

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

**YVONNE A/P KULANDAISAMY**

**UNIVERSITI SAINS MALAYSIA**

**2020**

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

by

**YVONNE A/P KULANDAISAMY**

**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.

## TABLE OF CONTENTS

<b>ACKNOWLEDGEMENT</b> .....	<b>ii</b>
<b>TABLE OF CONTENTS</b> .....	<b>iii</b>
<b>LIST OF TABLES</b> .....	<b>xiii</b>
<b>LIST OF FIGURES</b> .....	<b>xix</b>
<b>LIST OF ABBREVIATIONS</b> .....	<b>xxi</b>
<b>LIST OF APPENDICES</b> .....	<b>xxii</b>
<b>ABSTRACT</b> .....	<b>xxv</b>
<b>ABSTRAK</b> .....	<b>xxvii</b>
<b>CHAPTER 1 INTRODUCTION</b> .....	<b>1</b>
1.1 Introduction.....	1
1.2 Background of study .....	4
1.3 Problem Statement .....	12
1.4 Purpose of the Study .....	17
1.5 Research Objective .....	18
1.6 Research Questions (RQ).....	19
1.7 Hypotheses .....	20
1.8 Rationale of the Study.....	22
1.9 Significance of the Study .....	24
1.10 Limitations of the Study.....	25
1.11 Operational Definitions.....	26
1.12 Summary .....	30
<b>CHAPTER 2 LITERATURE REVIEW</b> .....	<b>31</b>
2.1 Introduction.....	31
2.2 Matriculation Program .....	31
2.3 Chemistry at Matriculation College.....	32

2.3.1	Mole and Stoichiometry .....	33
2.3.2	Atomic Structure .....	35
2.3.3	Chemical Equilibrium .....	37
2.3.4	Acid and bases .....	39
2.3.5	Reaction Kinetics .....	41
2.3.6	Thermochemistry .....	42
2.3.7	Electrochemistry .....	44
2.3.8	Teaching and Learning of Chemistry Concepts.....	45
2.4	Chemistry Laboratory Learning Environment.....	47
2.4.1	Past Studies on Laboratory Learning Environment using SLEI .....	49
2.4.1(a)	Student Cohesiveness .....	52
2.4.1(b)	Open Endedness .....	53
2.4.1(c)	Integration.....	53
2.4.1(d)	Rule Clarity .....	54
2.4.1(e)	Material Environment.....	55
2.4.2	Teaching Strategies and Learning Environment.....	56
2.5	Critical Thinking.....	58
2.5.1	Past Studies on Critical Thinking .....	61
2.5.2	Studies using Watson Glaser Critical Thinking Appraisal .....	63
2.5.2(a)	Recognize Assumptions .....	63
2.5.2(b)	Evaluate Arguments .....	64
2.5.2(c)	Draw Conclusions .....	65
2.5.3	Teaching Strategies and Critical Thinking.....	66
2.6	Green Chemistry .....	67
2.7	Activity Theory.....	73
2.8	Summary .....	78

<b>CHAPTER 3</b>	<b>CONCEPTUALISATION OF THE STUDY</b>	<b>79</b>
3.1	Introduction	79
3.2	Social Constructivism	79
3.3	Activity Theory based Green Chemistry (ATGC) Experiments	82
3.3.1	ATGC Experiments and Social Constructivism	86
3.4	Spiral of Knowing	88
3.4.1	Spiral of Knowing and Social Constructivism	94
3.4.2	Past Studies on the Spiral of Knowing	95
3.5	Constructivist Learning Environment	97
3.5.1	Constructivist Learning Environment and ATGC Experiments	99
3.6	Paul-Elder Critical Thinking Model	100
3.6.1	Paul-Elder Critical Thinking Model and Social Constructivism	105
3.7	Theoretical Framework of the Study	106
3.8	Conceptual Framework	107
3.9	Summary	108
<b>CHAPTER 4</b>	<b>METHODOLOGY</b>	<b>110</b>
4.1	Introduction	110
4.2	Research Paradigm	110
4.3	Mix Method Research (MMR)	112
4.3.1	Intervention Mix Method Research Design	115
4.4	Quantitative Research Design	119
4.5	Sample	120
4.6	Research Variables	121
4.6.1	Dependent Variables	122
4.6.2	Independent Variables	122
4.6.3	Extraneous Variables	122

4.7	Instruments.....	123
4.7.1	Chemistry Understanding Test (CUT).....	124
4.7.2	Chemistry Laboratory Environment Inventory (CLEI) .....	132
4.7.3	Watson Glaser II Critical Thinking (WGCT) Appraisal.....	134
4.8	Pilot Study.....	136
4.9	Quantitative Data Analysis .....	140
4.10	Qualitative Study .....	142
4.10.1	Interviews.....	143
4.10.2	Document Analysis .....	145
4.10.3	Qualitative Data Analysis .....	146
4.10.3(a)	Thematic Analysis .....	146
4.10.3(b)	Thematic Analysis for Exploring the Current Context of Teaching and Learning in The Chemistry Laboratory.....	147
4.10.3(c)	Thematic Analysis for Students' Chemistry Laboratory Learning Environment.....	152
4.10.3(d)	Thematic Analysis for Students' Critical Thinking Skills .....	160
4.10.3(e)	Content Analysis of Students' Open Ended Response of CUT .....	163
4.10.4	Procedures Taken to Ensure Validity of the Qualitative Data.....	166
4.11	Intervention.....	169
4.12	Summary.....	171
<b>CHAPTER 5 RESULTS AND FINDINGS.....</b>		<b>176</b>
5.0	Introduction.....	176
5.1	Current Context of Teaching and Learning in the Chemistry Laboratory to Answer RQ1 .....	177
5.1.1	Analysis of Lecturers' Interview Responses.....	178
5.1.2	Analysis of Students' Interview Responses .....	186

5.1.3	Merging of the Qualitative Findings of Lecturers and Students in Exploring the Current Context of Teaching and Learning in the Chemistry Laboratory.....	194
5.2	How the findings of RQ1 guided the adaptation of ATGC experiments as an intervention and answering RQ2? .....	197
5.3	To Identify the Effectiveness of ATGC Experiments on Students' Understanding of Chemistry Concepts and Answering RQ 3a.....	201
5.3.1	Normality of Data for Chemistry Understanding Test (CUT).....	202
5.3.2	Descriptive Statistics for CUT Scores .....	202
5.3.3	Checking the Assumptions for One Way Repeated Measure ANOVA .....	203
5.3.4	Outcome for One-way Repeated Measure ANOVA for CUT Scores.....	204
5.3.5	Pair-wise comparison of the mean values for CUT .....	205
5.3.6	Students' Open Ended CUT Response Analysis .....	206
5.3.6(a)	Open Ended CUT Response Analysis for Category Transfer.....	207
5.3.6(b)	Open Ended CUT Response Analysis for Category Depth.....	220
5.3.6(c)	Open Ended CUT Response Analysis for Category Predict/Explain.....	227
5.3.6(d)	Open Ended CUT Response Analysis for Category Problem Solve.....	237
5.3.6(e)	Open Ended CUT Response Analysis for Category Translate.....	247
5.3.6(f)	Summary of the Open Ended CUT Qualitative Findings .....	256
5.3.7	Overall Summary for Students' Understanding of Chemistry Concepts .....	256
5.4	To Identify the Effectiveness of ATGC Experiments on Students' Chemistry Laboratory Learning Environment.....	257
5.4.1	Outcome for Students' Chemistry Laboratory Learning Environment using CLEI .....	258



5.4.1(a)	Normality of the Data for Chemistry Laboratory Learning Environment .....	258
5.4.1(b)	Descriptive Statistics for Chemistry Laboratory Learning Environment .....	259
5.4.1(c)	One-Way Repeated Measure MANOVA for Chemistry Laboratory Learning Environment .....	260
5.4.1(d)	Checking the Assumptions for One Way Repeated Measure MANOVA and Univariate Analysis for Chemistry Laboratory Learning Environment .....	261
5.4.1(e)	The Outcome of One Way Repeated Measure MANOVA for Chemistry Laboratory Learning Environment.....	262
5.4.1(f)	Simple Interaction between Overall Perception of Chemistry Laboratory Learning Environment and Time .....	266
5.4.1(g)	Pairwise Comparisons for the Actual Preferred Mean Discrepancy Value.....	268
5.4.2	Outcome for Student Cohesiveness (SC) Subscale .....	268
5.4.2(a)	Descriptive Statistics for SC Subscale .....	269
5.4.2(b)	Simple Interaction between SC and time .....	269
5.4.2(c)	Pairwise Comparisons for the Actual Preferred Discrepancy Mean Value for Student Cohesiveness Subscale.....	271
5.4.2(d)	Interview Responses Analysis for Student Cohesiveness Subscale .....	272
5.4.2(e)	Summary of Interview Response for Student Cohesiveness of Qualitative Findings .....	276
5.4.2(f)	Overall Summary for Student Cohesiveness Subscale.....	276
5.4.3	Outcome for Open Endedness (OE) Subscale .....	277
5.4.3(a)	Descriptive Statistics for OE Subscale .....	277
5.4.3(b)	Simple Interaction between OE and time .....	278
5.4.3(c)	Pairwise Comparisons for the Actual Preferred Discrepancy Mean Value for Open Endedness Subscale.....	279

5.4.3(d)	Interview Responses Analysis for Open Endedness Subscale.....	281
5.4.3(e)	Summary of Interview Responses for Open Endedness Qualitative Findings .....	285
5.4.3(f)	Overall Summary for Open Ended Subscale.....	286
5.4.4	Outcome for Integration Subscale.....	286
5.4.4(a)	Descriptive Statistics for Integration Subscale.....	287
5.4.4(b)	Simple Interaction between Integration and time.....	287
5.4.4(c)	Pairwise Comparisons for the Actual Preferred Discrepancy Mean Value for Integration Subscale .....	289
5.4.4(d)	Interview Responses Analysis for Integration Subscale.....	290
5.4.4(e)	Summary of Interview Responses for Integration Qualitative Findings.....	293
5.4.4(f)	Overall Summary for Integration Subscale .....	294
5.4.5	Outcome for Rule Clarity (RC) Subscale .....	295
5.4.5(a)	Descriptive Statistics for RC Subscale.....	295
5.4.5(b)	Simple Interaction between RC and time.....	296
5.4.5(c)	Pairwise Comparisons for the Actual Preferred Discrepancy Mean Value for Rule Clarity Subscale.....	297
5.4.5(d)	Interview Responses Analysis for Rule Clarity Subscale.....	298
5.4.5(e)	Summary of Interview Responses for Rule Clarity Subscale.....	301
5.4.5(f)	Overall Summary for Rule Clarity Subscale.....	302
5.4.6	Outcome for Material Environment (ME) Subscale.....	302
5.4.6(a)	Descriptive Statistics for ME Subscale .....	303
5.4.6(b)	Simple Interaction between ME and time .....	303

5.4.6(c)	Pairwise Comparisons for the Actual Preferred Discrepancy Mean Value for Material Environment Subscale .....	305
5.4.6(d)	Interview Responses Analysis for Material Environment Subscale.....	306
5.4.6(e)	Summary of Interview Responses for Material Environment Subscale.....	309
5.4.6(f)	Overall Summary for Material Environment Subscale.....	310
5.4.7	Overall Summary for Chemistry Laboratory Learning Environment.....	310
5.5	To Identify the Effectiveness of ATGC Experiments on Students' Critical Thinking Skills.....	311
5.5.1	Outcome for Overall Subscales for Students' Critical Thinking Skills.....	312
5.5.1(a)	Normality of the data for Critical Thinking Skills.....	312
5.5.1(b)	Descriptive Statistics for Critical Thinking Skills Scores .....	313
5.5.1(c)	One-Way Repeated Measure MANOVA for Critical Thinking Skills .....	314
5.5.1(d)	Checking the Assumptions for One-Way Repeated Measure MANOVA and Univariate Analysis for Critical Thinking Skills.....	314
5.5.1(e)	The Outcome of Repeated Measure MANOVA for Critical Thinking Skills.....	315
5.5.1(f)	Simple Interaction between Overall Critical Thinking Skills and Time .....	318
5.5.1(g)	Pairwise Comparisons for the Mean Score Value for Critical Thinking Skills.....	320
5.5.2	Outcome for Recognize Assumption (RA) Subscale.....	320
5.5.2(a)	Descriptive statistics for RA Scores .....	321
5.5.2(b)	Simple Interaction between Recognizing Assumptions and time .....	321

5.5.2(c)	Pairwise Comparisons for the Mean Score Value for Recognize Assumption Critical Thinking Skill.....	323
5.5.2(d)	Interview Response Analysis for Recognize Assumption Critical Thinking Skills.....	324
5.5.2(e)	Summary of Interview Responses for Recognizing Assumptions Critical Thinking Skill.....	329
5.5.2(f)	Overall Summary for Recognize Assumption Skill.....	330
5.5.3	Outcome for Evaluate Arguments (EA) Subscale .....	330
5.5.3(a)	Descriptive Statistics for Evaluate Arguments Scores .....	330
5.5.3(b)	Simple Interaction between Evaluate Arguments and Time .....	331
5.5.3(c)	Pairwise Comparisons for the Mean Score Value for Evaluate Arguments .....	332
5.5.3(d)	Interview Response Analysis for Evaluate Arguments Critical Thinking Skills.....	334
5.5.3(e)	Summary of Interview Responses for Evaluate Arguments Critical Thinking Skill .....	337
5.5.3(f)	Overall Summary for Evaluate Argument Skill.....	338
5.5.4	Outcome for Draw Conclusions (DC) Subscale .....	338
5.5.4(a)	Descriptive statistics for Draw Conclusions Scores .....	338
5.5.4(b)	Simple Interaction between Draw Conclusions and time .....	339
5.5.4(c)	Pairwise Comparisons for the Mean Score Value for Draw Conclusions .....	340
5.5.4(d)	Interview Response Analysis for Draw Conclusions Critical Thinking Skill .....	342
5.5.4(e)	Summary of Interview Responses for Draw Conclusions Critical Thinking Skill .....	349
5.5.4(f)	Overall Summary for Draw Conclusion Skill .....	349

5.5.5	Overall Summary for Critical Thinking Skills.....	350
5.6	Summary .....	350
<b>CHAPTER 6 DISCUSSION AND CONCLUSION.....</b>		<b>352</b>
6.0	Introduction.....	352
6.1	Current Practices of Teaching and Learning at the Matriculation College .....	353
6.2	Adaptation of ATGC Experiments as an Intervention.....	353
6.3	ATGC Experiments Improved Students' Understanding of Chemistry Concepts .....	356
6.4	ATGC Experiments Improved Students' Perception of the Chemistry Laboratory Learning Environment.....	360
6.5	ATGC Experiments Enhanced Students' Critical Thinking Skills.....	365
6.6	Implication of the study .....	369
6.7	Recommendations and Suggestions.....	372
6.8	Conclusion .....	373
<b>REFERENCES.....</b>		<b>375</b>
<b>APPENDICES</b>		

## LIST OF TABLES

	<b>Page</b>
Table 2.1	12 Green Chemistry Principles ..... 69
Table 3.1	Sub Triangles Analysis of ATGC Experiments ..... 83
Table 3.2	Eight Characteristics of a Constructivist Learning Environment..... 98
Table 3.3	Universal Standards and Intellectual Traits ..... 102
Table 4.1	The Progression of the Study. .... 120
Table 4.2	Extraneous Threats to Internal Validity of One Group Pre-Test-Post-Test Design and Suggested Means of Control. .... 123
Table 4.3	Table of Specification According to the Revised Version of Bloom’s Taxonomy (Pre-Test)..... 126
Table 4.4	Task Analysis of CUT (Pre-Test) ..... 126
Table 4.5	Table of Specification According to The Revised Version of Bloom’s Taxonomy (Post-Test 1) ..... 128
Table 4.6	Task Analysis of CUT (Post-Test 1)..... 128
Table 4.7	Table of Specification According to The Revised Version of Bloom’s Taxonomy (Post-Test 2) ..... 130
Table 4.8	Task Analysis of CUT (Post-Test 2)..... 130
Table 4.9	Descriptive Information and Sample Items for Each Subscale of CLEI ..... 133
Table 4.10	Categorization of Items in CLEI..... 134
Table 4.11	WGCT II Appraisal Subscale Descriptions. .... 135
Table 4.12	The Internal Consistency (Cronbach Alpha Coefficient) for CLEI Scales ..... 139
Table 4.13	The Internal Consistency (Cronbach Alpha Coefficient) for WGCT II Appraisal Subscales ..... 140
Table 4.14	Analysis Method Based on Quantitative Research Questions..... 141
Table 4.15	Data Collection Method and Its Purpose Based on Qualitative Research Questions ..... 142

Table 4.16	Collation of Codes into Subthemes for Lecturers' and Students' Interview Responses .....	150
Table 4.17	Codes Used to Generate Subthemes for Chemistry Laboratory Learning Environment.....	155
Table 4.18	Themes Formed after Reviewing and Refining Process of Students' Interview Responses for Chemistry Laboratory Learning Environment .....	156
Table 4.19	Codes Used to Generate Subthemes of Critical Thinking .....	161
Table 4.20	Guideline to interpret the Cohen Kappa Coefficient (Landis & Kosh, 1977) .....	169
Table 4.21	List of green chemistry experiments and chemistry concepts in the proposed laboratory activities .....	170
Table 4.22	Description of underlying theory and models used in the progression of an activity.....	172
Table 5.1	Summary of Responses From RQ1 Findings.....	197
Table 5.2	Skewness and Kurtosis Value .....	202
Table 5.3	Descriptive Statistics of CUT Scores.....	203
Table 5.4	Mauchly's Test of Sphericity for CUT Scores.....	203
Table 5.5	Result of One-Way Repeated Measure ANOVA for CUT Scores .....	204
Table 5.6	Tests of Within-Subjects Effects.....	205
Table 5.7	Pair-Wise Comparison for Overall Mean Value of CUT Score .....	205
Table 5.8	Example of Students' Responses Obtained for Post-Test 1 Category Transfer .....	210
Table 5.9	Example of Students' Responses Obtained for Post-Test 2 Category Transfer .....	215
Table 5.10	Example of Students' Responses Obtained for Post-Test 1 Category Depth .....	222
Table 5.11	Example of Students' Responses Obtained for Post-Test 2 Category Depth .....	225
Table 5.12	Example of Students' Responses Obtained for Post-Test 1 Category Predict/Explain .....	229

Table 5.13	Example of Students' Responses Obtained for Post-Test 2 Category Predict/Explain .....	233
Table 5.14	Example of Students' Responses Obtained for Post-Test 1 Category Problem Solve .....	242
Table 5.15	Example of Students' Responses Obtained for Post-Test 2 Category Problem Solve .....	244
Table 5.16	Example of Students' Responses Obtained for Post-Test 1 Category Translate .....	249
Table 5.17	Example of Students' Responses Obtained for Post-Test 2 Category Translate .....	254
Table 5.18	Skewness and Kurtosis value .....	259
Table 5.19	Descriptive Statistics for Chemistry Laboratory Learning Environment.....	260
Table 5.20	Actual Preferred Mean Discrepancy of Chemistry Laboratory Learning Environment.....	260
Table 5.21	Mauchly's Test of Sphericity .....	262
Table 5.22	Result obtained from Wilks' Lambda Test.....	263
Table 5.23	Tests of Within-Subjects Effects.....	264
Table 5.24	Result of One-Way Repeated Measure ANOVA for Overall Five Subscales.....	267
Table 5.25	Mauchly's Test of Sphericity .....	267
Table 5.26	Tests of Within-Subjects Effects.....	267
Table 5.27	Pair-Wise Comparisons for the Actual Preferred Mean Discrepancy Values.....	268
Table 5.28	Descriptive Statistics of student cohesiveness subscale .....	269
Table 5.29	Result of One-Way Repeated Measure ANOVA for Student Cohesiveness Subscale .....	270
Table 5.30	Mauchly's Test of Sphericity .....	270
Table 5.31	Tests of Within-Subjects Effects.....	270
Table 5.32	Pair wise comparison for student cohesiveness subscale .....	271
Table 5.33	Summary of Students Responded According to the Codes .....	272
Table 5.34	Descriptive Statistics of open endedness subscale.....	278



Table 5.35	Result of One-Way Repeated Measure ANOVA for Open Endedness Subscale .....	278
Table 5.36	Mauchly's Test of Sphericity .....	279
Table 5.37	Tests of Within-Subjects Effects.....	279
Table 5.38	Pair wise comparison for open endedness subscale.....	280
Table 5.39	Summary of Students Responded According to the Codes .....	281
Table 5.40	Descriptive Statistics of integration subscale.....	287
Table 5.41	Result of One-Way Repeated Measure ANOVA for Integration Subscale.....	288
Table 5.42	Mauchly's Test of Sphericity .....	288
Table 5.43	Tests of Within-Subjects Effects.....	288
Table 5.44	Pair wise comparison for integration subscale.....	289
Table 5.45	Summary of Students Responded According to the Codes .....	290
Table 5.46	Descriptive Statistics of rule clarity subscale .....	295
Table 5.47	Result of One-Way Repeated Measure ANOVA for Rule Clarity Subscale .....	296
Table 5.48	Mauchly's Test of Sphericity .....	296
Table 5.49	Tests of Within-Subjects Effects.....	297
Table 5.50	Pair wise comparison for rule clarity subscale .....	297
Table 5.51	Summary of Students Responded According to the Codes .....	298
Table 5.52	Descriptive Statistics of Material Environment Subscale.....	303
Table 5.53	Result of One-Way Repeated Measure ANOVA for Material Environment Subscale.....	304
Table 5.54	Mauchly's Test of Sphericity .....	304
Table 5.55	Tests of Within-Subjects Effects.....	304
Table 5.56	Pair wise comparison for material environment subscale.....	305
Table 5.57	Summary of Students Responded According to the Codes .....	306
Table 5.58	Skewness and Kurtosis value .....	313

Table 5.59	Descriptive Statistics of Overall for Critical Thinking Skills .....	313
Table 5.60	Mauchly's Test of Sphericity.....	315
Table 5.61	Result obtained from Wilks' Lambda Test.....	316
Table 5.62	Tests of Within-Subjects Effects.....	317
Table 5.63	Result of One-Way Repeated Measure ANOVA for Overall Three Subscale .....	319
Table 5.64	Mauchly's Test of Sphericity.....	319
Table 5.65	Tests of Within-Subjects Effects.....	320
Table 5.66	Pair-wise comparison for overall mean score value of critical thinking skills.....	320
Table 5.67	Descriptive Statistics of recognize assumption critical thinking skill .....	321
Table 5.68	Result of One-Way Repeated Measure ANOVA for RA Critical Thinking Skill .....	322
Table 5.69	Mauchly's Test of Sphericity.....	322
Table 5.70	Tests of Within-Subjects Effects.....	322
Table 5.71	Pair wise comparison for recognize assumptions critical thinking skill .....	323
Table 5.72	Summary of Students Responded Correctly to the Proposed Assumptions.....	325
Table 5.73	Descriptive Statistics of evaluate arguments critical thinking skill .....	331
Table 5.74	Result of One-Way Repeated Measure ANOVA for Evaluate Arguments Critical Thinking Skill.....	331
Table 5.75	Mauchly's Test of Sphericity.....	332
Table 5.76	Tests of Within-Subjects Effects.....	332
Table 5.77	Pair wise comparison for evaluate arguments critical thinking skill .....	333
Table 5.78	Summary of Students Correctly Evaluated the Arguments .....	335
Table 5.79	Descriptive Statistics of draw conclusions critical thinking skill.....	339

Table 5.80	Result of One-Way Repeated Measure ANOVA for Draw Conclusion Critical Thinking Skill .....	339
Table 5.81	Mauchly's Test of Sphericity .....	340
Table 5.82	Tests of Within-Subjects Effects.....	340
Table 5.83	Pair wise comparison for draw conclusion critical thinking skill.....	341
Table 5.84	Summary of Students Demonstrated the Skills.....	344
Table 5.85	Characteristics of Current Practice Versus ATGC Experiments .....	351

## LIST OF FIGURES

	<b>Page</b>
Figure 1.1	Components of the activity system (Engestorm, 1987, p.78)..... 5
Figure 2. 1	First generation of Activity Theory ..... 73
Figure 2. 2	Second generation of Activity Theory ..... 74
Figure 3. 1	The Spiral of Knowing ..... 89
Figure 3.2	Paul-Elder critical thinking model..... 101
Figure 3.3	Theoretical framework of the study ..... 107
Figure 3.4	Conceptual framework of the study ..... 109
Figure 4.1	Intervention mix method design of the study ..... 117
Figure 4.2	One-way repeated measure design with dependent variables repeatedly measured across time. .... 119
Figure 4.3	Thematic map of teachers’ and students’ responses to explore current context of chemistry laboratory teaching and learning ..... 151
Figure 4.4	Thematic map of students’ responses for chemistry laboratory learning environment ..... 159
Figure 4.5	Thematic map for interview responses of students’ critical thinking skills ..... 162
Figure 5.1	Estimated marginal means of CUT scores ..... 206
Figure 5.2	The profile plots of the actual preferred mean discrepancy values of students’ perception on the five subscales of chemistry laboratory learning environment across three different times (Pre-test, Post-test I and Post-test II) ..... 265
Figure 5.3	Estimated marginal means of the actual preferred discrepancy mean values for student cohesiveness subscale across three different times (Pre-test, Post-test I and Post-test II)..... 272
Figure 5.4	Estimated marginal means of the actual preferred discrepancy mean values for open-endedness subscale across three different times (Pre-test, Post-test I and Post-test II)..... 281

Figure 5.5	Estimated marginal means of the actual preferred discrepancy mean values for integration subscale across three different times (Pre-test, Post-test I and Post-test II) .....	290
Figure 5.6	Estimated marginal means of the actual preferred discrepancy mean values for rule clarity subscale across three different times (Pre-test, Post-test I and Post-test II). .....	298
Figure 5.7	Estimated marginal means of the actual preferred discrepancy mean values for material environment subscale across three different times (Pre-test, Post-test I and Post-test II).....	306
Figure 5.8	The profile plots of the three critical thinking skills (subscales) across three different times (Pre-test, Post-test I and Post-test II).....	318
Figure 5.9	Estimated marginal means of critical thinking recognize assumption skill across three different times (Pre-test, Post-test I and Post-test II).....	324
Figure 5.10	Estimated marginal means of critical thinking evaluate arguments skill across three different times (Pre-test, Post-test I and Post-test II).....	333
Figure 5.11	Estimated marginal means of critical thinking draw conclusions skill across three different times (Pre-test, Post-test I and Post-test II).....	341

## 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

## LIST OF APPENDICES

APPENDIX 1	CURRICULUM VITAE OF CHEMISTRY LECTURERS CONDUCTED THE INTERVENTION
APPENDIX 2	PRE TEST
APPENDIX 3	PRE TEST MARK SCHEME
APPENDIX 4	POST TEST 1
APPENDIX 5	POST TEST 1 MARK SCHEME
APPENDIX 6	POST TEST 2
APPENDIX 7	POST TEST 2 MARK SCHEME
APPENDIX 8	CHEMISTRY LABORATORY ENVIRONMENT INVENTORY (CLEI) STUDENTS' ACTUAL FORM
APPENDIX 9	CHEMISTRY LABORATORY ENVIRONMENT INVENTORY (CLEI) STUDENTS' PREFERRED FORM
APPENDIX 10	CURRICULUM VITAE OF EXPERIENCED CHEMISTRY LECTURERS AT MATRICULATION COLLEGES
APPENDIX 11	CURRICULUM VITAE OF EXPERIENCED MALAY LANGUAGE TEACHERS
APPENDIX 12	CONTENT VALIDATION FOR CUT PRE TEST, POST TEST 1 AND POST TEST 2
APPENDIX 13	VALIDATION OF CHEMISTRY LABORATORY ENVIRONMENT INVENTORY (CLEI)
APPENDIX 14	VALIDATION OF WATSON GLASER CRITICAL THINKING (WGCT) II APPRAISAL
APPENDIX 15	INTERVIEW PROTOCOL MATRIX
APPENDIX 16	INTERVIEW QUESTIONS FOR LECTURERS AND STUDENTS BEFORE INTERVENTION.
APPENDIX 17	CHEMISTRY LABORATORY LEARNING ENVIRONMENT INTERVIEW QUESTIONS AFTER INTERVENTION.

APPENDIX 18A-18D	INTERVIEW EXCERPTS OF CHEMISTRY LECTURERS' RESPONSES TO EXPLORE THE CURRENT CONTEXT OF TEACHING AND LEARNING IN THE CHEMISTRY LABORATORY
APPENDIX 19A-19D	INTERVIEW EXCERPTS OF STUDENTS' RESPONSES TO EXPLORE THE CURRENT CONTEXT OF TEACHING AND LEARNING IN THE CHEMISTRY LABORATORY
APPENDIX 20A-20E	LIST OF CODES WITH EXTRACTED DATA IN INTERVIEW FOR CHEMISTRY LABORATORY LEARNING ENVIRONMENT
APPENDIX 21A-21C	STUDENTS' INTERVIEW EXCERPTS FOR CRITICAL THINKING SKILLS
APPENDIX 22A-22B	PRE DETERMINED CODES AND CATEGORIZATION TO MEASURE STUDENTS' UNDERSTANDING OF CHEMISTRY CONCEPTS IN CUT
APPENDIX 23	VALIDATION OF INTERVIEW QUESTIONS FOR LECTURERS AND STUDENTS (BEFORE INTERVENTION).
APPENDIX 24	VALIDATION OF CHEMISTRY LABORATORY LEARNING ENVIRONMENT INTERVIEW QUESTIONS (AFTER INTERVENTION).
APPENDIX 25	VALIDATION OF WATSON GLASER CRITICAL THINKING (WGCT) II APPRAISAL
APPENDIX 26	INTER-RATER RELIABILITY FOR CUT 1 AND CUT 2 OPEN ENDED RESPONSES
APPENDIX 27	INTER-RATER RELIABILITY FOR INTERVIEW RESPONSES TO EXPLORE CURRENT CONTEXT OF TEACHING AND LEARNING IN THE CHEMISTRY LABORATORY
APPENDIX 28	INTER-RATER RELIABILITY FOR INTERVIEW RESPONSES OF STUDENTS' CHEMISTRY LABORATORY LEARNING ENVIRONMENT
APPENDIX 29	INTER-RATER RELIABILITY FOR INTERVIEW RESPONSES OF STUDENTS' CRITICAL THINKING SKILLS
APPENDIX 30A-30D	TEACHER'S LESSON PLAN
APPENDIX 31A-31D	STUDENTS' LAB SHEET



APPENDIX 32	Q-Q PLOTS FOR CUT SCORES
APPENDIX 33A-33C	Q-Q PLOTS FOR CLEI SCORES
APPENDIX 34	Q-Q PLOTS FOR CRITICAL THINKING SKILLS SCORE
APPENDIX 35	APPROVAL OF ‘BAHAGIAN PERANCANGAN DAN PENYELIDIKAN DASAR PENDIDIKAN’ MINISTRY OF EDUCATION TO CONDUCT RESEARCH
APPENDIX 36	APPROVAL OF ‘BAHAGIAN MATRIKULASI’ MINISTRY OF EDUCATION TO CONDUCT RESEARCH
APPENDIX 37	APPROVAL OF ‘JAWATANKUASA ETIKA PENYELIDIKAN MANUSIA (JEPEM)’ USM

**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 menghubungkan 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 Experiments*. 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 eksperimen, 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 21<sup>st</sup> 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 & Sjoström, 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 21<sup>st</sup> 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 place. 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.

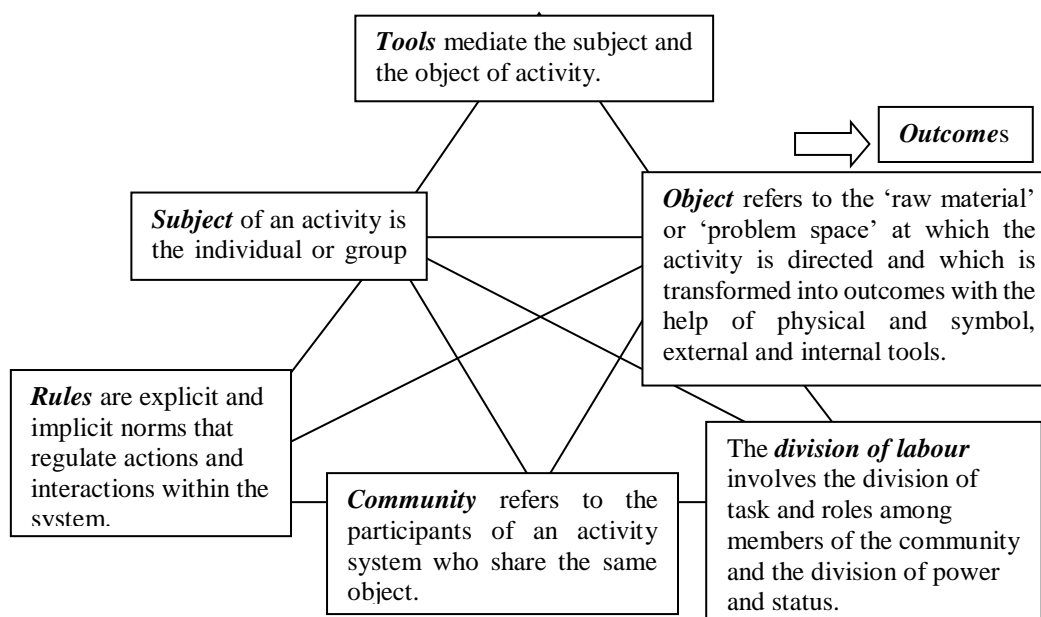


Figure 1.1. Components of the activity system (Engestrom, 1987, p.78)

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 & Yeziarski, 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 Engestrom (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; Tsapalis, 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 & Sevia, 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<sub>02a</sub>: 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<sub>02b</sub>: 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<sub>02c</sub>: 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<sub>02d</sub>: 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<sub>02e</sub>: 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<sub>03</sub>: 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<sub>03a</sub>: There is no significant differences between pre-test, post-test 1 and post-test 2 mean scores of recognize assumption subscale.
  - b) H<sub>03b</sub>: 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 21<sup>st</sup> 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