EMPLOYING ACTIVITY THEORY BASED GREEN CHEMISTRY EXPERIMENTS TO IMPROVE CHEMISTRY LEARNING AMONG MATRICULATION STUDENTS

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UNIVERSITI SAINS MALAYSIA

2020

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by

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Thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy

July 2020

ACKNOWLEDGEMENT

Firstly I would like to give thanks to the Almighty for giving me the strength to endure this PhD journey of mine and to complete this thesis successfully. I would also like to address my gratitude to the following professionals, individuals, groups, and organisations whom had assisted and guided me in making this thesis possible.

Thank you to the Scholarship and Financing Division, Ministry of Education Malaysia for granted me the HLP scholarship to pursue my PhD studies. Heartfelt gratitude to my main supervisor, Associate Professor. Dr. Mageswary Karpudewan who gave her valuable guidance and support along my academic journey and also my co supervisor, Dr. Lee Hooi Ling for her assistance and support in completing my thesis.

To my dearest mom, sister, brothers, and relatives whom had encouraged and given me the full support during my study. Thank you to all the lecturers and staff of School of Educational Studies, Universiti Sains Malaysia for their patient assistance and guidance during my days in the institution.

Appreciation to the officers of various education departments for their cooperation in providing me the ease of access to Matriculation Colleges for data collection. Thank you to the lecturers and students whom had given me full support and cooperation in the period of my study.

Gratitude to my friends and comrades along my academic journey whom selflessly gave motivation and support to complete this thesis. Finally, I dedicate my piece of work and my doctoral degree to my late father Mr. Kulandaisamy who had silently supported and wished my success in completing this thesis of mine.

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LIST OF ABBREVIATIONS

ATGC	Activity Theory based green chemistry
CLEI	Chemistry Laboratory Environment Inventory
WGCT	Watson Glaser Critical Thinking
CUT	Chemistry Understanding Test
MMR	Mix Method Research

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EMPLOYING ACTIVITY THEORY BASED GREEN CHEMISTRY EXPERIMENTS TO IMPROVE CHEMISTRY LEARNING AMONG MATRICULATION STUDENTS

ABSTRACT

The central role of laboratory work in learning of Science like Chemistry is fundamental. In learning Chemistry, the abstract concepts hinders students from relating their own experience of the concept and therefore unable to identify the importance of learning Chemistry. Effective instructional strategies are crucial for making abstract concepts more tangible. This study introduced the Activity Theory based Green Chemistry (ATGC) Experiments as a laboratory instructional strategy. Simultaneously, this study measured the effectiveness of ATGC Experiments on students' understanding of Chemistry concepts, Chemistry laboratory learning environment and critical thinking skills. Intervention mixed method design was employed for twelve weeks with 90 Matriculation students. The effectiveness of ATGC Experiments on students' understanding of Chemistry concepts measured using the Chemistry Understanding Test (CUT). The Chemistry laboratory learning environment measured using the Chemistry Laboratory Environment Inventory (CLEI) and Watson Glaser II Critical Thinking (WGCT) Appraisal measured critical thinking skills. The ANOVA performed indicated that the ATGC Experiments improved students' understanding of Chemistry concepts ($F(2,88) = 150.276$, $p < 0.05$, $\eta 2 = 0.774$). The content analysis performed on the CUT showed improved ability of students to demonstrate fragments of conceptual understanding through the ATGC Experiments. The MANOVA and ANOVA indicated that the ATGC Experiments improved

students' Chemistry laboratory learning environment ($F(4, 86) = 21.102$, $p < 0.05$, $\eta^2 = 0.495$). The thematic analysis performed on the interview responses indicated that the ATGC Experiments provided a more open-ended approach to experimentation, an adequate material environment and an integration of laboratory activities with theory. The MANOVA and ANOVA also indicated the ATGC Experiments improved students critical thinking skills ($F(2,88) = 104.546$, $p < 0.05$, $\eta^2 = 0.704$). The thematic analysis performed showed students were able to recognize assumptions, evaluate arguments and draw conclusion through the ATGC Experiments. Collectively, the ATGC Experiments improved the understanding of Chemistry concepts, improved the learning environment in the Chemistry laboratory and enhanced critical thinking skills of students.

MENGGUNAKAN EKSPERIMEN KIMIA LESTARI BERASASKAN TEORI AKTIVITI UNTUK MENINGKATKAN PEMBELAJARAN KIMIA DALAM KALANGAN PELAJAR MATRIKULASI

ABSTRAK

Peranan utama kerja amali adalah asas kepada pembelajaran Sains seperti Kimia. Dalam pembelajaran Kimia, konsep abstrak menghalang pelajar daripada menghubungkait pengalamannya mengenai konsep Kimia dan oleh itu tidak dapat mengenal kepentingan mempelajari Kimia. Strategi pengajaran yang efektif adalah penting supaya konsep abstrak menjadi lebih konkrit. Kajian ini memperkenalkan *Activity Theory based Green Chemistry (ATGC) Experiments* atau Eksperimen Kimia Lestari berasaskan Teori Aktiviti sebagai strategi pengajaran di makmal Kimia. Pada masa yang sama, kajian ini mengukur keberkesanan Eksperimen Kimia Lestari berasaskan Teori Aktiviti terhadap pemahaman pelajar tentang konsep-konsep Kimia, persekitaran pembelajaran makmal Kimia dan kemahiran pemikiran kritis. Rekabentuk penyelidikan campuran intervensi digunakan selama dua belas minggu dengan 90 pelajar Matrikulasi. Keberkesanan *ATGC Experiments* terhadap pemahaman konsep-konsep Kimia pelajar diukur dengan menggunakan *Chemistry Understanding Test (CUT).* Persekitaran pembelajaran makmal Kimia dinilai menggunakan *Chemistry Laboratory Environment Inventory (CLEI) dan Watson Glaser II Critical Thinking (WGCT) Appraisal* mengukur kemahiran pemikiran kritis. Keputusan ANOVA menunjukkan bahawa *Activity Theory based Green Chemistry (ATGC) Experiments* meningkatkan pemahaman pelajar terhadap konsep Kimia ($F(2,88) = 150.276$, $p < 0.05$, $\eta^2 = 0.774$). Analisis kandungan terhadap *Chemistry Understanding Test (CUT)*

menunjukkan peningkatan dalam kebolehan pelajar mendemonstrasikan elemen-elemen pemahaman konseptual melalui *ATGC Experiment*s. Keputusan MANOVA dan ANOVA menunjukkan persekitaran pembelajaran makmal Kimia yang lebih baik dicapai ($F(4, 86) = 21.102$, $p < 0.05$, $\eta^2 = 0.495$). Keputusan analisis tematik dari respon temuduga menunjukkan *ATGC Experiments* menyediakan persekitaran pembelajaran yang lebih terbuka dari aspek experimen, persekitaran bahan yang mencukupi dan pengintegrasian aktiviti makmal dan teori. Keputusan MANOVA dan ANOVA juga menunjukkan peningkatan dalam kemahiran berfikir kritis pelajar ($F(2,88) = 104.546$, $p < 0.05$, $\eta^2 = 0.704$). Keputusan analisis tematik dari respon temuduga menunjukkan pelajar dapat mengenal pasti andaian, menilai hujah dan membuat kesimpulan melalui *ATGC Experiments*. Secara kolektif, *ATGC Experiments* telah meningkatkan pemahaman konsep Kimia, menambah baik persekitaran pembelajaran makmal Kimia dan meningkatkan kemahiran berfikir kritis pelajar.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Teaching and learning of science in the 21st century is challenging for both educators and students. In a world where creation of new knowledge is rapidly accelerating, curriculum and the instructional methods employed in the classroom needs to be timely, particularly in science teaching. This is because scientific knowledge rapidly evolves in line with the advancement in Science and Technology and also partly due to globalization as proclaimed by McFarlane (2013) in quote below.

"We are living in a world where science itself must adapt and thus, we ourselves especially educators and teachers must immediately recognise we are not teaching a static discipline. We must therefore broaden our own horizons as new knowledge and ideas, emerge to replace and add credibility to those we have held on to as the correct way, while recognizing that some ideas become obsolete"

(McFarlane, 2013 p.36)

In the context of Chemistry learning, because Chemistry consisted of abstract concepts students frequently regard learning of Chemistry is difficult (Levy Nahum, Hofstein, Mamlok-Naaman, & Bar-Dov, 2004; Srihan, 2007; Taber, 2002b; Tsaparlis, 2016; Tumay, 2016). The abstract concepts hinders students from relating their own experiences about the concepts with the classroom learning. Subsequently, this resulted in students unable to identify the importance of learning Chemistry (Grove & Bretz, 2012). In sum, study by Grove and Bretz revealed that students were in dilemma why they need to learn Chemistry on the contrary to the claim Chemistry is a mother to all the Sciences and Chemistry is fundamental for many developments including health care (Christensson & Sjostrom, 2014). Some studies suggested this gap could be bridged if context-based teaching was performed (Burmeister & Eilks, 2012; Miller, 2012). This calls for the use of the right pedagogy to deliver Chemistry in the form of context relevant to the students (Broman & Parchmann, 2014; King, Bellocchi, & Ritchie, 2008; Miller, 2012). For instance, Miller (2012) demonstrated an increase in students' mastery of the content and interest through a context base approach using Green Chemistry/bio-remediation Principles among High School Chemistry students. This was possible as Green Chemistry has the connectivity between the subject matter and students' everyday living (Braun et al., 2006) and the laboratory work on Green Chemistry helped students see the relevance of scientific knowledge to their real life context and thus improved their understanding (Chua, Karpudewan, & Chandrakesan, 2017; Karpudewan, Treagust, Mocerino, Won, & Chandrasegaran, 2015; Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012).

In contextualising the learning, it required high level of engagement and participation of the students (Obenland, Munson, & Hutchinson, 2013). Learning grounded from the Activity Theory deliberately have encouraged participation of students and other relevant parties in the teaching and learning context (Hung & Wong, 2000; Thomas & McRobbie, 2013). Activity Theory described the activity system as a unit of analysis where the subject and object are mediated by tools, at the same time it is simultaneously influenced by the rules, the learning community and the division of labour (Jonassen & Rohrer-Murphy, 1999). Activity Theory has been seen in literature to help students seek the relevance of chemistry (Van Aalsvoort, 2004). As literature revealed Green Chemistry laboratory a platform that established the connectedness between scientific knowledge and real life context and Activity Theory on the other hand promoted engagement of learners from various perspective, in this study the Activity Theory based Green Chemistry Experiments (ATGC) was introduced in teaching and learning of Chemistry at Matriculation level.

Laboratory learning environment is one of the important criteria that influenced students' learning in the laboratory (Ahmad, Osman, & Halim, 2010b; Aladejana & Aderibigbe, 2007). As effective lab environment could be established using appropriate teaching approaches in which the approach required students' active participatory (Robinson, 2013), ATGC Experiments was a viable approach that had influenced students' view on the chemistry laboratory environment.

"The development of critical thinking skills is often listed as the most important reason for formal education because the ability to think critically is essential for success in the contemporary world where the rate at which new knowledge is created is rapidly accelerating" (Marin & Halpern, 2011). The assertion by Marin and Halpern portrayed that every individual completing education in the 21st century should have the ability to be critical. A well designed teaching strategy is required to ensure critical thinking skills have been successfully inculcated among students and for this purpose, curriculum developers have altered the goals of laboratory components in many science curricula (Chase et al., 2016). Laboratory activities that focused on students collaborative efforts have exhibited improved critical thinking (Kim, Sharma, Land, & Furlong, 2013). As such, ATGC Experiments conducted in this study was a kind of intervention that had inculcated critical thinking skills among the Matriculation students.

1.2 Background of study

Green Chemistry, also known as Sustainable Chemistry, is a form of Chemistry designed to prevent pollution (Anastas & Warner, 1998). It emphasized the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes. It include practices that reduce the use of hazardous, non-hazardous materials, energy, water or other resources and protect natural resources through efficient use. There were 12 principles that underlie the green approach to Chemistry and the implementation of Green Chemistry into practice was guided by these 12 principles (Anastas & Warner, 1998). Green Chemistry provided opportunities for discussing sustainable development in the classroom (Wardencki, Curylo, & Namiesnik, 2005). There were several ways which Green Chemistry was introduced in the curricula. Marteel-Parrish (2007) introduced a Green Chemistry course in the classroom setting. In this course, students engaged in small group discussions, discussed about the traditional approaches to perform chemical reaction and then followed by the definition of tools and application of Green Chemistry in industry and academia to replace the traditional polluting chemistry. Students then choose real life examples of interest to them and communicated their findings from the class to the next class period. Writing assignments, oral presentation and team mini proposal were also included to better understand the Green Chemistry principles and compared the traditional and 'greener' approaches.

Adopting Green Chemistry principles to the practice of laboratory work was another alternative to introducing Green Chemistry in education. Karpudewan, Ismail, and Mohamed (2009) in their study, integrated Green Chemistry experiments with sustainable development concepts into a pre-service teachers' curriculum and resulted change in students' values and behaviour. Andraos and Dicks (2012) demonstrated in a laboratory setting meaningful teaching and learning of Green Chemistry took placed. Another approach that was used to introduce Green Chemistry into the curriculum was by using controversial sustainability issues or socio-scientific issues for example, the debating over the usage of plastics as a socio-scientific issue in Chemistry Education (Burmeister & Eilks, 2012).

Activity Theory proposed as a framework has led learning of Science into a new light (Criswell, Calandra, Puvirajah, & Brantley-Dias, 2015). Activity Theory worked on six elements: subject, object, tools, rules, community and division of labour (Jonassen & Rohrer-Murphy, 1999). The connectivity of these six elements are presented in Figure 1.1. As illustrated in Figure 1.1, students who are the subjects would use tools as mediation to achieve the object or the problem to be addressed. This would be assisted by the elements of rule and division of task. Teachers and students as community of learners actively involve to achieve the outcome.

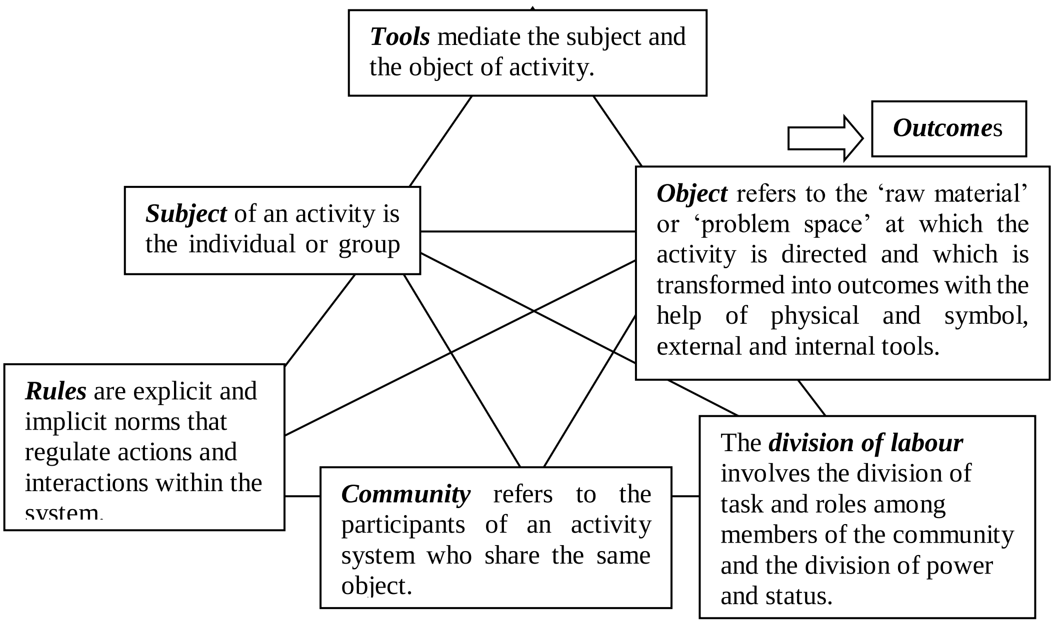

Figure 1.1. Components of the activity system (Engestorm, 1987, p.78)

Van Aalsvoort (2004) in a study had used Activity Theory as a tool to address the problem of chemistry's lack of relevance at Secondary School level. The author asserted that Activity Theory did not create a disconnectedness between knowledge and practice but learning was seen as more functional and multi perspective. In another study that involved Year 11 students revealed that altering components of the activity system in the Chemistry class assisted students to understand and engage in thinking. Students participated in this study had greater transactions between the teacher and students and also between students themselves in terms of developing chemistry understanding (Thomas & McRobbie, 2013).

Chemistry in the Matriculation Programme is a compulsory subject to be taken by all Science students. The subject is taught through three modes of instruction which are lecture, tutorial and laboratory/practical sessions. For the chemistry laboratory sessions, students' experiments for Physical Chemistry includes concepts of formula unit(empirical formula), acid base titration, determining the molar mass of a metal, Charles' Law and the Ideal gas law, chemical equilibrium, pH measurements and its applications, rate of reaction, heat of reaction and electrochemical cells. Currently, the laboratory sessions conducted weekly required students to answer prepared questions (pre lab), conduct experiment, and discussion of results (post-lab). Some of the concepts that were taught to students through experiments during laboratory sessions were not exposed to students, either in lecture or tutorial beforehand and therefore, students encountered difficulties in grasping the concepts during laboratory sessions. As previous research showed that Chemistry was a difficult subject (Grove & Bretz, 2012; Levy Nahum et al., 2004; Taber, 2002b; Tsaparlis, 2016; Tumay, 2016), students at the Matriculation Colleges also faced difficulties in learning Chemistry. A survey was done by Ibrahim, Othman, and Talib (2015) that involved 159 students and 30 lecturers in a Matriculation College to compare students' and Chemistry lecturers' views on the level of difficulty of Chemistry. Through the survey, it was found that students frequently had problem understanding the content correctly. Therefore, Ibrahim et al. (2015) proposed that the problem of students' lack of understanding can be reduced by implementing more effective strategies.

Learning environment is an important aspect in the teaching and learning process (Wolf & Fraser, 2008). Positive learning environment are associated with students being able to gain important learning outcomes (Ahmad, Osman, & Halim, 2010a; Wolf & Fraser, 2008). As laboratory played a major role in providing a Science learning setting and most Science activities are designed to take place, hence the laboratory environment was very important for effective learning (Aladejana & Aderibigbe, 2007). In the Chemistry Laboratory Environment Inventory (CLEI) (Wong & Fraser, 1997), the five dimensions of laboratory environment identified included student cohesiveness, open-endedness, integration, rule clarity and material environment.

According to Wong and Fraser (1997), the student-cohesiveness referred to the extent to which students helped each other and are being supportive. Open-endedness referred to the extent to which the laboratory activities were focused on open-ended divergent approach to experimentation. Integration was referred to the extent at which the laboratory activities are integrated with the theory classes. Rule clarity was seen as how the behaviour in the laboratory was guided by formal rules. Material environment was referred to which extent were the equipment and materials sufficient.

In the Activity Theory, the interaction between the subject and object was mediated by tools, but was simultaneously influenced by rules, the community, and division of labour. The interaction between the subject (teacher-student and student-student) increased student cohesiveness. The tools that were used as mediation (for example, Green Chemistry experiments, the activity which includes observations and group discussions) to interact between the subject and object (which is transformed into outcomes) emphasized open-endedness and also integration of laboratory activities and theories. The mediation of tools which was influenced by rules and division of labour/task enhanced the rule clarity of students. The proper use of tools in the laboratory especially the integration of Green Chemistry contributed to the material environment.

Chemistry is an experimental Science which both theoretical and practical aspects are important within its instruction. An important outcome in Chemistry teaching includes teaching students skills that are relevant for Chemistry field, including critical thinking which has been the focal point of many recent chemical educational studies (Carmel & Yezierski, 2013; Chase et al., 2016; Ghadi, Abu Bakar, Alwi, & Talib, 2013; Stephenson & Sadler-McKnight, 2016). Three critical thinking skills (subscales) as in the Watson-Glaser II Critical Thinking Appraisal included recognize assumptions, evaluate arguments and drawing conclusions (Technical Manual and User's Guide, Watson-Glaser II Critical Thinking Appraisal).

In the context of Chemistry learning in this study, the following subscales are described. Recognize assumptions describes students recognizing unstated assumptions or presuppositions in given statements, assertions and also in scientific investigations. Evaluate arguments referred to evaluation relating to the focus on experimental procedure during which students assess the credibility of statements and justify their reasoning based on relevant evidence, concepts, methods or standards and also ability of justifying and assessing statements and ideas that are put forward.

Lastly, drawing conclusions involved inference, deduction and interpretation. Making inference referred to how students draw conclusions from the obtained evidence. Deduction involved students to determine if certain conclusions necessarily follow from information in given statements or premises and interpretation referred to students weighing evidence and deciding if generalization or conclusion based on the given data was acceptable.

There are four instructional approaches to teach critical thinking; general approach; infusion approach; immersion approach; and the mixed approach (Ennis & Norris, 1989). Ennis and Norris further elaborated that general approach focuses on teaching critical thinking outside any particular discipline; infusion approach involved instruction within the subject matter with explicit teaching; immersion was similar to infusion but does not include explicit teaching; and the mixed approach involved explicit instruction of critical thinking combined with application of the skills in a specific subject matter.

The ATGC Experiments created an opportunity for students' development of critical thinking as the mediation of the right tools was used to help students work collaboratively in the laboratory using Green Chemistry experiments. The immersion approach was possible with ATGC Experiments in the laboratory. As the core element of the Activity Theory was the mediation of tools, a context was presented to students in the pre lab to gather information and gain students' interest on the concept to be taught. Students were also required to plan an investigation through a guided inquiry laboratory activity. Students discussed in groups and also presented their findings and plan of investigation. Through the information obtained and experimental procedures planned, students assessed their information and justified their reasoning based on relevant information and evident. The Green Chemistry experiments that were carried out was governed by rules, division of labour and learning community where students worked in groups and were responsible to carry out the experiment and collect data. Hager, Sleet, Logan, and Hooper (2003) found that task in small cooperative groups and applying Chemistry to everyday issue or problem enhanced critical thinking. After conducting the experiment and data collection, students in groups interpreted the data and drew conclusion from the evidence that was obtained. This process showed how students were able to interpret the data and evidence, made inferences and determine whether the conclusions made followed from the gathered information and evident. Finally, through the post lab and extended post lab phases, students were required to carry out some evaluation in relation to the experiment and its relevant evidence. This was done by addressing the context or issue that was put forward at the pre lab and also stated assumptions and conclusion reached.

Chemistry curriculum in schools are mainly responsible to cover the fundamental concepts of Chemistry which students are required to comprehend. With regard to this, finding ways to enable students to grasp the abstract concepts of Chemistry must be given much importance (Kırık & Boz, 2012; Miller, 2012). Over the years, many research have studied students' misconceptions and lack of understanding of concepts being taught in Chemistry (Kamaruddin & Ismail, 2009; Karpudewan, Treagust, et al., 2015; Ozmen, 2004; Tumay, 2016; Vrabec & Proksa, 2016). A similar issue was faced by students at the Matriculation College. This was asserted by Ibrahim et al. (2015) in a survey that the reason students faced difficulties in Chemistry was due to the fact that they did not understand the content correctly. Ibrahim et al. (2015) proposed students' lack of understanding could be overcome by implementing more effective teaching approaches.

Activity Theory was seen as a framework that actively engaged students in learning (Patchen & Smithenry, 2014) by using the six elements proposed by Engestorm (1987). Green Chemistry on the other end, was a platform where the subject matter and real life contexts go hand in hand. This naturally gave Green Chemistry a perspective of providing students a connectedness of what is being taught and their real life experiences (Prescott, 2013). Past studies have supported the notion that Green Chemistry helped students improve their understanding in chemistry (Karpudewan et al., 2009; Karpudewan, Roth, & Sinniah, 2016; Karpudewan, Roth, & Ismail, 2015; Miller, 2012). As such, ATCG Experiments was an appropriate teaching strategy in the laboratory to address the issue of students' lack of understanding in Chemistry at the Matriculation College.

Integrating Green Chemistry into the framework of Activity Theory or known as Activity Theory based Green Chemistry (ATGC) Experiments were carried out in the laboratory to investigate its effect on students' understanding of chemistry concepts. The chemistry concepts that were investigated included stoichiometry (limiting reactant and percentage yield), electron configuration, chemical equilibrium, acids and bases (pH and its application and acid base titration), rate of reaction, thermochemistry (exothermic and endothermic reactions and heat of combustion), electrochemistry (oxidation and reduction and redox reactions) and synthetic polymers. Through the ATGC Experiments, students were given a context related to the concept which was discussed at the pre lab session. Students were also required to plan an investigation based on a guided inquiry laboratory activity. Discussion at the beginning of the lab session was carried out to discuss students' gathered information. Students who were the subjects carried out Green Chemistry experiments which functioned as tools to arrive at the object (content matter) which was then transformed into intended outcomes. At the same time, students in groups (known as the community of learners) were guided by rules (experimental procedures and other rules by students in groups) and division of task/labor (shared responsibilities among students in groups). After the experiment was completed, post lab and extended post-lab sessions were carried out and the context or issue at the pre lab session was addressed. The relevant Chemistry concept to be learnt was discussed and the outcome was achieved.

1.3 Problem Statement

Past studies have discussed that students face difficulties to learn the topics in Chemistry particularly at higher institutions (Grove & Bretz, 2012; Srihan, 2007; Taber, 2002a; Tsaparlis, 2016). Topics like Matter (Stamovlasis, Tsitsipis, & Papageorgiou, 2012), Atomic Structure and Periodic Table (Wang & Barrow, 2013), Chemical Equilibrium (Karpudewan, Treagust, et al., 2015), Ionic Equilibria (acid and base) (Jing & Mei, 2007), Reaction Rate (Yaw & Subramaniam, 2016), Thermochemistry (Greenbowe & Meltzer, 2003; Sözbilir, 2003; Wren & Barbera, 2013) and Electrochemistry (Karsli & Calik, 2012; Rahayu, Treagust, Chandrasegaran, Kita, & Ibnu, 2011). Literatures also showed that studies conducted among Malaysian students did reveal students having difficulties and developed misconceptions on the aforementioned topics.

A study conducted by Kamaruddin and Ismail (2009) to determine students' misconceptions and their level of mastering the mole and chemical equation concepts which included definitions of mole, relationship between mole and mass, number of particles (ions, molecules and atoms), balancing the chemical equation based on mole concept, changing the chemical equation from statement to symbol, changing the chemical equation to ionic equation and solving chemical equation problems stoichiometrically involving 160 Form 5 students from a particular district in the state of Johor revealed that students had misconceptions and level of mastering was weak. Dadi (2007) reported that the level of students' understanding in topics related to Atomic Orbital and also concepts in the chapter of Atomic Structure (relevant to Matriculation syllabus) showed that Bohr's Atomic Model and orbitals had lowest score compared to other topics. Chemical Equilibrium and Ionic Equilibrium (acid and base) were also topics that students faced difficulties. Karpudewan, Treagust, et al. (2015) in a study that investigated the understanding of 56 Year 12 (lower 6) students in a private Secondary School indicated limited understanding of the various concepts related to chemical equilibrium. For the topic of Ionic Equilibrium (acid and base), study showed that students' understanding on the concept of acid and base are only at an average level and students were not able to relate these concepts to their daily lives (Kassim & Tan, 2009). In the topic of Electrochemistry, in a study by Mustafa (2008) that involved 100 Secondary School students showed students' lack of knowledge in the reactivity of metals in the electrochemical series and also writing cell equations.

Research in students difficulties and identifying misconceptions and finding effective ways to overcome them have become one of the major concerns in chemistry education research (Chandrasegaran, Treagust, Waldrip, & Chandrasegaran, 2009; Dadi, 2007; Karpudewan, Treagust, et al., 2015; Naah & Sanger, 2012; Stamovlasis et al., 2012). In the context of Matriculation students, Ibrahim et al. (2015) in a survey reported that students faced difficulties in understanding of chemical concepts, proposed that this problem could be addressed by implementing more effective strategies. Past studies have also revealed that effective teaching instructions or strategies are important aspects that have helped students to understand the Chemistry concepts being taught (Demircioğlu, Ayas, & Demircioğlu, 2005; Günter & Alpat, 2017; Karpudewan, Roth, et al., 2015; Kırık & Boz, 2012).

The learning environment particularly laboratory learning environment is a key factor that influence students' learning (Aladejana & Aderibigbe, 2007; Halim, 2009; Wolf & Fraser, 2008). Studies on laboratory learning environment showed that currently the traditional labs were unable to provide much conducive environment for students to learn (Aladejana & Aderibigbe, 2007). In the context of Malaysian schools, Talib and Ismail (2015) in a study that involved 340 Form Four students from 9 various schools in Perak, found that there was a significant difference between students' perception towards their actual and preferred laboratory learning environment where their perception towards their preferred laboratory environment was higher than their actual and results indicated that students were in need of a more conducive learning environment in the laboratory.

A similar results was obtained in another study by Ahmad et al. (2010a). In this study that involved 800 students from 100 schools in Selangor revealed that the average score for their preferred laboratory learning environment was significantly higher compared to their actual laboratory learning environment. The findings also revealed that students would be more satisfied when there was a good material environment, a good integration of theory learned with practical work, the chance to generate their own ideas and also laboratory that have clear stated rules. Studies like these showed that the current laboratory learning environment was not conducive and therefore attention needs to be taken in order to reduce the gap between students' actual and preferred laboratory learning environment. This was because the smaller the gap between students' actual and preferred laboratory learning environment, it would improve students' learning cognitively and affectively (Fraser, 1998b). In addition to the aforementioned studies, Ahmad et al. (2010b) in a research to determine teachers' and students' perception on the physical and psychosocial aspects of Science laboratory learning environment, showed that the current laboratory was not conducive for learning and could be improved. Students must also be engaged more actively by allowing and providing them opportunities to generate ideas and become building blocks to their own knowledge, however, if teachers want their students to be more actively engaged in the learning process, they need to re-consider the way they teach and use suitable instructional strategies that could lead to an active students' learning environment.

Good critical thinking is important to students' development and a valued skill that must be possessed for a success in academic and career. However, past studies that were conducted on Form Two, Form Four and Matriculation students showed that their critical thinking were only at an average level (Aziz, 2014; Kamrin & Noordin, 2008; Osman, Iksan, & Halim, 2007). These studies highlighted a change in instructional strategies were needed in order to enhance students' critical thinking skills. Laboratory work should be conducted in an inquiry, hands-on and minds-on manner for students to be more actively engaged to promote thinking skills. In addition, instructional strategies must be student centered activities to provide opportunities for higher order thinking among students.

In a similar context of the study conducted by Darby and Rashid (2017) on the critical thinking disposition of students at a Technical Matriculation College found that the conventional teaching approach were more exam oriented. As such, the learning environment did not require them to think critically. In a more recent study by Shafii and Jaafar (2018) revealed Form Four students' critical thinking were at an average level and using Problem-Based Learning as an intervention did improve students' critical thinking as comparison to the existing instructional strategy. The aforementioned studies over a past decade still showed similar level of critical thinking among students. As the instructional strategies did not differ much in Secondary Schools and Matriculation Colleges, similar outcomes were obtained. This concluded there was a need for more effective instructional strategies to be implemented in order to enhance critical thinking among students.

Laboratory work played an essential role to enhance students' understanding. According to Hofstein and Lunetta (2004) in Science Education, the role of laboratory was central and distinctive and suggestions have been made by Science educators that tremendous benefits are gained from using laboratory activities. However, educators have not been using practical work on a regular basis in an authentic way. This indicated that were more potential in utilising laboratory work in a meaningful manner (Hofstein, 2017). In the Malaysian context, data analysis revealed that some aspects of the Science laboratory learning still needs improvement. Exposure to the latest teaching techniques were important and seen vital to overall improve the teaching and learning in the laboratory (Ahmad, Osman, & Halim, 2013). Green Chemistry laboratory were example of using laboratory work more effectively and an alternative to address the issues of students having difficulties in learning Chemistry concepts (Cacciatore & Sevian, 2006; Karpudewan, Roth, et al., 2015; Karpudewan et al., 2016; Prescott, 2013; Tan & Karpudewan, 2017). From the perspective of effective practices using Activity Theory, studies have demonstrated positive outcome from the implementation of Activity Theory (Bagarukayo, Ssentamu, Mayisela, & Brown, 2016; Hung & Wong, 2000; Thomas & McRobbie, 2013).

As the nature of Activity Theory as a framework that engaged students actively was highlighted through the interaction of the six elements of subject, object, tools, rules, division of labor and learning community and the characteristics of Green Chemistry being a suitable context for learning through the connectivity of the subject matter and daily living was highlighted, merging Activity Theory and Green Chemistry appeared as a viable approach to improve understanding of students, improve students' perception on the laboratory learning environment and enhancing students' critical thinking. Literatures have not highlighted the merging of Activity Theory and Green Chemistry as a pedagogy that could be incorporated into teaching and learning. Therefore, as in this study the Activity Theory based Green Chemistry (ATGC) Experiments were implemented and its effectiveness on improving students' understanding of chemistry concepts, improving students' perception on laboratory learning environment and enhancing students' critical thinking at the Matriculation College were studied.

1.4 Purpose of the Study

This study investigated the effect of ATGC Experiments on 90 Matriculation students' understanding of chemistry concepts, perception about the chemistry laboratory learning environment and critical thinking. For the purpose of this study, an Intervention Mixed Method design was used. The intervention design is one that is used to study a problem by conducting an experiment or an intervention trial and adding qualitative data into it. Within this pre and post-test model with an experimental intervention, the qualitative data was added into the intervention before, during and after the intervention. For the qualitative data collection procedure, interview was used before the intervention to explore the current context of teaching and learning in the chemistry laboratory at the Matriculation College which helped to develop the intervention. Document analysis was carried out during the intervention to help explain the quantitative outcome of students' understanding of chemistry concepts. Interview and document analysis were used after the intervention to follow up on the outcome and helped explain in more detail than the statistical results alone. The qualitative data of interviews and document analysis were embedded into this larger intervention design for the purpose of supporting the quantitative data findings.

The quantitative data procedures of close ended test and survey were used to predict whether the ATGC Experiments would positively or negatively influence the understanding of chemistry concepts, the perception of the chemistry laboratory learning environment and critical thinking of Matriculation College students. As this study employed the Intervention Mixed Method research design, the rationale of collecting both the quantitative and qualitative data was that the qualitative data supported the stand alone quantitative data.

1.5 Research Objective

This study aimed to achieve the following research objectives:

1. To explore the current context of teaching and learning of chemistry in the laboratory at Matriculation College focusing on experiments relevant to the chemistry concepts investigated.

2. To identify the effectiveness of ATGC Experiments on students' understanding of chemistry concepts.

3. To identify the effectiveness of ATGC Experiments on students' chemistry laboratory learning environment with respect to the following subscales:

a. Student cohesiveness

b. Open-endedness

c. Integration

d. Rule clarity

e. Material environment

4. To identify the effectiveness of ATGC Experiments on students' critical thinking skills with respect to the following subscales:

   a. Recognize Assumption

   b. Evaluate Arguments

   c. Draw Conclusions

1.6 Research Questions (RQ)

The research questions are as follows:

1. What are the current practices of teaching and learning of chemistry in the laboratory at Matriculation College focusing on experiments relevant to the chemistry concepts investigated?

2. How the findings of RQ1 guides the adaptation of ATGC experiments as an intervention?

3a. Is there any significant differences between pre-test, post-test 1 and post-test 2 mean scores of Chemistry Understanding Test (CUT)?

3b. How does students' understanding of chemistry concepts changed after completing the ATGC Experiments.

4a. Does ATGC Experiments have any significant effect on students' perception of the chemistry laboratory learning environment and its subscales (student cohesiveness, open endedness, integration, rule clarity and material environment)?

4b. What are students' perception of the chemistry laboratory learning environment after completing the ATGC Experiments?

5a. Does ATGC Experiments have any significant effect on students' critical thinking skills and its subscales (recognize assumption, evaluate arguments and draw conclusions)?

5b. What are students' critical thinking skills after completing the ATGC Experiments?

1.7 Hypotheses

Based on the research questions the following hypotheses were formulated:-

1) H_{01}: There is no significant differences between pre-test, post-test 1 and post-test 2 mean scores of Chemistry Understanding Test.

2) H_{02}: There is no significant mean difference in the actual-preferred discrepancy of the perception on chemistry laboratory learning environment between pre-test, post-test 1 and post-test 2.

- There is no significant main effect of the chemistry laboratory learning environment subscales
- There is no significant main effect of the test time
- There is no significant interaction of chemistry laboratory learning environment subscales x test time

a) H_{02a}: There is no significant mean difference in the actual-preferred discrepancy of student cohesiveness perception between pre-test, post-test 1 and post-test 2.

b) H_{02b}: There is no significant mean difference in the actual-preferred discrepancy of open endedness perception between pre-test, post-test 1 and post-test 2.

c) H_{02c}: There is no significant mean difference in the actual-preferred discrepancy of integration perception between pre-test, post-test 1 and post-test 2.

d) H_{02d}: There is no significant mean difference in the actual-preferred discrepancy of rule clarity perception between pre-test, post-test 1 and post-test 2.

e) H_{02e}: There is no significant mean difference in the actual-preferred discrepancy of material environment perception between pre-test, post-test 1 and post-test 2.

3) H_{03}: There is no significant differences between pre-test, post-test 1 and post-test 2 mean scores of critical thinking skills

- There is no significant main effect of the critical thinking skill subscales
- There is no significant main effect of the test time
- There is no significant interaction of critical thinking skill subscales x test time

a) H_{03a}: There is no significant differences between pre-test, post-test 1 and post-test 2 mean scores of recognize assumption subscale.

b) H_{03b}: There is no significant differences between pre-test, post-test 1 and post-test 2 mean scores of evaluate argument subscale.

c) H_{03c}: There is no significant differences between pre-test, post-test 1 and post-test 2 mean scores of draw conclusion subscale.

1.8 Rationale of the Study

Ibrahim and Osman (2012) in a study to compare the Chemistry Education Models to characterize the Chemistry Matriculation course found that the Matriculation course showed characteristics of the Traditional Model of Chemistry Education. This showed there was a need for consideration of chemistry education researches to be given a larger role in improving the chemistry teaching at Matriculation Colleges. Ibrahim et al. (2015) in a survey to compare the views of students and teachers on the level of difficulty of the semester one Matriculation Chemistry topics, reported several responses from the students as of why chemistry topics were difficult to them. The most frequent response given was difficulties to understand the concepts followed by the content was too much to remember and memorise. Time constraint to cover the topics was also included as latter topics became difficult for students. The researcher proposed that this problem could be reduced by implementing more effective teaching strategies. The study revealed an important need for a more effective teaching strategy at the Matriculation Colleges. As Ministry of Education's Matriculation Program was the main Pre University channels for secondary Science stream students to pursue Bachelor degree programs in Public Institutions of Higher Learning (IPTA), therefore the program has a crucial role in determining progress and excellence of Science and Technology fields in higher education institutes of the country. In order to carry out this role, the current Chemistry course must be able to equip students with the right knowledge of Chemistry in line with learning in the 21st century and preparing students to face a changing and challenging world of globalisation.

Green Chemistry was proposed to be an effective laboratory-based pedagogy to improve students' understanding in chemistry concepts, increase their motivation of learning and also to promote pro-environmental behaviour. Green Chemistry experiments were developed with the aim of preventing and reducing pollution of the environment and risk to human health. Green Chemistry has a nature of relating to real life issues and scenarios and therefore integrating Green Chemistry into teaching especially laboratory work would enable students to apply and see the connectivity of chemical concepts to students' daily life and hence makes the learning process more meaningful to them. This study looked into the effect of implementing Green Chemistry in the laboratory on students' understanding of various chemistry concepts, on students' chemistry laboratory learning environment and on students' critical thinking. However, as studies revealed there was room for improving the teaching at Matriculation Colleges to depart from the Traditional Model of Chemistry Education (Ibrahim & Osman, 2012), therefore, it is only right to address this need and as an education researchers to identify approaches that would help in producing an effective teaching strategy.

Laboratory work has played a central role in Science teaching and therefore its importance cannot be denied. Implementing a good and valuable teaching instruction in the laboratory would contribute to effective laboratory learning. Past studies have shown various teaching approaches which have been incorporated in the laboratory for example, problem-based learning, inquiry approach and cooperative learning has seen to bring about conceptual gains to students. Less studies have demonstrated the use of Activity Theory especially in Science Education, particularly in the laboratory setting.

Activity Theory as a framework helped researchers make sense of complex real-world data sets in a manageable and meaningful manner (Yamagatha-Lynch, 2010).

Looking into a need to transform and provide a good teaching approach for learning at Matriculation Colleges, therefore this study incorporated the interdisciplinary nature of Green Chemistry with Activity Theory, a useful Social Learning Theory. The ATGC Experiments exhibited teaching and learning of Chemistry at Matriculation Colleges in a different point of view and perspective and was a possible solution to overcome the issues of difficulties in learning chemistry concepts, improving the chemistry laboratory learning environment and also promoting critical thinking among students.

1.9 Significance of the Study

The ATGC Experiments and the findings obtained through this study would be resourceful for curriculum planners and policy makers. The experiments introduced in this study would portray a greener version of experiments currently existing in Semester one and two Matriculation laboratory syllabus. As such, this study represented one way of introducing a new teaching approach in the Chemistry laboratory setting. Implementation of the ATGC Experiment as in this study is one of the approaches to reform existing laboratory work at Matriculation College which could be replicated by curriculum planners. Findings from this study also provided insights on the impact of ATCG Experiments on students' chemistry laboratory learning environment and critical thinking.

Teachers would be able to use this new approach of teaching and learning in the laboratory as a new way of conducting lessons in a greener version. The ATGC