 51 psychology course students to investigate the effect of multimedia on students' engagement and self-efficacy. The control group was taught using traditional instructional method (notes and whiteboard) and the experimental group was taught using same notes but the notes were presented through PowerPoint presentations. Both groups were given a 15 items questionnaire on their perception towards multimedia and the research found out that students showed more positive perception towards PowerPoint presentation and believed that the learning was more effective because the notes in PowerPoint presentation were more organized and systematic. This was because technology integrated in writing encourages students infuse more multi-mode representations in their writing and subsequently enhance their experiences to learn chemistry using computer simulations.

1.2 Problem Statement

Among the various chemistry concepts, chemical equilibrium is considered as one of the most difficult topic to understand by students in general chemistry curriculum (Finley, Stewart & Yarroch, 1982; Solomonidou & Stavridou, 2001; Piquette & Heikkinen, 2005; Ozmen, 2008). For this reasons, it is evident from studies performed in the past three decades students hold misconceptions in chemical equilibrium (Berquist & Heikkinen, 1990;Chiu,Chou & Liu, 2002; Piquette & Heikkinen, 2005; Bilgin, 2006; Chandrasegaran, Treagust, Mauro, Mihye & Mageswary, 2014). Particularly, misconceptions in chemical equilibrium is notable among Malaysian Matriculation students regarding application of the principle of Le Chatelier's principle, concepts toward equilibrium, the equilibrium constant, the impact on the equilibrium catalyst and equilibrium in heterogeneous system (Ahmad & Su, 2014). This is because domination of teacher centered strategy in the Matriculation chemistry lessons (Saleh & Aziz, 2012).

Pre-university students find it very difficult to retain their knowledge in chemical equilibrium because of its abstract character and its demands of the mastery of larger number of subordinate concepts (Solomonidou & Starvridou, 2001). However,it is very important to mastery chemical equilibrium concepts because it plays essential role in developing understanding of other areas of chemistry needed for tertiary education such as acid-base behavior and oxidation –reduction (Voska & Heikkinen, 2000).

Embedding and translating between multi-mode representations evident to improve understanding of chemistry concepts such as electrochemistry (Gunel, Kingir & Aydemir, 2016); transition metals (Karpudewan & Balasundram, 2019) and nucleophilic substitution reactions (Balasundram, 2017). Particularly, a research conducted by Balasundram and Karpudewan (2017) among Form six students in Malaysia asserted that students were not able to use modes such as equations, graph, notation, symbols and text to illustrate the nucleophilic substitution concepts rather than using text only to explain the reaction. A mixed method study conducted by Mageswary and Balasundram (2019) among 81 pre-university students found out that students use various ways to embed and translate multi-mode representations after being exposed to “popplet” applications. However, embedding and translating in the context of learning Chemical equilibrium is not found. Despite multi-mode representations forms the integral part of chemical equilibrium as it involves learning using three level of representation.

Hand, McDermott and Prain (2016) recommended usage of digital tool to encourage embedding and translating. Except the study by Balasundram (2019) on using “popplet” application to encourage embedding and translating in learning about transitional metals, no studies at this point of time reported using digital tool to embed and transition metals especially in lessons in chemical equilibrium. PhET provide dynamic access to multiple representations (Moore, 2014). According to Perkins and Wieman (2018), PhET incorporate multiple representations (symbolic, graphical, particulate and macroscopic) to help students see important connections between the representations. However, there were no studies conducted to predict how PhET interactive simulations encourages embeddedness and translation between multi-mode representations.

PhET interactive simulations has been used widely to teach physics, chemistry and biology concepts (Perkins, Adams, Dubson, Finkelstein, Reid, Wiemann, LeMaster, 2006; Wiemann, Adams, Loeblein & Perkins, 2010) to enhance conceptual understanding (McKagan, Perkins, Dubson, Malley, Reid, LeMaster, Wiemann, 2008). However, the usage of PhET interactive simulations in chemistry still lacking and in chemical equilibrium is not found.

1.3 Purpose of the Study

The purpose of this study is to investigate the effectiveness of PhET interactive simulations to embed and translate multi-mode representations; effectiveness of embedding and translating multi-mode representations on students’ misconceptions and retention of knowledge in chemical equilibrium. This study also investigated the effectiveness of embedding and translating multi-mode representations on students flow experiences towards learning chemistry.

1.4 Research Objectives

1) a) To evaluate the effectiveness of PhET interactive simulations in enhancing students' ability to embed multi-mode representations in open ended questions.

   - Embeddedness in term of Text Production
   - Embeddedness in term of Mode Representation Score
   - Embeddedness in term of Average Embeddedness.

   b) To explore the embedding of multi-mode representations in open-ended questions.

2) a) To evaluate the effectiveness of PhET interactive simulations in enhancing students' ability to translate multi-mode representations in their open-ended questions.

   - Cohesiveness

   b) To explore the translation between multi-mode representations in open-ended questions.

3) a) To evaluate the effect of ability to embed and translate multi-mode representations in their open- ended questions to reduce misconceptions held by the students in chemical equilibrium concepts.

   - Misconceptions in Heterogeneous Mixture
   - Misconceptions in Equilibrium
   - Misconceptions in Rate Constant
   - Misconceptions in Le Chatelier's Principle

   b) To identify the misconceptions in pre-test and post-test regarding chemical equilibrium.

4) a) To evaluate the effect of ability to embed and translate multi-mode representations in their open- ended questions to retain students' knowledge in chemical equilibrium concepts.

- Students' retention of knowledge in Heterogeneous Mixture
- Students' retention of knowledge in Equilibrium
- Students' retention of knowledge in Rate Constant
- Students' retention of knowledge in Le Chatelier's Principle

5) a) To evaluate the effect of ability to embed and translate multi-mode representations in enhancing students' flow experiences towards learning chemistry.

- Flow experiences in term of Enjoyment
- Flow experiences in term of Concentration
- Flow experiences in term of Control
- Flow experiences in term of Challenge
- Flow experiences in term of Engagement

b) To identify students' flow experiences towards learning chemistry in the pre-test and post-test.

1.5 Research Questions

Based on the above research objectives, the following research questions were posed:

1.0 Is there any statically significant difference in linear combinations of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations after controlling the pre-test scores?

a) Is there any statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations in term of Text Production (TPS) after controlling pre-test scores.

b) Is there any statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations in term of Mode Representation (MRS) after controlling pre-test scores.

c) Is there any statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations in term of Average Embeddedness (AES) after controlling pre-test scores.

1.1 How do students embed multi-mode representations in open-ended questions?

2.1 Is there any statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to translate multi-mode representations after controlling pre-test scores?

2.2 How do students translate multi-mode representations in open-ended questions?

3.1 Is there any statically significant difference in linear combinations of post-test scores between PhET and Traditional group ability to embed and translate in multi-mode representations in reducing misconceptions after controlling the pre-test scores?

a) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding heterogeneous mixture after controlling pre-test scores?

b) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding equilibrium after controlling pre-test scores?

c) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding rate constant after controlling pre-test scores?

d) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding Le Chatelier's principle after controlling pre-test scores?

3.2 How misconceptions in chemical equilibrium differ in pre and post interview?

4.1 Is there any statically significant difference in linear combinations of delayed post-test scores between PhET and Traditional group ability to embed and translate in multi-mode representations in retaining students' knowledge after controlling the pre-test scores?

a) Is there any statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding heterogeneous mixture after controlling pre-test scores?

b) Is there any statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding equilibrium after controlling pre-test scores?

c) Is there any statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding rate constant after controlling pre-test scores.

d) Is there any statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding Le Chatelier's after controlling pre-test scores.

5.1 Is there any statically significant difference in linear combinations of post-test scores between PhET and Traditional group ability to embed and translate in multi-mode representations in enhancing students' flow experiences towards learning chemistry after controlling the pre-test scores?

a) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding enjoyment towards learning chemistry after controlling the pre-test scores after controlling pre-test scores?

b) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding concentration towards learning chemistry after controlling the pre-test scores after controlling pre-test scores?

c) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding control towards learning chemistry after controlling the pre-test scores after controlling pre-test scores?

d) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding challenge towards learning chemistry after controlling the pre-test scores after controlling pre-test scores?

e) Is there any statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences mode regarding engagement towards learning chemistry after controlling the pre-test scores after controlling pre-test scores?

5.2 How students' flow experiences towards learning chemistry differs in pre and post interview?

1.6 Hypothesis

1) H_{01}: There is no statically significant difference in linear combinations of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations after controlling the pre-test scores?

a) H_{01a}: There is no statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations in term of Text Production (TPS) after controlling pre-test scores.

b) H_{01b}: There is no statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations in term of Mode Representation (MRS) after controlling pre-test scores.

c) H_{01c}: There is no statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to embed multi-mode representations in term of Average Embeddedness (AES) after controlling pre-test scores.

2) H_{02}: There is no statically significant difference of post-test scores between PhET and Traditional group in enhancing students' ability to translate multi-mode representations after controlling pre-test scores.

3) H_{03}: There is no statically significant difference in linear combinations of post-test scores between PhET and Traditional group ability to embed and translate in multi-mode representations in reducing misconceptions after controlling the pre-test scores.

a) H_{03a}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding heterogeneous mixture after controlling pre-test scores.

b) H_{03b}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding equilibrium after controlling pre-test scores.

c) H_{03c}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding rate constant after controlling pre-test scores.

d) H_{03d}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in reducing misconceptions regarding Le Chatelier's principle after controlling pre-test scores.

4) H_{04}: There is no statically significant difference in linear combinations of delayed post-test scores between PhET and Traditional group ability to embed and translate in multi-mode representations in retaining students' knowledge after controlling the pre-test scores.

a) H_{04a}: There is no statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding heterogeneous mixture after controlling pre-test scores.

b) H_{04b}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding equilibrium towards learning chemistry after controlling the pre-test scores after controlling pre-test scores.

c) H_{04c}: There is no statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding rate constant after controlling pre-test scores.

d) H_{04d}: There is no statically significant difference of delayed post-test scores between PhET and Traditional group ability to embed multi-mode representations in retaining students' knowledge regarding Le Chatelier's after controlling pre-test scores.

5) H_{05}: There is no statically significant difference in linear combinations of post-test scores between PhET and Traditional group ability to embed and translate in multi-mode representations in enhancing students' flow experiences towards learning chemistry after controlling the pre-test scores.

a) H_{05a}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding enjoyment towards learning chemistry after controlling the pre-test scores after controlling pre-test scores.

b) H_{05b}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding concentration towards learning chemistry after controlling the pre-test scores after controlling pre-test scores.

c) H_{05c}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding control towards learning chemistry after controlling the pre-test scores after controlling pre-test scores.

d) H_{05d}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' flow experiences regarding challenge towards learning chemistry after controlling the pre-test scores after controlling pre-test scores.

e) H_{05e}: There is no statically significant difference of post-test scores between PhET and Traditional group ability to embed multi-mode representations in enhancing students' engagement regarding engagement towards learning chemistry after controlling the pre-test scores after controlling pre-test scores.

1.7 Significance of the Study

Embedding and translating multi-mode representations encourages students to learn science concepts effectively because multi-mode representations allow clear representation of the difficult concepts that encourages students to enhance their understanding in open ended questions. Effective science learning required to share ideas, knowledge and information among individual to achieve a specific purpose (Gunel, 2006). Effective learning method is one of the Millennial (Generation Z) students learning skill that is needed to be nurtured among students (Dimock, 2019). Moreover, this study provided a platform for poor writing skill students to express their explanations using different modes rather than using text. For instance, multi-mode representations such as diagram to represent dynamic equilibrium could be used to explain the characteristic of dynamic equilibrium. By doing so, students were able to obtain minimum score with different level of understanding.

PhET interactive simulations proposed in this study is a type of generation Z teaching strategy (Hariadi, Sunarto, Sudarmaningtyas & Jamiko, 2019). This is because generation Z teaching strategy focuses on technology to promote students' understanding (Dimock, 2019). The PhET interactive simulations allow teachers to be in line with millennial students teaching strategy by developing positive environment when the students engaged in the classroom as the teacher act as facilitator to guide the students. In handling PhET interactive simulations, students worked in a group to perform activities or virtual experiments for each concepts and present their findings in the class with the guidance from the teacher. As such, the teacher indirectly helps the Matriculation students to learn collaborative skills that are required by the pre-university students.

Students' perception towards learning chemistry using computer simulations had increased (Kozma & Russell, 2005). This is because computer simulations enable the students' to visualize abstract concepts clearly and transform the knowledge into writing products by embedding and translating between multi-mode representations. In this study, PhET simulations were used to increase students' flow experiences towards learning chemistry.

The teachers' guide for activities and lesson plan on PhET interactive simulations used in this study provided a detailed explanation on how to implement teaching strategy that consist of four parts: introduction, activity, class discussion and summary to encourage embeddedness and translation of multi-mode representations in chemical equilibrium concepts. Therefore, the teacher guide for activities and lesson plan are very useful to Matriculation curriculum developer. Matriculation curriculum developer would be able to suggest the teacher guide and lesson plan as an alternative for the current traditional teaching strategy.