Effect of Computer Simulation-Based Instruction in Chemistry on the Academic Achievement of Grade 12 Learners

By

SAMUEL JERE

A thesis submitted in fulfilment of the requirements for the degree of

DOCTOR OF EDUCATION

In the

DEPARTMENT OF CURRICULUM STUDIES

SCHOOL OF EDUCATION

UNIVERSITY OF VENDA

PROMOTER: **DR M. MPETA**

CO-PROMOTER: **DR S.J.M. KAHERU**

SEPTEMBER, 2020

DECLARATION

I, **SAMUEL JERE**, declare that:

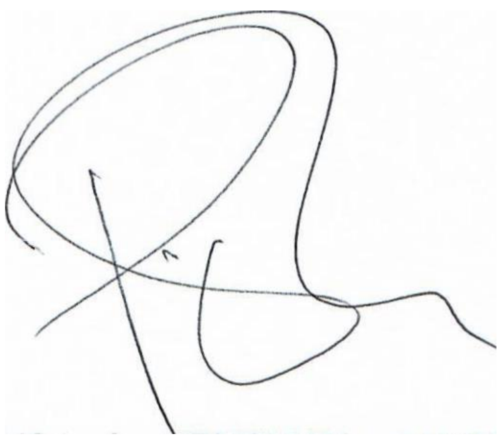
'Effect of Computer Simulation-Based Instruction in Chemistry on the Academic Achievement of Grade 12 Learners' is my own work and has not been previously submitted in any form whatsoever, by myself or anyone else, to this university or any other educational institution for any degree or examination purposes. All resources that I have used or quoted have been indicated and duly acknowledged by means of complete references.

Signature…………………………………….. **Date:** 01/09/2020…………………………

Letter from the Editor

26 June, 2020

This is to certify that I, Dr P Kaburise, of the English Department, University of Venda, have proofread the research report titled - **Effect of Computer Simulation-Based Instruction in Chemistry on the Academic Achievement of Grade 12 Learners** - by Samuel Jere (student number: 18006077). I have indicated some amendments which the student has undertaken to effect, before the final report is submitted.



Dr P Kaburise (0794927451 / 0637348805; Phyllis.kaburise@gmail.com)

Dr P Kaburise: BA (Hons) University of Ghana (Legon, Ghana); MEd University of East Anglia (Cambridge/East Anglia, United Kingdom); Cert. English Second Language Teaching, (Wellington, New Zealand); PhD University of Pretoria (South Africa)

DEDICATION

I would like to take this opportunity to dedicate this thesis to the two important women in my life – my mom Irene and my wife Susan. To my wife, Susan - you gave me the valuable support I needed to complete the doctoral journey – and no words are sufficient to thank you. In addition, I dedicate the thesis to our two sons Tadiwanashe and Leslie. I hope that they will take this experience as an example to inspire their own academic pursuits. To my father, Lingford, I know he was going to be very proud of me if he was still with us.

ACKNOWLEDGEMENTS

I would like to express my profound gratitude to my supervisor, Dr Mamotena Mpeta. Her encouragement, support and guidance made it possible to reach this point. I owe her special thanks for painstakingly reading, re-reading and commenting on the many drafts of the study. She provided valuable advice in all aspects of this study and made my visit to the university on numerous occasions - worthy. Dr Mpeta was competently assisted by Dr Sam Kaheru who offered me valuable advice throughout my doctoral journey. The statistical expertise of Dr Kaheru was especially valuable as I approached the twilight of this study.

Furthermore, I would like to express my sincere gratitude to the principals of the schools that participated in this study for allowing me to conduct the study at their institutions. I am highly indebted to the learners who participated in the study. As I was teaching them I also learned a lot from them. One of them summarized the study by stating "... *in the Physical Sciences things we are talking about are things that we don't see".* In a way, this study was an attempt to make them *'see'* the Chemistry we teach them. I would also like to thank my own principal who gave me permission to attend to classes in other schools. I am grateful to the Limpopo Department of Education for permitting me to conduct the study in Limpopo Province.

The acknowledgements would be incomplete if I do not mention the valuable contribution of Professor Peter Mulaudzi and all the academic members of the University of Venda, School of Education. Professor Mulaudzi provided valuable critique of my proposal resulting in the study taking a wider view different from its conception. While I have not managed to mention by name all the academic members of the School of Education, my interaction with these members gave me a sense of purpose. Finally, I would like to thank Dr Phyllis Kaburise for her valuable time in editing this thesis.

To end, I would like to share my favourite quotation from Nelson Mandela who said, "a good head and good heart are always a formidable combination. But when you add to that a literate tongue or pen, then you have something very special." These words will guide me as I continue furthering my career.

Abstract

Chemical Reaction Rate (CRR) is one of the topics which Grade 12 Physical Sciences learners find challenging. The purpose of this study was to examine the effect that the use of Computer Simulation-Based Instruction (CSBI) in teaching CRR in Physical Sciences, as one of the alternative strategies to traditional teaching, would have on the academic achievement of Grade 12 learners in this topic. The Cognitive Theory for Computer Simulation-Based Instruction was the theoretical framework guiding the study. The study employed a mixed method approach and a sequential explanatory design was used. The population was all Grade 12 Physical Sciences learners in Mopani District of Limpopo Province in South Africa. The sample consisted of one hundred and eighteen learners in two classes, from two secondary schools located in a rural area; one of which served as experimental and the other a control. The experimental group was taught CRR using CSBI and the control group using the traditional teaching approach. The null hypothesis tested was: There is no significant difference in academic achievement of learners taught using CSBI and those taught using traditional teaching approach. Data were collected using pre-test and post-test in the quantitative phase of the study. Test on Chemical Reaction Rate Concepts (TCRRC) and Attitudes Towards Chemistry Lessons Scale (ATCLS) were the research instruments used. The qualitative data were collected using semi-structured interviews with five purposively sampled learners from each of the two groups and analysed using the qualitative content analysis technique. The quantitative data were analysed through the independent *t*-test. There was a statistically significant difference in the scores of the experimental group and the control group in the post-test with a moderate effect size in favour of the experimental group. The findings were that CSBI improved learners' conceptual understanding of CRR and was therefore a more effective teaching approach than the traditional method. The findings are expected to inform Chemistry educators, subject advisors and curriculum developers on strategies that can improve the academic achievement of learners, in CRR, in Chemistry.

Key concepts: Traditional Instruction, Conceptual Understanding, Cognitive Theory for Computer Simulation-Based Instruction, Computer Simulation-Based Instruction, Learner-Centred Instruction, Chemical Reaction Rate, Academic Achievement.

Table of Contents

Appendices

List of Figures

List of Tables

List of Abbreviations

ACM	Attitude Construal Model
ATCLS	Attitudes Towards Chemistry Lessons Scale
CAPS	Curriculum and Assessment Policy Statement
CG	Control Group
CLT	Cognitive Load Theory
CR	Correct Response
CRR	Chemical Reaction Rate
CSBI	Computer Simulation-Based Instruction
CTCSI	Cognitive Theory for Computer Simulation-based Instruction
CTML	Cognitive Theory of Multimedia Learning
CVI	Content Validity Index
DBE	Department of Basic Education
E_A	Activation Energy
EG	Experimental Group
LK	Lack of Knowledge
LTM	Long Term Memory
NCGD	Non-equivalent Control Group Design
NOS	Nature of Science
NR	Non-Randomisation
NSC	National Senior Certificate
O	Pre/Post Test
POE	Predict-Observe-Explain
PU	Partial Understanding
Q	Question
QCA	Qualitative Content Analysis
qual	Qualitative
QUAN	Quantitative
RQ	Research Question
SCVI	Scale Level Content Validity Index
SPS	Science Process Skills
SPSS	Statistical Package for Social Sciences
STAT SA	Statistics South Africa

SU	Sound Understanding
TCRRC	Test on Chemical Reaction Rate Concepts
UK	United Kingdom
USA	United States of America
X	Treatment
ZPD	Zone of Proximal Development

Chapter 1 Introduction of the Study

1.1 Introduction

This Chapter presents the introduction to the study so that the background of the study is described. The problem addressed is presented with the aim of showing why it is worth investigating. The study was carried out in rural South Africa, with the intention of finding out the effect of Computer Simulation-based Instruction (CSBI) underpinned by the Cognitive Theory for Computer Simulation-Based Instrucion and other related cognitive theories, on learners' academic achievement in Chemical Reaction Rate (CRR). The study was carried out after the realisation that learners have difficulties in understanding the concepts in CRR. The Chapter also describes the purpose of the study, the research questions, the hypotheses and the theoretical framework guiding the study. This is followed by a brief description of the research paradigm, design and methodology as well as methods used in an analysis of the data. A discussion of the delimitations and significance of the study is followed by the ethical considerations observed and, finally, an outline of the whole study is given.

1.2 Background of the study

Physical Sciences investigates physical and chemical phenomena through scientific inquiry, application of scientific models, theories and laws to explain and predict events in the physical environment (Department of Basic Education [DBE], 2011:8). It consists of Physics and Chemistry disciplines. Physical Sciences is included in the South African curricula to prepare learners for future learning, specialist learning, employment, citizenship, holistic development, socio-economic development, and environmental management (DBE, 2011:8). It is clearly an important learning area in the school curriculum, hence, learners are expected to perform well in Physical Sciences.

Chemical Reaction Rate (CRR) is a topic in the Chemistry section of Physical Sciences. In CRR, learners study factors affecting the rate of reaction, mechanisms of chemical reactions and catalysis and the factors affecting CRR are explained in terms of the collision theory (DBE, 2011:11). On measuring of the reaction rate, learners are expected to suggest suitable experimental techniques for measuring rates. These techniques include - measuring of gas volumes, turbidity, change of colour and change of mass of reaction vessel. These concepts fall under the knowledge area of Chemical Change which is taught from Grade 10 and increases in complexity in Grade 12 (DBE, 2011:11).

CRR, also referred to as 'chemical kinetics', is a basic, important and anchoring concept in Chemistry (Bain & Towns, 2016:246). This is because it provides insight into the nature of chemical reactions and chemical change (Bain & Towns, 2016:246). Concepts in CRR are linked to other basic concepts in Chemistry, such as thermodynamics and equilibrium and they also find wide application in industry, medicine, pharmacy and even in explaining some everyday phenomena. An understanding of CRR is therefore essential for further learning in Chemistry and related future careers.

Regardless of its importance, reports of external examinations show that, learners do not perform well in Physical Sciences, in general, and in CRR in particular (DBE, 2017:185). The difficulty of this topic has also been corroborated in research in other countries, such as Thailand (Chairam *et al.,* 2015:937). This poor performance, therefore, calls for investigation into teaching methods that may have the potential to help learners overcome any difficulties, since CRR is a crucial topic in Physical Sciences.

In South Africa, different interventions have been adopted by the DBE to assist learners to improve in Physical Sciences performance, in general with a focus on CRR. The interventions adopted include - teachers' workshops, engagement of Physical Sciences subject advisers and provision of extra lessons. Despite these, learners continue to underperform in CRR (DBE 2015:185, DBE 2016:188, DBE 2017:185). As these approaches do not appear to be effective, perhaps, the focus should now be to investigate the effectiveness of other strategies, such as computer simulations, to assist learners.

Interventions that use computer simulations have proved to be quite effective in helping learners understand scientific concepts. Simulated computer animations, for example, were used to teach Nuclear Chemistry to Grade 12 learners who were identified as having learning difficulties in this topic, in Nigeria (Zephrinus & Phoebe, 2015). This study concluded that the use of computer simulations and animations in teaching, reduced learning difficulties experienced by the learners in Nuclear Chemistry. Likewise, in South Africa the use of computer simulations to teach geometrical optics to Grade 11 Physical Sciences learners showed that girls had sizable and significant improvement in the post-tests (Kaheru & Kriek, 2016:67).

Other researchers have used computer simulations to give learners laboratory experience in virtual chemical laboratories. For example, Kamtor (2016:464), studied the impact of virtual laboratories on academic achievement and motivation of Sudanese secondary school learners. This study concluded that the virtual laboratory increased learners' achievement levels and made a positive impact on their attitudes towards chemistry (Kamtor, 2016:477). In a similar study, the effect of combined virtual and real laboratories on learners' achievement in practical chemistry, was carried out in Nigeria (Omilani *et al.,* 2016:27). The results of this study showed that the virtual laboratory combined with traditional laboratory had a significant effect on learners' achievement in Chemistry practical tests.

A review of research on computer simulations in science education has shown that simulations are effective in science learning (Rutten *et al.,* 2012:136). It is reported in this review that studies that compare conditions with or without simulations show positive results for the condition where simulations are used to replace or enhance traditional lecture. When computer simulations are used to replace laboratory activities or as preparatory laboratory activities, very large effect sizes for time on task are reported in favour of simulation-based instruction. Where simulations are used as a preparatory activity for real laboratory activities, positive effects are found on comprehension of tasks and practical skills during the real laboratory.

The review also showed large effect sizes of up to 1.5 for post-test scores and above 2 on scores related to motivation and attitudes in favour of simulations (Rutten *et al.,* 2012:151). It may, hence, be deduced that learners enjoy simulation activities as they result in positive and improved learner attitudes and interest in science. It is observed that success in learning, positive attitudes and motivation to learning are linked (Sirhan, 2007:14). This implies that if a teaching and learning strategy can motivate learners, then their performance may improve, hence, computer simulations have the potential to help learners understand concepts in CRR.

The use of simulations in learning challenging topics in Physical Sciences, such as CRR, may also be appealing to current and future generations of learners. It is observed that today's learners are adopting and using information and communication technology (ICT) from an early age (Prensky, 2007:40). As information technology becomes increasingly ubiquitous, it is recognised that there is a pressing need to utilize digital technologies in teaching and learning in a manner that is responsive to the needs of today's learners (Gallardo-Echenique *et al.,* 2015:173). It is generally accepted that internet devices such as computers, mobile phones and tablets have potential to support learning (Margaryan *et al*., 2011:13). As we live on the verge of the fourth industrial revolution (Chung & Kim, 2016:1311), digital technology now permeates through almost every facet of human activity, from industry, to entertainment and communication, therefore, it seems that it is the right way to go, even in teaching and learning.

1.3 Statement of the Problem

Chemical reaction rate is one of the challenging topics in Physical Sciences (Cakmakci & Aydogdu, 2011:15, Gegios *et al.,* 2017:151) in the South African schools' curriculum. CRR is central to the understanding of many other topics in chemistry, such as chemical equilibrium, chemical thermodynamics, industrial processes and electrochemistry. Mastery in CRR concepts is, therefore, important to learning and comprehension of other related-foundational concepts in chemistry. On the contrary, low mastery of CRR concepts may contribute to inability to adequately comprehend related concepts in other topics and to poor achievement in Physical Sciences.

Academic achievement in this topic, despite its importance, has been found to be poor. For instance, an analysis of the Grade 12 Physical Sciences final examination questions in the Chemistry Section on CRR has shown that on average, learners obtain low marks on the questions on CRR (DBE, 2015:185, DBE, 2016:188, DBE, 2017:185). Poor academic achievement in CRR has also been reported in other countries (Chairam *et al.,* 2015:937, Demircioğlu & Yadigaroğlu, 2011:510).

Poor academic achievement in Physical Sciences, including Chemistry, has been attributed to a variety of factors, such as, the instructional strategies used by teachers. In South Africa, research has shown that there is an over-reliance on traditional teaching strategies (Koopman, 2013:7), which have been implicated in the poor academic achievement of learners in Physical Sciences (Malan & Ndlovu, 2014:2). Traditional instruction has been found to result in low levels of conceptual understanding in learning CRR concepts. Thus, the use of these methods of teaching, has not been able to raise the academic achievement of learners in CRR (Cakmakci & Aydogdu, 2011:26). CSBI has been cited as a vital strategy to enhance the comprehension of CRR concepts by learners, however, a dearth exists in studies that focus on the use of CSBI in the teaching of CRR and the effects thereof (Bain & Towns, 2016:258, Van Driel *et al.,* 2002:306). This study, therefore, examined the effects of using CSBI as a strategy when teaching CRR.

1.4 Purpose of the Study

The purpose of this study was to examine the effects of Computer Simulation-Based Instruction (CSBI) on the academic achievement of learners in the topic, CRR in Chemistry. To achieve the purpose of the study, the following objectives were developed:

1.4.1 Objectives of the Study

The objectives of the study were to:

1. Determine the effectiveness of using CSBI and the traditional approach on the academic achievement of learners in CRR.
2. Establish the effects of CSBI and the traditional approach on learners' attitudes towards chemistry lessons in CRR.
3. Describe how CSBI influences the learners' conceptual understanding of CRR, compared to traditional instruction.

1.4.2 Research Questions

The main research question based on the purpose of the study was: *What are the effects of using CSBI on the academic achievement of Grade 12 learners in CRR topic?*

The following subsidiary questions were raised:

1. How effective is the use of CSBI compared to the traditional approach on the academic achievement of learners in CRR concepts?
2. What are the effects of CSBI and the traditional approach on learners' attitudes towards the chemistry lessons in CRR?
3. Does Computer Simulation-Based Instruction improve learners' conceptual understanding of Chemical Reaction Rate as compared to traditional instruction?

1.4.3 Null Hypotheses

Null Hypothesis 1: There is no significant difference in learners' academic achievement when taught CRR using CSBI or using a traditional method at the .05 level of significance.

Null Hypothesis 2: There is no significant difference in learners' attitudes towards chemistry lessons in CRR when taught using CSBI or traditional method at the .05 level of significance.

1.5 Theoretical Framework: The Cognitive Theory for Computer Simulation-Based Instruction

In this section the theoretical framework adopted for the study is briefly discussed. The study was underpinned by the Cognitive Theory for Computer Simulation-Based Instruction. This theory was developed from elements from different cognitive theories of learning. These cognitive theories are - the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2003:129); Cognitive Load Theory (CLT) (Sweller *et al.,* 1998:256); and the sociocultural theory (Vygotsky, 1978:39). It was necessary to use different cognitive theories as it was noted that there was no single theory that could shed light on all aspects of CSBI. This is supported by Troudi (2014:2) who asserts that researchers may combine elements from more than one theoretical model in the formulation of a theoretical framework. The justification for using these theories is provided in Chapter Two of this research report.

Using the lens of the Cognitive Theory for Computer Simulation-Based Instruction helped to choose methods - in data collection, in analysis and interpretation of the data. The CTML was used to select the simulations, animations and virtual experiments that were used in the study. The CTML together with the CLT and the socio-cultural theory were used in decisions that had to be made regarding the planning and implementation of CSBI. In addition to these three theories, the Attitude Construal Model (Schwarz, 2006:20) was adopted to assist in the understanding of 'why' and 'how' attitudes may change. The Cognitive Theory for Computer Simulation-Based Instruction is presented in Chapter Two.

1.6 Definition of Key Concepts

In this section, key concepts are defined in accordance with how they should be understood in the study.

Computer Simulation-Based Instruction: computer simulations are computer programmes that contain a model of a natural or artificial system or a process (De Jong & Van Joolingen, 1998:179). Simulations may be defined in terms of what they enable learners to achieve. Consistent with Moore *et al.,* (2013:257-258), simulations enable learners to interact with dynamic visualizations, permitting focused exploratory investigations; attain speedy response when carrying out experiments; and see multiple representations, involving macroscopic, microscopic and/or symbolic representations. In this study, CSBI is regarded as a learner-centred instructional approach in which computer simulations, including visualizations, animations, and interactive virtual laboratories, are used as a teaching aid to enable learners to carry out virtual experiments. When carrying out virtual experiments, learners explore relationships among variables and learn chemistry concepts through multiple representations. Computer Simulation-Based Instruction, as used in this study, involved the use of the Predict-Observe-Explain strategy during demonstrations of the virtual experiments and simulations of chemical reaction rate concepts.

Predict-Observe-Explain Strategy: Treagust (2013:375), defines Predict-Observe-Explain (POE) as a strategy used to make demonstrations learner-centred. Learners are first asked to predict what would happen in a demonstration, then they observe the demonstration carefully, and finally they explain what they had observed. This is followed by a teacher-led group or whole class discussion of the observations and explanations of the learners. Bajar-Sales *et al.,* (2015:5), consider POE as a metacognitive instructional tool, used to make learners aware of their own thinking and assist them in regulating their own thinking in which they, firstly, predict, then observe a demonstration or conduct an experiment and finally compare their explanations with the observations. In this study POE is a learner-centred, metacognitive instructional strategy in which learners, firstly, predict what should happen in a virtual experiment, carry out the virtual experiment and make observations, then explain any discrepancy between their predictions and explanations.

Instruction: is the construction of situations for learners to experience that leads to an intended change in their knowledge (Mayer, 2010:546). It may also be defined as the arrangement of learning conditions to attain some intended learning goal (Driscoll, 2005:345). Learning conditions refer to both internal cognitive processes, such as encoding and retrieval of information and external conditions, such as methods of instruction to facilitate learning (Driscoll, 2005:347). Instruction as used in this study, hence, refers to careful planning of a teaching strategy (Predict-Observe-Explain Strategy) aided with computer simulations, for learners to attain conceptual understanding of CRR concepts.

Traditional Instruction: Prince and Felder (2006:123) define traditional teaching as a deductive teaching method in which teacher teaching, for example, Mathematics begins by giving information on general principles, then uses the principles to derive mathematical models; shows illustrative applications of the models; gives learners practice in similar problems in homework; and finally assesses their ability to do the same tests. Jony (2016:172), views traditional teaching method as an approach to teaching where the teacher gives information most of the time and learners watch, listen and take notes; work individually on tasks and assignments; and are passive and do not take responsibility for their own learning. In this study, traditional teaching method is defined as a teacher-centred method which is deductive, in which the teacher starts by giving information and explaining the concepts, followed by illustrations using specific examples, and concludes with learners working on similar problems.

Academic achievement: In this study, academic achievement refers to the scores obtained in the Test on Chemical Reaction Rate Concepts (TCRRC).

1.7 Research Paradigm, Design and Methodology

In this section the focus is on the research paradigm, design and methodology.

1.7.1 Research Paradigm

Paradigms are sets of philosophical assumptions about the nature of reality and the researcher's role in constructing it and agreed upon by a community of scholars (Creamer, 2019:4). A paradigm consists of ontology, epistemology and methodology (Scotland, 2012). Ontology is concerned with the nature of reality; epistemology is concerned with the nature of knowledge; and methodology is concerned with how data in a research is collected and analysed. The paradigmatic assumptions in this study were based on pragmatism. Pragmatism as a paradigm accepts diversity and complexity; does not prioritize debates about philosophy; and puts emphasis on what works in answering important research questions (Creamer, 2019:6).

1.7.2 Research Design and Methodology

The study adopted a mixed-method approach with a sequential explanatory design (Creswell *et al*, 2003:178). The study adopted the mixed-method design as it sought to investigate the cause-and-effect relationships and to gain an in-depth understanding of these relationships. A mixed method is a design that uses both quantitative and qualitative methods in data collection, analysis or interpretation phases of the research (Onwuegbuzie, 2000:20). The mixed-method design enabled the use of quantitative methods to collect data to answer the first and second research questions. The third research question sought to find out if CSBI assisted learners in conceptual understanding of CRR concepts. This research question could best be answered by using qualitative methods.

The sequential explanatory design was used in the study. It is a design in which the collection and analysis of quantitative data is followed by similar processes with qualitative data (Creswell *et al*, 2003:178). The qualitative results were used in explaining and interpreting the findings of the quantitative study. Sampling methods used in the study are described in the next section.

1.8 Sampling

This section discusses the population and sampling procedures.

1.8.1 Population

A population can be defined as all people or items with the characteristics that one wishes to study (Bhattacherjee, 2012:65). The population of interest in this study was all the Physical Sciences Grade 12 learners in Limpopo Province, in South Africa.

1.8.2 Sample

Sampling is the selection of a subset of a population so that the results of the study of the sample can be used to make inferences about the population (Corbetta, 2011:3) The sample used in the research consisted of two Grade Twelve classes at two different schools in Mopani District, Limpopo Province. The Experimental Group (EG) had 53 learners and the Control Group (CG) had 65 learners.

1.8.3 Quantitative Sampling

The sampling procedure that was used was non-probability convenience sampling of schools. Learners were assigned to classes by school principals at the beginning of the academic year, therefore, it was not possible to randomly assign learners to the Experimental Group and Control Group. The quantitative phase of the study used a quasi-experimental design with a Non-Equivalent Control Group Design (NCGD) (Cohen *et al.,* 2007:283). I had no control over the composition of those classes, therefore, it was not possible to randomly assign learners to the CG and EG in a quasi-experimental study because of these practical reasons (Levy & Ellis, 2011:155). Another practical reason randomization of learners into the EG and CG was not possible, was because learners were from different schools, hence, this study is a quasi-experimental study using a NCGD design for the quantitative phase of the study.

1.8.4 Qualitative sampling

Purposeful sampling was used in the qualitative phases of the research. Purposeful sampling is a sampling strategy used in qualitative research to select individuals who have the experience of the issue being studied (Creswell, 2009:217). This sample consisted of five participants from the EG, five participants from the CG and one participant was the teacher of the EG.

1.9 Measures of Quality Control

This section discusses the validity and the reliability of quantitative data collection instruments, and the credibility and trustworthiness of qualitative data collection.

1.9.1 Validity and Reliability of Quantitative Research Instruments

This section discusses validity and reliability of quantitative data collection.

1.9.1.1 Validity

Validity refers to the accuracy of a research instrument (Lodico, 2006:88). The following paragraphs describe the distinct types of validity.

1.9.1.1.1 Content Validity

Content validity concerns the degree to which a sample of items taken together constitutes an adequate definition of a construct (Polit & Beck, 2006:490). In content validation of the research instruments, the methods suggested by other researchers, like, Polit and Beck (2006:491), were followed. The details are given in Chapter 4.

1.9.1.1.2 Construct Validity

Construct validity is an estimate of the extent to which variance in the measure reflects variance in the underlying construct (Westen & Rosenthal, 2003:609).

1.9.1.2 Reliability

Reliability is concerned with the ability of an instrument to measure consistently (Tavakol & Dennick, 2011:53). In this study, reliability of TCRRC and ATCL Scale was determined through the test-retest method, as described in Chapter 4.

1.9.2 Trustworthiness of qualitative Data

There are four criteria that should be addressed to ensure trustworthiness of qualitative research: credibility, transferability, dependability and confirmability (Shenton, 2004:63). How the trustworthiness of the qualitative data was ensured is described in Chapter 4.

1.10 Data Analysis

This section discusses data analysis for quantitative and qualitative data.

1.10.1 Quantitative Data Analysis

The first part of this discussion is on the analysis of the quantitative data.

1.10.1.1 Data from Test of Chemical Reaction Rate Concepts (TCRRC)

Data from the Test of Chemical Reaction Rate Concepts (TCRRC) were analysed using Statistical Package for Social Sciences (SPSS) Version 26. Data analysis was done through descriptive and inferential statistics. Descriptive statistics were used to determine the mean, the median, the mode and the standard deviation from the data generated by the Test on Chemical Reaction Rate Concepts (TCRRC). An independent sample *t*-test was used to test if there was any significant difference between the means of pre-test scores of the EG and CG performed at $p = .05$ for the TCRRC. A related samples *t*-test was used to test for the significance of the difference between the means of EG for the pre-test and post-test scores in the TCRRC. Cohen's d was computed to find the effect size (ES) of CSBI on learners' achievement as it was found that there was a significant difference in the means of the EG in the pre-test and post-test scores on the TCRRC (Cohen, 1992:157).

1.10.1.2 Data from Attitudes Towards Chemistry Lessons Scale (ATCLS)

Attitudes of learners towards the lessons presented through CSBI were assessed using Attitudes Towards Chemistry Lessons Scale (ATCLS). This instrument is a Likert-type scale instrument. According to de Winter and Dodou (2010:1), it is unclear whether the items' data from Likert-type questions should be analysed using parametric or nonparametric tests.

In this research, Mann-Whitney U, a non-parametric test, was used to test if there was a significant difference between the medians of pre-test scores and post-test scores of the EG and CG for the scores from ATCLS (Nachar, 2008:13). Mann-Whitney U is used when the measured variables are of ordinal type (Nachar, 2008:13), such as in Likert-type scale.

1.10.2 Qualitative Data Analysis

The raw data from the interviews were digitally recorded and transcribed verbatim for analysis which was done using qualitative content analysis (Morse, 2012:199). Qualitative content analysis is a research method used for a subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns (Hsieh & Shannon, 2005:1278).

1.11 The Significance of the Study

This study is significant in several ways which are articulated below.

1.11.1 Significance for Teachers

First, it was hoped that the findings of the study would make a meaningful contribution to improving the teaching strategies used by practising Physical Sciences teachers.

1.11.2 Significance for Future Research

Second, the research study was designed to contribute to the knowledge base on the effectiveness of CSBI at secondary school level, in the field of chemistry education. It was hoped that the study would provide data for future studies in this area, as very little research has been done in chemistry education in CRR in South Africa.

1.11.3 Significance for Policy Makers

Third, the study had practical significance as it would inform policy-makers about the relevance or otherwise of technology-based instruction in Physical Sciences. Policy-makers can then make informed decisions about the possibility of increasing, relevant resources, like computer laboratories in schools.

1.11.4 Significance for pre-service teacher preparation

Fourth, it will add to an increased understanding of the role of computer simulations on learners' understanding of science concepts, which can be used in pre-service teacher preparation.

1.11.5 Significance for Learners

Finally, it would shed light on how computer simulations affect learners' motivation. It was essential to find out if computer simulations could improve the attitudes of learners towards Physical Sciences as this could help learners to improve their performance.

1.12 Delimitation

The study was conducted in Mopani District, Limpopo Province, South Africa. The schools that participated in the study were in Greater Letaba and Greater Giyani (Figure 1.1) Circuits/Municipalities.

Figure 1.1 Greater Letaba Municipality (Main, 2018)

The study was delimited to Mopani District and to the topic “Chemical Reaction Rates” as it was not possible to teach more topics due to time constraints.

1.13 Ethical Considerations

At the initial stage, before commencing with data collection, permission to conduct the study was sought from the DBE and from the school principals (Appendices 2-4). In addition, the University of Venda provided ethical clearance for the research (Appendix 1). Furthermore, full information was provided to learners and informed consent was sought from their guardians before the research was conducted (Appendix 5). The guardians of the participants signed the consent forms as the participants were minors. These steps were guided by the following ethical principles - human dignity (respect for persons); non-maleficence (no harm to participants); and beneficence (participants should benefit from the research) as outlined by Cohen *et al.,* (2007:58). Anonymity of participants was ensured in that the names of the school and the participants were protected and not revealed. As both the EG and CG were taught during the normal school timetabled hours, no group was disadvantaged.

1.14 Outline of the Study

The dissertation is organised as follows:

Chapter 1: Introduction of the study

The Chapter begins with the *Background of the Study*, followed by the *Statement of the Problem.* Then, the *Purpose of the Study* is presented, followed by the *Research Questions*, the *Hypotheses*, *Theoretical Framework* and *Definition of Key Terms*. Thereafter, a brief outline of the *Research Design and Methodology*, the *Sampling*; *Measures of Quality Control* and *Data Analysis* is presented. A discussion of the *Significance of the Study*, *Delimitations* and *Ethical Considerations* is also presented and finally, the Chapter is concluded with an *Outline of the Study.*

Chapter 2: The Cognitive Theory for Computer Simulation-Based Instruction

The Chapter begins with a discussion of Forms of Knowledge in CRR which provides justification for the theoretical framework. Different cognitive theories are presented and from these theories, the Cognitive Theory for Computer Simulation-Based Instruction is formulated.

Chapter 3: Teaching Chemical Reaction Rate through Computer Simulations

The Chapter discusses *Computer Simulation-Based Instruction*, *Science Process Skills, Chemical Reaction Rate in Physical Sciences in the South African Curriculum and Other Countries* and *Concepts in Chemical Reaction Rate.* In addition, literature on studies to improve learners' understanding in reaction rate is reviewed. The gap(s) in these studies are identified and discussions on how this study will attempt to fill the gap are presented. *Literature on Attitudes of Learners towards Simulations* is also presented.

Chapter 4: Research Paradigm, Design and Methodology

The Research Paradigm - pragmatism - adopted for the study is discussed. The *Research Design and Methodology,* the explanatory sequential, mixed-method design and the *Non-*

Equivalent Control Group Design are outlined. In the Methodology section, *Data Collection Instruments and the actual process of Data Collection* are presented; the Chapter concludes with how the collected data's Reliability, Validity and Trustworthiness were determined.

Chapter 5: Data Analysis

The Chapter begins with a presentation of *Data from Chemical Reaction Rate Concepts, initially,* through *Descriptive Statistics*. *Measures of Central Tendency*, *Measures of Dispersion* of the Data and *Pictorial Representations* through graphs were the ways of presenting the data. *Inferential Statistics* were used. Then, the *Data from Attitudes Towards Chemistry Lessons Scale (ATLS)* were analysed through descriptive and inferential statistics which were followed by the qualitative data analysis. An interpretation of both the quantitative and qualitative data follows the presentation.

Chapter 6: Findings, Recommendations and Conclusion

Chapter 6 summarises the *Findings* of the study. Based on these findings, I present the *Recommendations* and *Conclusions* of the whole study.

Chapter 2 The Cognitive Theory for Computer Simulation-Based Instruction

2.1 Introduction

The research question that the present study addressed is: *What are the effects of using Computer Simulation-Based Instruction (CSBI) on the academic achievement of Grade 12 learners in Chemical Reaction Rate (CRR)?* To address this research question, the study was guided by the cognitive and the sociocultural cognitive perspectives in developing a theoretical framework that acted as a 'lens' that informed the investigation. Specifically, the study was informed by the scholarship from the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2002:37); the Cognitive Load Theory (CLT) (Sweller, 1988:257); the sociocultural theory (Vygotsky, 1978:34) and the Attitude Construal Model (ACM) (Schwarz, 2007:638). These theories informed the study, not only in terms of the methodological issues but also in the interpretation of the findings and the conclusion.

The CLT and the CTML formed the theoretical base that addressed design principles and optimum utilisation of simulations in CSBI. The sociocultural theory, and the Zone of Proximal Development (ZPD), informed the study on the role of the learner and the teacher in CSBI while the ACM underpinned the investigation of attitude changes during CSBI. The cognitive theories of learning fall under cognitive science and information processing model of cognition (Sorden, 2005:263). The emphasis of cognitive theories is on mental processing of information. Cognitive theories are concerned with how knowledge is constructed, acquired, organized, coded, rehearsed and retrieved from memory when learning with simulations (Schunk, 2012:22). As suggested by Schunk (2012:25), for instruction to be effective the researcher should adopt the best theoretical perspective for the intended forms of learning. Cognitive theories, hence, appear to be more appropriate for complex and difficult topics such as CRR.

The Chapter begins with a discussion of the forms of knowledge in CRR. This provides justification and the rationale for using cognitive theories, as the guiding framework. This is followed by a discussion of the basic tenets of each theory and their implications for the study. Finally, a theoretical framework for the study is formulated from these theories.

2.2 Forms of Knowledge in Chemical Reaction Rate

The advancement of retention and transfer of learning are some of the major aims of education (Mayer, 2002:226). To achieve these, learners should acquire both general skills and domain-specific skills (Schunk, 2012:280). The former involves diverse skills such as problem-solving, critical thinking, inventive and creative thinking, decision-making, planning and metacognition (knowledge of and regulation of cognition) (Magno, 2010:151; Schunk, 2012:280). The latter - domain-specific knowledge - includes declarative, factual and procedural knowledge (Krathwohl, 2002:215). It is argued that transfer of learning needs knowledge of facts, concepts, and principles of the domain acquired, through practice and learning strategies that can be generalised to other domains (Schunk, 2012:181). It can, thus, be assumed that in learning reaction rates, CSBI should foster retention and transfer of learning through acquisition of general skills and domain-specific skills.

Cognitive theories inform the study about how best to help learners acquire and retain facts, concepts and skills of reaction rates and how to generalise the acquired information in solving unfamiliar problems when learning, using simulations. It is argued that it is not the simulations *per se* that enable learners to acquire declarative, factual and procedural knowledge (Renkl & Atkinson, 2007:236). Instruction, when learning using simulations, should be planned such that learners use cognitive processes. It is the cognitive processes that learners engage in when learning using simulations that enable them to acquire declarative, factual and procedural knowledge.

The aim of teaching reaction rates using simulations is to ensure that meaningful learning occurs. Meaningful learning is the ability to solve new problems based on the acquired domain-specific knowledge (Mayer, 2002:226). In the revised taxonomy of educational objectives, six domain-specific cognitive processes identified are: *remembering, understanding, applying, analysing, evaluating, and creating* (Krathwohl, 2002:215). Of these cognitive processes, *remembering* is the cognitive process associated with retention of declarative knowledge. *Remembering* is important for meaningful learning in chemical reaction rate when the recalled information is used in problem-solving of more complex tasks. The other cognitive processes such as *understanding* and *applying* are associated with transfer, hence, meaningful learning.

Learners *understand* concepts in CRR if they can *interpret, exemplify, classify, summarize, infer, compare*, and *explain* the concepts; they are able to *apply* if they can *execute* a procedure they learn in CRR in familiar situations or *implement* a procedure in unfamiliar situations to solve a problem; learners can *analyse* if they are able to *differentiate, organize*, and *attribute*; learners can *evaluate* if they are able to make judgments based on criteria and standards; they can *create* if they are able to reorganise elements into a new pattern (Mayer, 2002:227). These are the cognitive processes involved in meaningful learning of reaction rate concepts.

Meaningful learning requires learners to be involved in deep-level processing. Metacognition is important for deep-level processing as it enable learners to make decisions on the best approach in solving a problem (Magno, 2010:151). Magno (2010:151) asserts that metacognition is important for development of learners' capabilities to make inferences, deduce conclusions, interpret data, evaluate judgements and recognise assumptions. It has also been characterised as that knowledge that helps in planning, managing information, monitoring, identifying and rectifying mistakes and evaluation (Tosun & Senocak, 2013:61). It is often necessary to teach learners metacognitive and self-regulation skills.

Sometimes learners need to be explicitly assisted to attain metacognition and self-regulation. During instruction in CRR using simulations, the teacher may provide external regulation by monitoring, evaluating, and providing feedback to the learner regarding their self-regulation and metacognitive skills (Tosun & Senocak, 2013:48). In the present study, various scaffolding techniques were used to enhance learners' metacognitive and self-regulatory skills. This study intended to find effective ways to infuse simulations into instruction to ensure that learners achieve the various forms of knowledge identified in this section. In order to understand how the learners may accomplish the intended forms of knowledge in learning CRR using simulations, the following sections discuss the theories that shed light on how best to achieve this.

2.3 The Cognitive Theory of Multimedia Learning Perspective on Computer Simulation-based Instruction

The Cognitive Theory of Multimedia Learning (CTML) is a research-based theory of how to construct effective instruction, based on multimedia (Mayer, 2010:549). Multimedia refers to words and pictures, such as those in computer-based simulations. The words can be spoken or written, while the pictures can be static, such as those in print media, or dynamic, such as those in simulations (Mayer, 2010:549).

The CTML is based on three principles (Mayer, 2003:129). The first is the *dual-channels assumption*. This principle assumes that humans have separate information processing systems for visual and verbal representations. It is a principle derived from Paivio's dual coding theory (as cited in Mayer, 2003:129). Images, hence, are processed in the visual/pictorial channel while spoken words are processed in the auditory/verbal channel. If learners use both the visual and the verbal channels, stronger encoding occurs, if the information is not redundant, resulting in meaningful learning (Moreno & Valdez, 2005:36). Learners, hence, learn better when presented with dynamic pictures and verbal explanations than either verbal explanations or pictures alone in simulations.

The second is the *limited capacity assumption* (Mayer, 2010:549). This principle says that each channel has limited capacity for processing information, hence, overloading of the working memory should be avoided. The last is the *active processing assumption* (Mayer, 2010:549). This principle assumes that meaningful learning occurs when learners engage in active cognitive processing. The cognitive processes are mental operations, procedures or processes the learners performs in learning with multimedia (Domagk *et al.,* 2010:1032). Mayer (2003:129) identifies the cognitive processes in multimedia learning. These are selecting relevant words from the presented text or narration; selecting relevant images from the presented illustrations; organizing the selected words into a coherent verbal representation; organizing selected images into a coherent pictorial representation and integrating the pictorial and verbal representations and prior knowledge.

The cognitive processing in multimedia can result in deep-level processing or surface-level processing (Domagk *et al.,* 2010:1028). Surface-level processing is characterised by repetitive rehearsal and rote memorisation resulting in retention and recall, while deep-level processing involves elaboration, organisation, self-regulation and critical thinking which integrates new information with prior knowledge resulting in deeper understanding and transfer of learning (Domagk *et al.,* 2010:1028). Strategies that enhance deep level cognitive processing in simulation-based learning, hence, should be incorporated for meaningful learning to occur.

Figure 2.1 represents the CTML and shows that learning from multimedia occurs through the verbal and the visual channels.

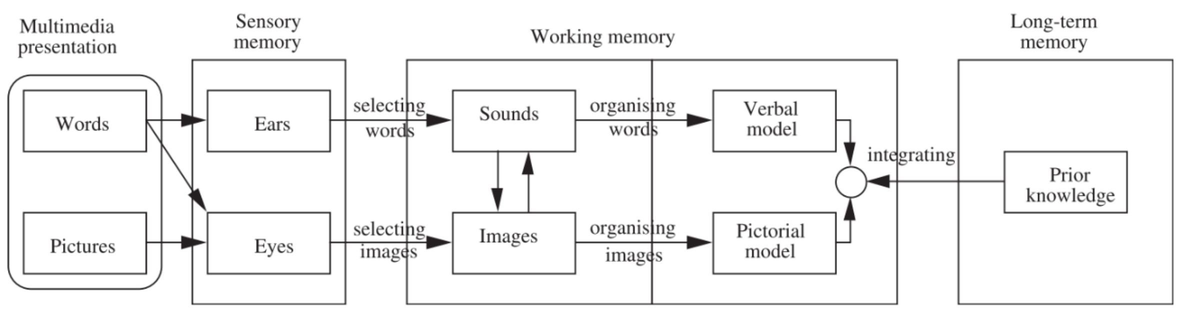


Figure 2.1 Cognitive Theory of Multimedia Learning (Mayer, 2010:545).

In the CTML framework in Figure 2.1, the learner begins with the words and pictures in a multimedia. Multimedia messages in the present study are from the interactive computer simulation. This is shown in the first column. Spoken words enter through the ears and are briefly held in the auditory sensory memory. Printed words and pictures enter through the eyes and are briefly represented in the visual sensory memory (Mayer, 2008:761). Selecting and organizing occur in the working memory. In the working memory, shown in the third column, the learner selects some sounds for further processing in the verbal channel and some images in the pictorial channel (Mayer, 2008:761). The processed sounds are organized into a verbal model and the processed images are organized into a pictorial model. The last column shows the Long-Term Memory (LTM). In the LTM prior knowledge may be activated and this may be integrated with the verbal and pictorial models in working memory. The resulting knowledge may then be stored in LTM.

As stated by Mayer (cited in Fiorella & Mayer, 2014:77) meaningful learning depends on the learner's ability to select the most relevant information from a lesson, organize it into a meaningful cognitive representation and integrate it with prior knowledge. The processes of selecting relevant words or pictures from a presentation and organizing them into a mental model are partly guided by the learner's prior knowledge (Mayer, 2003:45). These processes, shown by labelled arrows, in Figure. 2.1 represent active processing in multimedia learning. These processes place demands on the cognitive capacity of the information processing system (Mayer, 2003:45). If the demand placed on the information processing system by the learning task exceeds the processing capacity of the cognitive system, then cognitive overload occurs.

2.3.1 Cognitive Overload in Information Processing

Mayer (2003:45), identifies three kinds of cognitive demands that may be placed on the learner's cognitive system. The first is *essential processing*. This refers to cognitive processes required to make sense of the presented materials. Selecting relevant words and images, organizing them and integrating are essential processing. The second is *incidental processing* which refers to processes not necessary to understand the learning task. This is caused by the design of the task. An example is the inclusion of background music to a simulation, thus, the learner devotes some cognitive capacity to process the music; this may contribute to cognitive overload. The last is *representational holding*. In this case, the learner must hold a mental representation in working memory over a period. An example is where a simulation is presented in one window and its description is presented in another window, but only one window can be shown on the screen at any one time. The learner must hold the simulation in working memory while waiting for the description.

The total processing intended for learning consists of *essential processing*, *incidental processing* and *representational holding* (Mayer, 2003:45). If the total intended processing exceeds the learner's cognitive capacity, then cognitive overload occurs. The implications of the CTML for CSBI are discussed in the next section.

2.3.2 Implications of the Cognitive Theory of Multimedia Learning for Computer Simulation-based Instruction

In this section a discussion of some aspects of the CTML, with direct relevance to this study is presented. These aspects were considered in the design of CSBI as discussed under application of CTML in CSBI.

2.3.2.1 Segmentation

Mayer (2003:46), opines that cognitive overload may occur where a lot of new information is presented to the learners at a fast pace. In this case, learners may not have enough time to engage in deeper processing. S*egmenting* the presentation by allowing time between successive segments of the presentation is one solution to this problem (Mayer, 2003:46). This gives the learner time to organize and integrate selected words and images. The learner may then be ready for the next segment. This meant that in CSBI the simulations had to be segmented. Learners could stop a simulation to enable them to have time to organize and integrate selected images and words. The teacher used such breaks during the presentation to clarify any misunderstandings.

2.3.2.2 Pre-training

Pre-training may also be used to reduce cognitive overload (Mayer, 2003:45). This technique involves giving learners pre-instruction on components of the learning task. Construction of mental models is a two-step process (Mayer, 2003:45). Firstly, the learner should build component models which are representations of how each component work. The second step is the formation of mental causal models. Causal models are representations of how a change in one part of the system affects a change in another (Mayer, 2003:45). Giving learners pre-instruction on basic concepts, therefore, may help reduce cognitive overload on complex learning tasks, where learners should build mental causal models. In the context of this study, learners were provided with pre-training on identification of variables, construction of hypothesis, controlling variables and investigating factors affecting reaction rate before carrying out the virtual experiments.

2.3.2.3 Split Attention

The split attention effect, caused by the need for learners to integrate on-screen-text and pictures such as in a simulation, may result in cognitive overload. Suggested solutions include the use of verbal and visual clues to direct learners to the relevant parts and use of dual mode of presentation (Hasler *et al.,* 2007:716, Mayer, 2003:45). This means that in CSBI, learners were directed to the important elements of the presentation on the screen to lower cognitive load. Wherever possible, the simulations were presented to learners through both the visual mode and the verbal mode.

2.3.3 Application of Cognitive Theory of Multimedia Learning to Computer Simulation-based Instruction

This section discusses the application of the principles of CTML to CSB. This is illustrated by one of the simulations that was used in CSBI which is shown in Figure 2.2. This simulation enabled learners to change variables and investigate the effect of concentration, temperature and surface area on reaction rate.

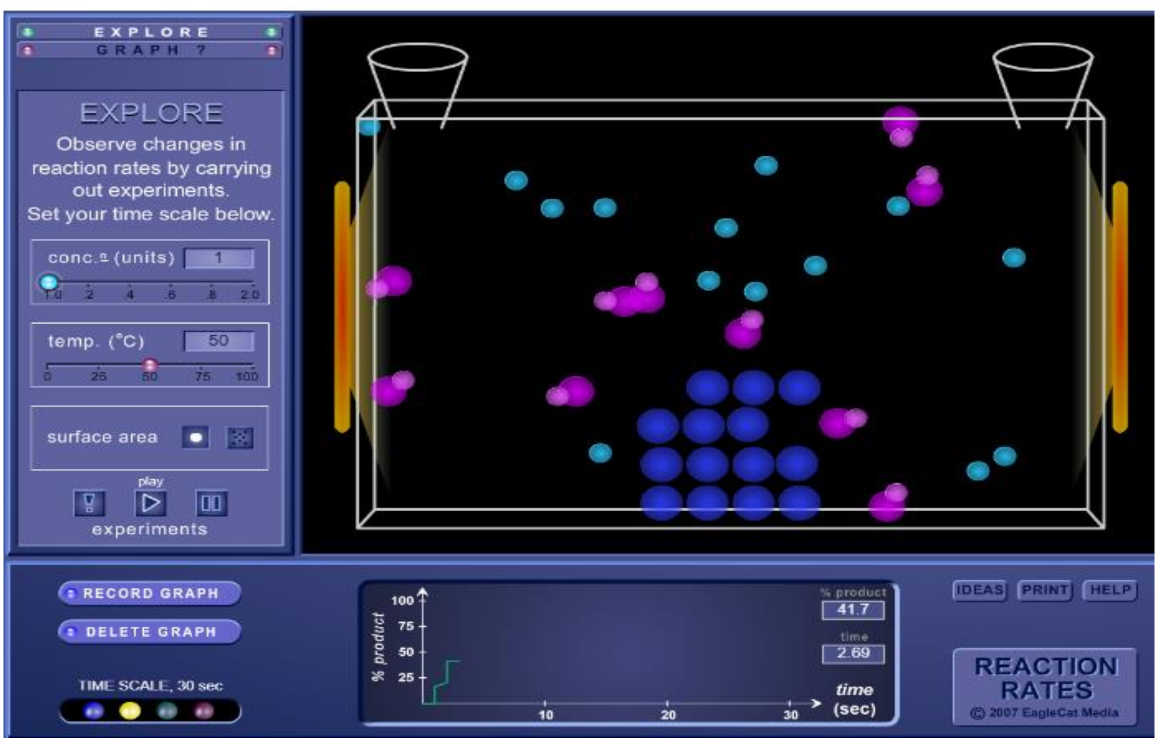


Figure 2.2 Simulation of Factors Affecting Reaction Rate: Effect of Concentration, Temperature and Surface area on Reaction Rate (Barassi, 2007).

The simulation prevents a split attention effect, due to the way it is designed. For example, by presenting the graph on the change in percentage of product versus time directly below the dynamic simulation of the reaction, instead of showing the graph in another window, split attention is avoided (Ayres & Paas, 2012:828). In addition, the graph is generated as the reaction proceeds. The graphs that are generated as the simulation occurs also serve to scaffold the learning process. As the computer was sketching the graph, it freed the learner's cognitive resources which were then used to make sense of what the graphs meant.

Furthermore, cueing, which is used to direct learners to specific parts of the animation and eliminate unnecessary search (Ayres & Paas, 2012:828) were used effectively in the same simulation (Fig 2.2). This was done by showing every effective collision by means of a red flash which gave emphasis. The reactant molecules A and B were shown by dark and light blue colours while the product, C was shown by a purple colour. This helped learners to pay attention to the important features of the simulation, hence cueing in the simulation was necessary in directing learners to what they should pay attention to, which ultimately is what was selected into the working memory.

The simulations used in the study on CRR had buttons which enabled the learners to control the pacing of the simulation. For example, there were buttons on *'new'*, which enable the learner to reset the simulation, play and pause. The pause button was used in the segmentation of the simulation, which is especially useful in dealing with the presentation of transient information (Ayres & Paas, 2012:828). Transient information disappears before the learner has time to process it and link it with newly-presented information (Ayres & Paas, 2012:828). Segmentation, thus, availed the learner the opportunity to process information in the working memory before new information appeared and may have reduced any extraneous cognitive load.

2.4 The Cognitive Load Theory Perspective on Computer Simulation-based Instruction

Cognitive Load Theory (CLT), like the CTML, is based on the Information Processing Theory. It assumes that the working memory is limited in capacity when dealing with new information (Paas *et al.,* 2004:2). The working memory is the cognitive structure in which conscious processing of information takes place (Sweller *et al.,* 1998:256). The working memory is able to hold seven, plus or minus two items of information at a time (Miller, 1956:81). When processing the information by organizing, contrasting or comparing, then the number of items of information may be reduced to two or three (Sweller *et al.,* 1998:256). In addition to the working memory, CLT assumes a cognitive architecture that also includes a Long-Term Memory (LTM) that stores an unlimited amount of information which includes large, complex interactions and procedures (Sweller *et al.,* 1998:254).

CLT is concerned with how to manage working memory load to ensure that schema construction and automation occurs in the Long-Term Memory (LTM) (Paas *et al.,* 2004:2). Consistent with the CLT, there are three types of cognitive load which are additive: intrinsic load, extraneous load and germane load (Paas *et al.,* 2004:2). Intrinsic load is due to the number of elements of information and their interactivity; this may be equated to essential processing in CTML. Extraneous cognitive load is due to how information is presented to the learner. This load is due to activities that do not contribute to schema construction and automation; it is like the incidental processing in CTML. One distinction between intrinsic cognitive load and extraneous cognitive load is that former cannot be altered, while latter can be deliberately changed through suitable instructional design (Hasler *et al.,* 2007:716). The load that contributes to schema construction and automation is called *germane load*. For effective learning to occur, the extraneous cognitive load should be low while the germane load should be high (Paas *et al.,* 2004:3). Since all the three cognitive loads are additive, effective instruction aims to ensure that the total cognitive load does not exceed the learners' working memory capacity (Hasler *et al.,* 2007:617).

The difficulty of learning a material such as Chemical Reaction Rates (CRR) has been linked to intrinsic cognitive load. Sweller (1994:307) posits that the intrinsic cognitive load is determined by element interactivity. He defines an *element* as any information that needs to be learned (Sweller, 1994:305). He further explains that elements have low interactivity if they can be learned in isolation. On the other hand, if elements need to be learned simultaneously, they will have high interactivity (Sweller, 1994:304). Most concepts in CRR are likely to have high interactivity as they may not be meaningfully learned in isolation. For example, to learn the effect of temperature on reaction rate, the learner needs to understand temperature as a measure of the average kinetic energy of molecules in a substance. Furthermore, the learner should know that increasing temperature increases the average kinetic energy of molecules. This knowledge should be connected to the activation energy. At a higher temperature, more molecules will have energy, equal to or greater than the activation energy, hence, more effective collisions occur per unit time. Learning of effect of temperature on reaction rate, thus, has high interactivity as it cannot be learned without simultaneously learning the connections between large numbers of elements.

In line with Sweller (1994:308), if the intrinsic cognitive load is high because of high element interactivity, then adding a high extraneous cognitive load may result in a total load that substantially exceeds cognitive resources available in working memory, therefore, leading to learning failure. The intrinsic cognitive load cannot be altered by instructional interventions as it is intrinsic to the material being dealt with (Sweller *et al.,* 1998:259). To avoid overloading working memory when dealing with material that has high intrinsic cognitive load such as in CRR, the extraneous cognitive load, hence, should be eliminated. The extraneous cognitive load is due to the way the material is presented or of the activities required of the learner (Sweller *et al.,* 1998:259). Some ways that may be used to reduce intrinsic cognitive load are - the use of goal-free strategy when solving problems; use of worked examples; integration of diagrams and associated texts and elimination of redundant information (Sweller, 1994:303).

2.4.1 Implications of Cognitive Load Theory for Computer Simulation-based Instruction

Direct guidance, schema construction and schema automation are some of the essential aspects of the CLT for the present study. These aspects have direct relevance to the approach of teaching adopted in this study.

2.4.1.1 Direct Guidance

The implications of CLT for the present study are that extraneous cognitive load needs to be reduced in learning concepts in CRR. The extraneous cognitive load may be reduced by methods, such as demonstrating how to use the simulation before learners explore the simulation on their own. As stated by Kirschner *et al.,* (2006:79), learners dealing with novel situations, such as when exploring simulations on CRR for the first time, should be explicitly shown what to do and how to do it. This is because the novice learners lack the necessary schemas to integrate the new information with their prior knowledge (Kirschner *et al.,* 2006:79). It is argued that guided instruction, by explicitly providing learners with knowledge of subject matter, not only produces immediate recall of facts but also helps learners with longer-term transfer and problem-solving skills (Kirschner *et al.,* 2006:79). For these reasons, the present study used direct instructional guidance to teach CRR. Kirschner *et al.,* (2006:75) elucidate that direct instructional guidance is providing information that fully explains the concepts and procedures that learners need to learn. They define *learning* as a change in LTM. Direct guidance is beneficial to novice learners, such as those learning CRR for the first time, as they lack knowledge in LTM to prevent unproductive problem-solving strategies.

Direct guidance during instruction in CRR most likely helps learners to acquire the necessary schemas that may help them to have knowledge of reaction rates. The guidance, which may be implicitly embedded in the simulation environment or may be explicitly provided by the teacher, involves such activities as giving feedback, reflection prompts or direct advice to the learner (Domagk *et al.,* 2010:1030).

2.4.1.2 Schema Construction

One goal of teaching CRR is for learners to acquire knowledge of reaction rate concepts. This knowledge is stored in the form of schemas in LTM (Sweller *et al.,* 1998:255), but these schemas are constructed in the working memory which is limited in capacity. Lower level schemas in CRR are combined to form more complex schemas and these complex schemas form the basis of human intellectual skill (Sweller *et al.,* 1998:255). The basic function of the schema is knowledge organization, storage and reduction in working memory load. Working memory can only deal with a few schemas at a time, as they may contain a huge amount of information; this reduces the working memory load (Sweller *et al.,* 1998:255). Strategies that assist learners to construct higher level schemas of chemical reaction rate concepts using computer simulations, hence, were critical. These strategies included the Predict-Observe-Explain model of teaching. The strategy most likely helped learners to link new and previous knowledge, hence, assisted them in organizing and storing the new knowledge.

2.4.1.3 Schema Automation

Information can be processed in a controlled way or in an automatic way (Shiffrin & Schneider, 1977:155). Controlled processing occurs in the working memory and requires the attention of the learner (Sweller *et al.,* 1998:256). It leads to working memory overload. On the other hand, automatic processing does not require the learner's attention and so it uses little working memory capacity (Sweller *et al.,* 1998:258). Automaticity results from a high level of practice (Sweller *et al.,* 1998:256). Automation frees the working memory capacity for other activities (Sweller *et al.,* 1998:258). When learning new tasks, such as when simulating experiments on factors affecting CRR, prerequisites should be automated so that working memory can be freed to allow unfamiliar aspects of the task to be learned without overloading the working memory. This is because when learners must deal with previously-learnt information stored in LTM, they can overcome the limitations of the working memory (Kirschner *et al.,* 2006:77). It can, hence, be concluded that the aim of learning CRR through CSBI is for learners to acquire schemas and ensure that these schemas are automated through practice. In the teaching of CRR, basic concepts such as factors affecting reaction rates were discussed before doing the virtual experiments. This was to ensure that these were automated, so that when doing the experiments, learners could offer sensible hypothesis.

2.5 The Sociocultural Theory Perspective on Computer Simulation-based Instruction

Cognitive development in Vygotsky's sociocultural theory occurs because of social interaction. Kozulin (2003:5) argues that learning is the driving force of cognitive development which occurs in a social setting. As stated by Vygotsky (1978:39):

> *"human learning presupposes a social nature and processes by which children grow into the intellectual life of those around them"*.

This means that learning, firstly, occurs through interaction with others before it is internalised by the learner. Samaras and Gismondi (1998:717) assert that thinking begins on the interpersonal or social plane before it is internalised as intrapersonal knowledge in Vygotsky's theory.

In addition to the social nature of learning, the sociocultural theory is shaped by the interplay between culture and learning. Culture affects learning through cultural artefacts and cultural tools. The tools are psychological in nature, as they are used to express thinking, include language, signs, symbols, texts and mnemonic techniques (Hall, 2007:96). As computer simulations are used to express thinking, they may also be regarded as psychological tools. As said by Hall (2007:96), Vygotsky's sociocultural theory implies that the cognitive development of a learner is not a direct result of activity, but it is indirect, in that other people must interact with the learner, using mediatory tools, such as simulations to facilitate the learning process.

Furthermore, the concept of higher mental functions is important in the sociocultural theory. These higher mental functions include - memory, attention, thinking, language and self-regulation, (Samaras & Gismondi, 1998:717). The higher mental functions are, firstly, mediated through social interactions then they are integrated into an individual's thinking using cultural tools, such as language (Samaras & Gismondi, 1998:717). Kozulin (2003:17) posits that the development of a learner's higher mental processes depends on the presence of mediating agents in the learner's interaction with the environment. These mediating agents are either human or symbolic.

Human mediating agents may be adults such as teachers or parents that interact with the learner. When learners interact with knowledgeable others, such as teachers, learners can accomplish more than when working alone. This idea is expressed in Vygotsky's concept of Zone of Proximal Development (ZPD) (Vygotsky, 1978:38). Vygotsky (1978:38) defines the ZPD as

> *"the distance between the actual developmental level as determined by independent problem-solving and the level of potential as determined through problem-solving under adult guidance or in collaboration with more capable peers"*.

The ZPD postulates two levels of development. The first one is the zone of actual development. This is determined by the problems that the learner can solve without assistance. The second level is the potential level of development. It is determined by what a learner can do with guidance from a teacher or a more capable peer. Teaching in the ZPD has been interpreted to mean providing aid or scaffolding to the learner (Puntambekar & Hubscher, 2005:2). Sharma and Hannafin (2007:28) propose that scaffolding "operationalizes Vygotsky's relationship between instruction and psychological development".

Lajoie (2005:542) describes a scaffold as a temporary framework to support learners when assistance is needed. The support is removed once it is no longer necessary. The teacher's role in CSBI, therefore, is to provide guidance to learners during the learning process. This is done through identifying and diagnosing the learner's level of understanding that enables him/her to acquire new concepts when learning CRR. The simulations in CSBI may also have scaffolds embedded in them, however, technology-enhanced scaffoldings differ from those provided by the teacher. They are static and do not change dynamically as circumstances evolve and so, they are less responsive to emerging learners' needs (Sharma & Hannafin, 2007:30). It is necessary, therefore, to supplement the scaffolds in the simulations with those provided by the teacher.

2.5.1 Implications of Vygotsky's Sociocultural Theory to Computer Simulation-based Instruction

From Vygotsky's sociocultural theory, learning of reaction rates, through simulations should occur within the learner's zone of proximal development. This may be achieved through scaffolding. Any guidance that the learner gets aimed at ensuring that the learner reaches the zone of potential development in CSBI, may be considered as a scaffold (Fraser *et al.,* 2015:299). In CSBI, scaffolding may be provided explicitly by the teacher or they may be embedded within the simulation itself.

Scaffolding that is dynamic, timely, situation-specific and involves continuous diagnosis of learners to determine the level of support they need, has been termed *soft scaffolding* (Brush & Saye, 2002:2). On the other hand, scaffolding that is static, anticipated and planned is *hard scaffolding* (Brush & Saye, 2002:2). The former is provided by the teacher during CSBI while the latter may be embedded within the simulation or may be explicitly provided by the teacher.

The scaffolds provided in learning of CRR through simulations, include - questioning, prompting, cueing, modelling, coaching, telling and discussing (Hmelo-Silver, 2006:150-151). Modelling involves demonstrating to learners how to explore the simulation on reaction rates while cueing involves directing learners to essential parts of the simulation. The guidance that is given to learners while exploring the simulation is what is referred to as *coaching.*

The Predict-Observe-Explain (POE) is another strategy for scaffolding reaction rates concepts. This is achieved by providing learners with worksheets to fill in partially-completed statements (Hmelo-Silver, 2006:151). This was applied in the Prediction stage where the learner completed partial statements on investigative questions and hypothesis. The stage of Explanation in POE helps to encourage reflection, make thinking visible and is necessary for discussion and revision of reaction rate concepts (Hmelo-Silver, 2006:151). When a learner gains competence, these techniques fade away.

Vygotsky's sociocultural theory, with emphasis on the ZPD together with the CTML and the CLT, provided guidance on how to optimize instruction of CRR by CSBI, however, optimization of learners' memory to enhance learning and performance may not be sufficient. Ismail *et al.,* (2013:330) opine that an instructional intervention should also be concerned with the motivational resources of learners, hence, a theory should be able to predict the influence that motivational factors will exert on the allocation of effort to learning. Attitude is one of the most influential factors that affect motivation, so, this study looked at the effect of CSBI on learners' attitudes (Mubeen & Reid, 2014:129). A theory that guided the study on attitudes of learners towards chemistry lessons taught through CSBI was the Attitude Construal Model (ACM) based on situated cognitive theories (Schwarz, 2007:638). The next section looks at the basic ideas of the ACM and the justification for using this theory in this study.

2.6 The Attitude Construal Model

Consistent with the ACM, attitudes are evaluative judgements that are constructed at the spot (Schwarz, 2006:19). This model differs from the traditional approach on attitudes which treats attitudes as enduring personal dispositions. In the ACM, it is argued that while evaluation is informed by past experiences, it should be highly sensitive to the specifics of the present (Schwarz, 2006:20). In this context-sensitive evaluation, Schwarz (2007:638), argues that recent experiences have more substance than remote experiences. Also, experiences from comparable situations have more substance than experiences from divergent situations. This theory is preferred in the present study as it excels at explaining variability in attitude judgements, across time and contexts (Schwarz, 2007:642). This is supported by Cohen and Reed (2006:3) who say that variance in attitudes is explained by the fact that accessibility of cognitive elements varies because of contextually generated factors. It is necessary, therefore, to look at the basic assumptions of this theory as put forward by Schwarz (2007:638).

According to Schwarz (2007:643), firstly, comparable judgements are expected when the context of judgement remains unchanged. In the context of the present study this implies that when learners are taught by the same method, such as the traditional teacher-talk-and-chalk approach, they may have the same attitudes at the beginning and end of teaching CRR. Secondly, Schwarz (2007:643) states that changes in inputs give rise to changes in judgement. In the present study, this means that when a different teaching method, such as CSBI is used, then the learners' attitudes could be different, at the end of instruction, from the attitudes they had at the beginning. Furthermore, if the information is highly accessible in presenting the attitude object, it results in assimilation effects. This means that including positive information results in positive attitudes. If the evaluation at Time 1 was based on a small amount of information, including positive information, it will result in a more positive evaluation of the attitude object at Time 2 (Schwarz, 2007:643). It is further argued that information that results in consistency at Time 1 and Time 2 decreases the size of the assimilation effects, hence, the converse of this statement, that inconsistency of information between Time 1 and Time 2 increases assimilation effects, should be true. In short, teaching using a different approach may result in higher assimilation effects. In the context of the present study, teaching CRR using CSBI is a departure from the usual talk-and-chalk approach and this leads to inconsistency. The learners' attitudes are then expected to change because of the assimilation effects, if the information is accessible to them.

On the relationship between attitude and behaviour, Schwarz (2007:647) posits that evaluation-behaviour consistency is higher when the learner has direct experience with the target. This means that learners' behavioural tendency towards CSBI would be influenced by having direct experiences with simulations. If learners gain experience in CSBI their attitudes towards this approach of teaching will be expected to be different at the end of the instruction to what it was at the beginning - consistent with the ACM. In agreement with this theory, learners do not "have" attitudes, as such, but attitudes are constructed on the spot in relation to the accessibility of information. Learners evaluate the CSBI differently, in different contexts. At the beginning of the instruction, learners may not have adequate knowledge of CSBI but at the end, they may have more information which may result in the judging of this approach of teaching, either positively or negatively depending on whether they could assimilate the teaching approach.

The next section is concerned with the integration of the foregoing theories in formulating a theoretical framework. This theoretical framework is referred to as the Cognitive Theory for Computer Simulation-based Instruction (CTCSI) as all theories used are based on cognition.

2.7 Integration of Cognitive Theories, Sociocultural Theory and Attitude Construal Model into the Cognitive Theory for Computer Simulation-based Instruction

The theoretical framework guiding this study is the Cognitive Theory for Computer Simulation-based Instruction (CTCSI) and is shown in Figure 2.3. The CTCSI is based on some aspects of CTML, CLT, Vygotsky's sociocultural theory and the ACM. As shown by literature on CTML and CLT, there are aspects of these theories that overlap, for example, both theories identify cognitive overload as a factor that any instructional approach should overcome if it is to be effective. These areas of overlap enabled me to integrate those aspects.

It is my opinion that the CTML and the CLT do not adequately address the issue of the role played by the teacher during the teaching-learning process. This issue is addressed by Vygotsky's social cognitive theory and the ZPD. In addition, this research looks at the effect of CSBI on learners' attitudes, hence, the ACM is used as a lens to look at how CSBI may influence learners' attitudes. Considering the concepts and principles explored in the CTML, CLT, Vygotsky's sociocultural theory and ZPD, as well as the ACM, the study puts forward the Cognitive Theory for Computer Simulation-based Instruction (CTCSI) as the theoretical framework for this study. Figure 2.3 shows the CTCSI.

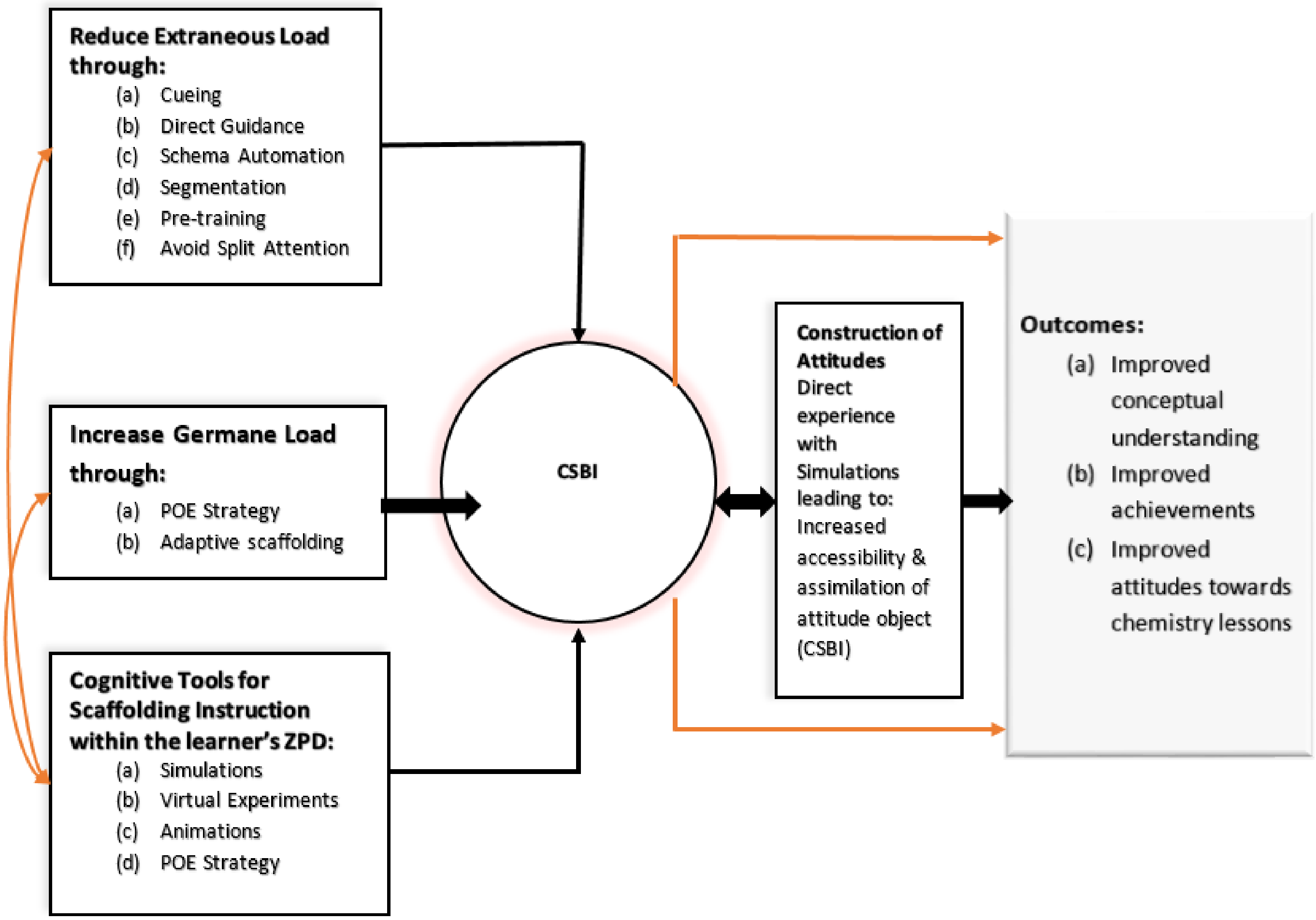


Figure 2.3 Cognitive Theory for Computer Simulation-Based Instruction

The arrows that leads to the CSBI in Figure 2.3 show that reducing extraneous load, increasing germane load and the use of cognitive tools for scaffolding instruction within the learner's ZPD results in CSBI leading to improved academic achievements, conceptual understanding and attitudes towards the chemistry lessons as shown by arrows from CSBI. POE strategy and adaptive scaffolding are cognitive tools for scaffolding instruction which increase germane load which is shown by arrows pointing in both directions. The same applies to techniques used to reduce extraneous load as these techniques scaffold instruction leading to better learning outcomes. The arrow pointing in both directions from CSBI and Construction of Attitudes shows that CSBI and Construction of Attitudes influence each other. This implies that direct experience with simulations leads to increased accessibility and assimilation of the attitude object (CSBI). This relationship also leads to improved attitudes towards the chemistry lessons. The theoretical framework guides the present study in addressing the research question: *What are the effects of using CSBI on the academic achievement of Grade 12 learners in CRR topic?*

2.8 Summary

This chapter provided justification for using cognitive theories in the formulation of a theoretical framework. At the heart of the chapter was an attempt to answer the question: *How best can computer simulations be used to assist learners in conceptual understanding of CRR?* While it is hypothesized in this study that simulations have the potential to help learners in understanding of complex and difficult topics, such as CRR, conditions under which this may happen need to be made explicit. This is because it is noted that just exposing the learners to simulations *per se* does not lead to conceptual understanding (Renkl & Atkinson, 2007:236). Simulations should be integrated into instruction based on sound theoretical grounds, however, no one theory was deemed sufficient to capture all the aspects of the study.

The CTML suggested that redundant information should be excluded from the simulation and when presenting the simulations, segmenting the simulation and providing pre-training may lead to better outcomes. The CTML also put emphasis on avoiding split attention in the design of the simulation. From the CLT it was noted that direct guidance, schema construction and schema automation were necessary considerations to optimize learning using simulations. The CLT and the CTML both advocates for reduction in extraneous cognitive load and an increase in germane cognitive load for optimal instruction using simulations.

The socio-cultural theory showed that scaffolding techniques should be used to ensure that learning occurs within the ZPD. Scaffolding is a way of freeing learners' cognitive resources so that these resources can be available for essential processing leading to increased conceptual understanding. The ACM laid out conditions under which attitudes may change and how they may change. The ideas from the CTML, the CLT, the socio-cultural theory and the ACM were considered in the formulation of the Cognitive Theory for Computer Simulation-Based Instruction which was used as a lens to look at methodology, the analysis and interpretation of the research findings. The approach adopted, as indicated in the theoretical framework, ensured that learners engaged in cognitive processing of CRR concepts as they learn through simulations. The following Chapter explores the literature on the teaching of Chemical Reaction Rate.

Chapter 3 Teaching Chemical Reaction Rate through Computer Simulations

3.1 Introduction

The purpose of this study was to investigate the effect of Computer Simulation-based Instruction (CSBI) on learners' academic achievement in Chemical Reaction Rate (CRR) and to determine whether it would improve their attitude towards chemistry lessons. CRR, also called *chemical kinetics*, is a topic in the Chemistry section of Physical Sciences. In this topic, like in other topics in chemistry, theories, laws and models are put forward to explain scientific phenomena. These include the atomic theory, kinetic theory of matter, the collision theory and the transition state theory, among others. This Chapter begins with an examination of ontological and epistemological issues about how scientific knowledge is constructed in the section on *Characteristics of Scientific Knowledge.* This discussion sheds light on the nature of the concepts that are learnt from simulations of CRR.

The Chapter highlights the characteristics of computer simulations and how they relate to goals of laboratory learning. In CSBI, the learners perform virtual experiments on CRR, hence, it is necessary to review the literature on how virtual experiments relate to goals of laboratory learning. The Chapter looks at how CSBI is supported by an active learning strategy called the Predict-Observe-Explain strategy (POE). CSBI makes use of Science Process Skills (SPS) in virtual experiments in the POE activities, hence, the study also highlights the role of SPS. Specific studies on how to improve learners' performance on CRR are also discussed and the gaps in literature in the use of simulations in teaching science concepts and chemical reaction rates were identified. A discussion of how this study attempted to fill these gaps is provided.

The Chapter looks at CRR in the South African Physical Sciences curriculum, highlighting the major concepts. The literature on difficulties and misconceptions in CRR and attitudes of learners towards chemistry is reviewed as the study also aimed to find the effect of CSBI on learners' attitudes towards the lessons.

3.2 Characteristics of Scientific Knowledge

In CRR, learners are expected to acquire scientific knowledge, thus, it is necessary to reflect on some of the characteristics of science and scientific knowledge. This is also referred to as the nature of science (NOS). NOS is concerned with the epistemology of science - the theory of how we know what we know (Osborne, 2014:180). In other words, it is the theory of how scientific knowledge is constructed. What follows is a discussion of some aspects of NOS which are relevant to the understanding of the concepts in CRR.

One characteristic of scientific knowledge is that, it is empirical. This means that it is a result of the observation of the natural world (Lederman, 2013:833). When scientists observe the natural world, they make use of their senses, however, scientists do not only describe what they observe but they make inferences from their observations. Observations are descriptions of the natural world that are obtained directly through the senses (Lederman, 2013:833). On the other hand, inferences are explanations, models or mechanisms, used by scientists to describe complex natural phenomena (Lederman, 2013:833). This means that the concepts in CRR are based on empirical data and inferences from the observations.

From observation of the natural phenomena, scientists may come up with laws and theories. Lederman (2013:833), describes scientific laws as statements or descriptions of the relationships among observable phenomena. On the other hand, theories are explanations deduced from observation of phenomena (Lederman, 2013:833). In Chemistry, a theory is a representation of the finest knowledge and beliefs of chemists about how chemical systems function (Christie & Christie, 2000:35). In the study of CRR, learners encounter some theories, such as the collision theory and the transition state theory. These theories, therefore, represent how scientists believe chemical reactions occur. As rightly noted by Christie and Christie (2000:36), theories in chemistry are often competing theories and chemists adopt the theory that is best suited to solve a problem. The function of scientific theories and models is to enable scientists to explain and predict scientific phenomena; generate further research and ensure internal consistency of explanations of phenomena (McComas, 1998:63, Abd-El-Khalick, 2012:1046).

Scientific knowledge is partly created through inference, imagination and creativity (Lederman, 2002:499). Scientists use their creativity to invent explanations as they make inferences from observations of natural phenomena (Lederman, 2013:834). This way, by inventing explanations from observation of natural phenomena, scientists construct knowledge. Consequently, this led Lederman (2013:834) to conclude that particles such as atoms, molecules and ions are not exact copies of reality but rather they are functional theoretical models, hence, this is the reason for their acceptance as true (McComas, 1998:67). These models, then, are the best representation of scientific knowledge and beliefs about chemical systems (Christie & Christie, 2000:35). In this study, scientific facts, concepts, theories and laws in CRR were presented to learners through simulations; the following section discusses these computer simulations.

3.3 Computer Simulation-Based Instruction

This section clarifies the concept of CSBI and further explores what comprises CSBI. CSBI involves virtual experiments, therefore, the goals of laboratory activities which may be attained through virtual experiments are evaluated. Furthermore, as virtual experiments enable learners to attain Science Process Skills (SPS), the section discusses SPS which may be attained through CSBI. Finally, a discussion of advantages and disadvantages of computer simulations concludes the section.

3.3.1 What is Computer Simulation-Based Instruction?

As stated by De Jong and Van Joolingen (1998:180), computer simulations are programmes that contain a model of a natural or artificial system. In computer simulations, learners explore relationships among variables in models of the system (Kulik *et al.,* 1980:529). Chemistry simulations are dynamic visualisations of chemical systems (Suits, 2015:611). Learners manipulate the variables of the system and then perform the simulation to observe its effect on the dependent variable (Suits, 2015:611).

The simulations should be interactive. The learner should be able to manipulate the independent variable and observe the effects on the dependent variable. Simulations which are exceptionally interactive, thus, permit the learner to input a value for the independent variable then the simulation reacts to the changes made by the learner (Suits, 2015:611).

Computer simulations used in education have certain characteristics such as - presence of a formalised, underlying model that can be manipulated; presence of learning goals; elicitation of learning processes and learner activity (De Jong & Njoo, 1992:415). A simulation has *learning goals* which can be either *conceptual knowledge, procedural knowledge*, or *psychomotor skills* (De Jong, 2012:415). The *learning processes* in simulations include hypothesis generation, predicting and model exploration. *Learner activity* involves the learner manipulating something within the simulation, like setting input variables, collecting data, deciding on the procedure, setting data presentations or controlling simulation time (De Jong & Njoo, 1992:415).

Computer simulations may be used as pedagogic simulations (Suits, 2015:611). When used in this manner they constitute CSBI. Considering the above and for the purposes of the present study, I define CSBI as an instructional approach in which computer simulations, such as visualizations, animations, and interactive virtual laboratories are used as teaching aids to support learning. Since the simulations used in the present study involve learners carrying out virtual experiments, it is necessary to look at the goals of laboratory teaching. The next section critiques the extent to which virtual experiments in CSBI satisfy the goals of laboratory teaching.

3.3.2 Virtual experiments and goals of laboratory teaching

Virtual experiments are used in CSBI, therefore, it is important to understand the goals of laboratory activities which may be attained through virtual laboratory experiments. These goals are the - *attainment of mastery of subject matter*; *scientific reasoning*; *understanding of the complexity and ambiguity of empirical work*; *practical skills*; *understanding of the nature of science*; *creating interest in science and interest in learning science* and *developing teamwork abilities* (Singer *et al.,* 2006:195).

Some of these goals of laboratory activities may be achieved through virtual experiments in CSBI, however, researchers question whether virtual laboratory experiments can be used as a substitute for hands-on laboratories in secondary schools (Burkett & Smith, 2016:8). The role of simulated laboratory experiments in education is contested, although De Jong *et al* (2013:305) argue that hands-on laboratories and virtual laboratories can achieve similar objectives. They identify - understanding the nature of science, teamwork skills, interest in science, promoting conceptual understanding, and developing inquiry skills as objectives that can be achieved using hands-on, physical or virtual laboratories. It is also claimed that virtual laboratory experiments are as effective as, or more effective than traditional hands-on laboratories (Tatli & Ayas, 2013:159, Burkett & Smith, 2016:8). This is possibly on the goal of *mastery of subject matter* or conceptual understanding. Virtual laboratories enable learners to acquire facts and concepts as well as science-process skills.

The goal of *scientific reasoning* may be achieved through simulated virtual experiments. To attain this goal Reyes *et al.,* (2014:90), argue that learners should participate in the design of the investigation, as well as the drawing and supporting of conclusions. In this situation, learners identify questions leading to scientific investigations; design and conduct scientific investigations; develop and revise scientific explanations and models and recognize and analyze alternatives (Reyes *et al.,* 2014:90). In the context of this study the learners designed experiments to investigate factors affecting reaction rate. In designing these investigations, they learnt how to formulate the investigative questions, and hypothesis; how to control variables and carry out the experiment and provide explanations for their observations. These processes involve scientific reasoning.

Scientific reasoning encompasses experimenting, hypothesis generation and evidence evaluation (Osborne, 2014:181). The reasoning in these activities can be deductive, inductive or abductive (Osborne, 2014:181). During these activities, scientists ask questions; design experiments to test the hypotheses; collect and analyse data and critically evaluate evidence (Osborne, 2014:181). The experimental method is used to test ideas and involve techniques, like - the use of controls; skilful analysis and interpretation of data and ultimately to the production of scientific knowledge (Osborne, 2003:15). The experimental method may be used in virtual experiments to explore concepts in CRR, and hence to achieve the goal of scientific reasoning.

It appears that when virtual experiments are compared to real laboratory experiments, the goal of *practical skills* is achieved more effectively through real experiments. This is because practical skills involve the proper use of scientific equipment and making accurate measurements and observations. To this end, De Jong *et al* (2013:305) states that physical, hands-on laboratories enable learners to develop skills, such as troubleshooting equipment - a practical skill which may be difficult to attain through virtual laboratories. In hands-on physical laboratories, learners experience some of the challenges faced by scientists when planning and setting up experiments. A related goal which appears problematic to attain through simulations, is the *understanding of the complexity and ambiguity of empirical work*. Complexities of science such as dealing with measurement errors may be achieved more effectively through physical laboratory activities (De Jong *et al*, 2013:306).

Interest in science and interest in learning science and *teamwork skills* may be achieved through simulated virtual experiments. A meta-analysis of the literature on simulations and games by Vogel *et al.,* (2006:335) reveals that simulations result in better cognitive outcomes and attitudes when compared to traditional teaching methods. This is supported by Burkett and Smith (2016:8) who claim that learners have positive attitudes towards virtual laboratory experiments. Virtual laboratories may also enable learners to develop *teamwork skills* which empower learners to acquire higher-order thinking abilities such as making distinctions, applying ideas, forming generalizations, raising questions, as opposed to just reporting experiences, facts, definitions or procedures (Reyes *et al.,* 2014:90).

The present study intended to investigate the effect of CSBI on learners' achievements in CRR and it was largely concerned with the conceptual understanding of CRR. *Mastery of subject matter,* therefore, was the major goal that the present work was aimed at. In addition, it was also concerned with finding out if learners' attitudes would be affected by using CSBI, and if so, how, hence, the other goal of interest in this study was *Interest in science and interest in learning science.* The study also enabled learners to acquire Science Process Skills (SPS) as virtual laboratory activities were carried out. This means that when learners carry out virtual experiments, they develop SPS.

3.3.3 Computer Simulation-Based Instruction and Science Process Skills

The current legal document guiding the teaching of Physical Sciences in South Africa is the Curriculum and Assessment Policy Statement (CAPS). The significance of SPS is clearly articulated in the aims of CAPS. One of the purposes of Physical Sciences, in accordance with CAPS, is equipping learners with investigative skills relating to physical and chemical phenomena (DBE, 2011:8). Some of the skills needed for the study of Physical Sciences are - classifying, communicating, measuring, designing an investigating, drawing and evaluating conclusions, formulating models, hypothesizing, identifying and controlling variables, inferring, observing and comparing, interpreting, problem solving and reflective skills (DBE, 2011:8).

The skills listed in CAPS fit the definitions for SPS postulated by other researchers. Abungu *et al.,* (2014:259) define SPS as activities which learners carry out in scientific investigations to enable the acquisition of scientific knowledge and skills. Ergul *et al* (2011:49) categorizes SPS into, basic SPS and integrated SPS. The skills listed in CAPS include both basic SPS and integrated SPS. Observing, classifying, measuring, using numbers, establishing space/time relations, predicting, inferring and communication, are basic SPS, while defining, and controlling variables, formulating and testing hypotheses, operational definition, and experimenting are integrated SPS (Duruka *et al*, 2017:119, Ergul *et al*, 2011:49). When learners carry out virtual experiments in CRR they collect and interpret data; construct tables of results and graphs; describe relationships between variables; design investigations; draw conclusions and generalize. The interactive virtual laboratory experiments in CSBI, therefore, facilitated learners in developing SPS.

Duruka *et al* (2017:119) considers SPS as a tool that enables learners to acquire research, investigative and critical thinking skills. It is argued that since scientists use these skills in solving complex problems, these are desirable skills for learners to develop. Furthermore, SPS demystifies science, as learners no longer 'see' the scientific enterprise as a pile of inert knowledge and possessing absolute facts (Duruka *et al*, 2017:117). Through SPS learners may come to understand how scientific knowledge is created.

SPS help learners to understand the nature of science and its methods of data collection as well as improve the learners' creativity (Duruka *et al*, 2017:118). For example, Aktamis and Ergin (2008:3) argue that creative thinking in applying SPS enables individuals to search for solutions to problems that are encountered in daily life and to make new products. The skills learners acquire allow them to develop into citizens capable of fully participating in a knowledge-driven society as they enhance learners' creativity (Duruka *et al*, 2017:118). Duruka *et al* (2017:118) further argues that the learners should develop into a producer of knowledge and a problem-solver in complex circumstances. This may be achieved when learners do scientific investigations through virtual experiments since experimenting affords them an opportunity to inquire about scientific phenomena. Virtual experiments and other forms of simulations of scientific phenomena, however, have advantages and disadvantages. The following section, therefore, examines the advantages and limitations of simulations.

3.3.4 Advantages of using computer simulations in teaching Chemical Reaction Rate

Computer simulations aid learners to observe details of chemical reactions that are too hazardous, expensive or timewasting for actual laboratory work (Justi, 2003:310). This implies that if access to internet and computers are available, it may be cheaper and less time-consuming to use simulations instead of real laboratory activities. Simulations also provide visualizations of phenomena that are impossible to see as they make unobservable processes at molecular level, such as bond-breaking and bond-making, visible (Ainsworth, 2008:193; Zhang & Linn, 2011:1178). The experience provides understanding that is difficult to achieve without the simulation. For example, they permit learners to gather data on CRR which are often impossible to obtain in a school laboratory. An example of such data is the rate of change in concentration of a reactant or product in real time. In a school laboratory, it is not possible to measure changes in concentration in real time, however, the data obtained can be shown graphically in a computer-simulation environment. Simulations aid learners to link processes at the molecular level with macroscopic observations (Zhang & Linn, 2013:2175). Furthermore, the interactive simulation environment allows learners to investigate factors affecting reaction rate, such as temperature, by controlling input values. Learners, in addition, can manipulate factors affecting the rate at their own pace.

As stated by Justi (2003:310), one of the major advantages of simulation environments is that they facilitate three-dimensional, dynamic depictions of chemical processes to be explained in abstract terms. This assists learners to visualize chemical phenomena and to switch from the macroscopic representation to the sub-micro level of thinking. This is necessary as learning difficulties in chemistry arise when learners try to understand chemical phenomena at the sub-microscopic level. As confirmed by Taber (2013:158), the sub-microscopic explanations of chemistry are a major field of concern in teaching chemistry topics, such as CRR.

Computer simulations include virtual laboratory activities and Daineko *et al.,* (2017:40 opine that virtual laboratory enables demonstrating processes that cannot be attained within a school for virtual laboratory activities can be done anywhere if there are computers. This makes it possible for virtual laboratory experiments to be conducted remotely, thus, they can be used as demonstrations in large classes without the need for physical laboratories and associated costs (Daineko *et al.*, 2017:40). Learners may perform virtual laboratory experiments in these demonstrations with the teacher's guidance.

In summary, chemical simulations are preferable for experiments that are dangerous; takes a long time to carry out and are costly. They also allow learners to observe chemical processes at a molecular level which is not possible in actual experiments. Within the simulation, learners can switch from macroscopic, sub-microscopic and symbolic representations; this helps learners in conceptualising abstract ideas in chemistry.

3.3.5 Disadvantages of Computer Simulations

The major disadvantage of simulated experiments is that real research cannot be done using them (Daineko, *et al.,* 2017:40). Real research, in this case, refers to carrying out actual experiments were learners use physical measuring instruments in measuring quantities. Simulations limit the ability of learners to develop practical skills such as the use of measuring instruments and handling of chemicals and apparatus. If the aim of the experiment is to develop psychomotor skills, then virtual laboratories may not be the best way to achieve this. Consequently, Daineko *et al.,* (2017:40) suggest that the inclusion of virtual experiments in science curricula should be done carefully and should be pedagogically justified, hence, the following section discusses how simulations may be effectively integrated into the teaching of CRR.

3.4 Traditional Instruction, Learner-Centred Instruction, and Computer Simulation-Based Instruction

In this section, traditional instruction, learner-centred instruction and CSBI are discussed.

3.4.1 Traditional Instruction

Traditional instruction is based on the behaviourist psychology of learning (De La Sablonniere *et al.,* 2009:2). This approach assumes that learners are like a 'tabula rasa' or empty vessels that need an expert to 'fill' with knowledge (De La Sablonniere *et al.,* 2009:1). In this approach, the teacher takes the leading role in instruction (Jony, 2016:172) and is responsible for all the decisions, such as planning the learning content and sequence, instructional activities and assessment.

Traditional instruction makes use of formal lectures in which the teacher provides the information while learners listen and take notes (De La Sablonniere *et al.,* 2009:1). Learners are assessed to find out whether they have mastered the knowledge transmitted by the teacher. Traditional instruction is relatively efficient as it allows teachers to teach many learners in a short period, however, it is criticized for promoting 'surface' learning rather than 'deep' understanding (De La Sablonniere *et al.,* 2009:1).

3.4.2 Learner-Centred Instruction

The learner-centred approach is rooted in the constructivist theory of learning (De La Sablonniere *et al.,* 2009:1). Consistent with Driver (1994) constructivism hypothesizes that knowledge is not transmitted exactly from one person to another but is actively constructed by the learner, therefore, in learner-centred teaching methods, learners take an active role in the learning process. This learning approach has its roots in the works of educational philosophers and psychologists like Dewey, Piaget, and Vygotsky (Jony, 2016:172).

Jony (2016:172) explains learner-centred instruction as an instructional approach in which learners play a role in the decisions on content, materials, activities, and pace of learning. The learner-centred instructional approach - emphasizes deep learning and understanding; increased responsibility and accountability on the learner; increased autonomy of the learner; interdependence between teacher and learner; and flexibility to teaching and learning on the part of both the teacher and the learner (Aydoğdu *et al.,* 2014:322). Learner-centred instruction uses active learning methods, such as role plays, group work and simulations. Advocates of this approach claim that it leads to increased motivation to learn; greater retention of knowledge; deeper understanding; and more positive attitudes towards the subject being taught (Aydoğdu *et al.,* 2014:331, Jony, 2016:172).

3.4.3 Computer Simulation-Based Instruction: Traditional or Learner-Centred?

Instructional approaches are often classified as either learner-centred or teacher- centred, O'Neill and McMahon (2005:29), however, argue that instruction is a continuum. At one extreme end of the continuum is the learner-centred approach while on the other extreme is the teacher-centred approach (Figure 3.1). In the present study, the instructional approach that was used was neither purely teacher-centred nor learner-centred.

Figure 3.1 Learner-Centred and Teacher-Centred Continuum (Adapted from O'Neill and McMahon (2005:29).

As said by Goedhart (2015:76), the fact that computers should be used in chemistry learning is not contested but the debate is on 'how' and 'when' they can be used effectively. CSBI, as used in the present study, is found in the middle in the continuum of instruction from learner-centred to teacher-centred but it leans more towards learner-centred instruction. Goedhart (2015:76) observes that computers have been used extensively to support active learning and learner-centred strategies, particularly in chemistry learning. To achieve active learning, the present study made use of the Predict-Observe-Explain (POE) (Bajar-Sales *et al*, 2015:6) strategy in CSBI.

As stated by Bajar-Sales *et al* (2015:5), POE is a metacognitive instructional tool that assists learners in conceptual understanding and problem-solving in chemistry learning. They define metacognition as the knowledge about one's capability to accomplish a task and control his/her thinking processes. It is claimed that POE can help to teach metacognition explicitly so that learners can be aware of their own thinking and how to regulate it (Bajar-Sales *et al*, 2015:5). POE is used in learning to obtain learners' ideas as it helps in promoting discussion about learners' ideas. For these reasons, it is thought to contribute to meaningful learning (Akpınar, 2014:528). In this study, POE was used to create an engaging atmosphere, to stimulate and support the learner (Bajar-Sales *et al*, 2015:2). POE was adopted in the present study to ensure that learners participated actively in the learning of CRR using CSBI. The next section discusses the teaching model in CSBI.

3.5 Teaching Model in Computer Simulation-Based Instruction: Predict-Observe-Explain

The study used demonstrations of simulations of CRR. Demonstrations were used because most schools in Limpopo do not have computer laboratories to enable learners to explore simulations in small groups (STAT SA, 2015:2). Another justification for using demonstrations is the large class sizes, hence, the simulations were displayed on a projector. The learner-centred teaching strategy that was used in CSBI was the Predict-Observe-Explain (POE).

POE activities can be used to make demonstrations more learner-centred in CSBI (Treagust, 2013:375). Predict-Observe-Explain strategy promotes interactivity when investigating using the simulation, therefore, learners, firstly, *predict* what should happen in a demonstration; they state the hypothesis and give reasons why this may be right (Kearney *et al*, 2001:590). Secondly, they *observe* a demonstration carefully, so they can gather relevant data. Lastly, they *explain* what they have observed, bringing out any discrepancy between their predictions and observations. Incorrect explanations are also useful as they may produce contradictions which lead to conflict. Contradictions may lead to metacognitive reflection and in the end the conflict may be resolved, therefore, asking learners to provide scientific explanation may lead to effective learning (Osborne, 2014:184). POE is considered an effective strategy for prompting learners' ideas and stimulating discussion about their observations and explanations (Treagust, 2013:375).

Interactive POE activities may be used together with demonstrations of simulations to aid understanding in chemistry; they provide genuine technology-arbitrated learning (Treagust, 2013:376). Karamustafaoğlu and Mamlok-Naaman (2015:923) investigated the effect of teaching electrochemistry concepts using the POE strategy; their study was a quasi-experimental design with 40 learners. The study showed a significant difference in the post-test in favour of the experimental group. They concluded that the POE strategy was effective in helping learners in conceptual understanding of electrochemistry. The next section is devoted to a discussion of the concepts and skills in CRR when learners are exposed to in CSBI.

3.6 Concepts and Skills in Chemical Reaction Rate in Physical Sciences

In this section, a summary of the major concepts and skills in CRR at secondary school level in South Africa and other countries is provided.

3.6.1 Chemical Reaction Rate in Physical Sciences in South Africa

In Chemical Reaction Rate (CRR), learners learn about rates of reaction and factors affecting the rate in South Africa (DBE, 2011:123). The factors listed in the curriculum document are: nature of reactants, concentration, pressure, temperature and the presence of catalysts. The experiments to determine the effect of various factors that affect reaction rate are listed and the document continues to state that the learners should study how to measure the rate of reaction. It is stated that this section is important for exemplifying and judging understanding of the investigative process; the relationship between theory and experiment; the importance of empirical data and mathematical modelling of relationships. CAPS suggests that teaching investigations should form part of this section. Learners are also expected to learn about the mechanism of reaction and catalysis. The specific content and concepts listed are - reaction rate; factors affecting reaction rate; collision theory; techniques for measuring rate; activation energy; graph of distribution of molecular energy; and catalysis (DBE, 2011:123).

This information was used to guide in the development of the research instrument which is a Test on Chemical Reaction Rates Concepts (TCRRC). These were also the concepts that learners study in CRR through CSBI.

3.6.2 Chemical Reaction Rate at Secondary Level in other countries

As stated by Justi (2003:29), in most countries, CRR at secondary level emphasize qualitative aspects. This approach is common, not only in South Africa but in countries like Australia, Brazil, the Netherlands, New Zealand, UK and USA (Justi, 2003:296). For example, in Greece, learners study reaction rate concept; factors affecting the reaction rate; the collision theory; the activated complex theory; energy diagrams; reaction mechanisms and catalysis (Gegios *et al.,* 2017:154). Unlike in South Africa, learners in Greece, also study rate laws. The colliding particle model is used to explain factors affecting the reaction rate. In South Africa, like in these countries, mechanism of reaction rate is not dealt with in much detail and concepts, such as *rate determining step*, *rate equation*, and *order of reaction* are not done at this level. Discussions about CRR using rate equations, the operation of different types of catalysts and quantitative relationships between CRR and thermodynamics are done at the university level (Justi, 2003:296). The next section examines the concepts, facts, theories and models that are used to explain CRR in South Africa.

3.7 Concepts in Chemical Reaction Rate

The major concepts in CRR in the South African Physical Sciences curriculum include - reaction rate; endothermic reaction; exothermic reaction; activation energy; collision theory; activated complex; temperature; concentration; contact surface/particle size; catalysis; Maxwell-Boltzmann Distribution curve and reaction mechanism (DBE, 2011:8). Concepts such as rate constant, rate equation, rate determining step in reaction mechanism, and order of reaction are not done at this level. The following section discusses the concepts in CRR, focussing mainly on aspects at secondary level in South

Africa, however, although elementary and complex reactions are not differentiated at this level, I consider the distinction as fundamental in a discussion of CRR.

3.7.1 Reaction Rate

Reaction rate is the change in concentration of a reactant or product per unit time. Reaction rate is also measured by a change in a quantity that is proportional to the concentration, such as a change in pressure or change in colour (Robinson *et al*, 1997:461). The reaction rate can be average rate, instantaneous rate or initial rate (Oxtoby *et al*, 2003:608-610). The average rate is the change in concentration of a reactant/product per unit time; instantaneous rate is the rate at an instant and is found by drawing a tangent to the curve of a concentration of a reactant/product versus time graph; and the initial rate is the rate when the reaction starts (at $t=0$) (Oxtoby *et al*, 2003:608-610).

3.7.2 The Collision Theory

In elementary reactions, two particles collide to form products and elementary reactions occur in one step only. For the collision to be successful, the reacting species (atoms, molecules or ions) must collide with correct orientation and colliding particles must have sufficient energy (Robinson *et al*, 1997:486-487). Only a fraction of all the collisions between A and B will be effective, leading to the successful formation of products. This is because energy is required to pass from reactants to products and only those collisions between particles having a certain minimum amount of energy, will lead to a successful collision (Connors, 1990:3). This minimum amount of energy needed for reactants to form products is called the 'activation energy' (E_A) (Oxtoby *et al*, 2003:635). In addition, only particles which collide with the correct orientation will lead to an effective collision. The collision theory provides an interpretation of why reaction rate is proportional to the concentration of the reactants and why temperature affects the reaction rate.

3.7.3 Effect of Concentration on Reaction Rate

Increasing the concentration of a reactant usually increases the rate of a reaction, however, in some cases, increasing concentration of a reactant has no effect on reaction rate and may even retard the rate. The relationship between concentration of a reactant and reaction rate, thus, is not ascertained easily (Oxtoby *et al*, 2003:607).

The collision theory can be used to explain why reaction rate depends on the concentration of reactants for elementary reactions. For a reaction between two reactants, A and B, the number of collisions per unit time is the collision rate (Mortimer & Taylor, 2002:35). The collision rate is directly proportional to product of the concentration of the reactants and a collision rate is not equal to the reaction rate, as not every collision leads to a reaction, since not all particles have sufficient energy to overcome the activation energy. For such reactions, the rate is a product of a constant and the concentration of both reactants (Mortimer & Taylor, 2002:36). The exact relationship between reaction rate and concentration is established empirically, through experimentation (Mortimer & Taylor, 2002:38).

3.7.4 Effect of Temperature on Reaction Rate

The Collision Theory can be used to explain the effect of temperature on reaction rate. It is noted that when temperature is increased, the rates of most reactions increase enormously (Oxtoby *et al*, 2003:633). The temperature-reliance of a reaction rate is explained by change in distribution of molecular kinetic energies of the reactants when temperature is increased. The particles in a gas have a range distribution of velocities at any instant and this distribution of speeds depends on temperature. This distribution can be represented by the Maxwell-Boltzmann distribution graph (Figure 3.2). The area under the curve represents the total number of molecules in the sample of the gas.

Increasing temperature causes an increase in the number of molecules with a high speed then the distribution curve becomes flatter and wider. The peak of the distribution, corresponding to the most probable speed, moves to a higher value (Mckee& Mortime , 2007:36).

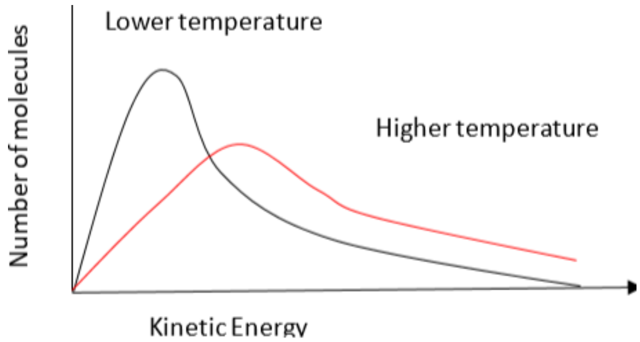


Figure 3.2 Maxwell-Boltzmann Distribution Curves at a lower and higher temperature.

Increasing temperature will increase the fraction of the fast-moving pairs of reacting molecules. At a higher temperature, the pairs of reacting molecules with the minimum energy needed to react, increases (Oxtoby *et al*, 2003:635). Increasing temperature also increases the collision rate of reacting pairs of molecules. These two factors result in an increase in reaction rate, however, the exception is when the energy barrier, also referred to as the 'activation energy', is zero (Oxtoby *et al*, 2003:635). In such cases the fraction of effective collisions will be constant and independent of temperature (Mckee & Mortimer, 2007:37). Increasing temperature in such reactions, which does not need activation energy, has little effect on reaction rate, hence, Turányi and Tóth (2013:110) argue that teachers should be cautious when explaining effect of temperature on reaction rate. They suggest that teachers should use phrases like "reaction rate *usually* increase, when temperature is increased". This may reduce the misconception that increasing temperature always results in an increase in reaction rate.

3.7.5 Effect of a catalyst on reaction rate

A catalyst is a substance that accelerates the rate of a reaction by providing a new pathway for the reaction but remains unchanged at the end (Oxtoby *et al*, 2003:637-638). A catalyst can either be homogenous, if it is in the same phase as the reactants; or heterogenous, if it is in a different phase from the reactants (Robinson *et al*, 1997:497-498). Both types of catalysts operate by offering a reaction pathway with a lower activation energy (E_A) (Robinson *et al*, 1997:499). For a reversible reaction, the activation energy of both the forward and reverse reactions is lowered in the presence of a catalyst, hence, the catalyst increases the rates of both the forward and the reverse reactions (Robinson *et al*, 1997:499). When the activation energy is decreased in the presence of a catalyst, the number of reactant molecules with energy greater than the activation energy increases. This results in more effective collisions per unit time, thereby, increasing reaction rate. This is shown in the graph of energy distribution in Figure 3.3.

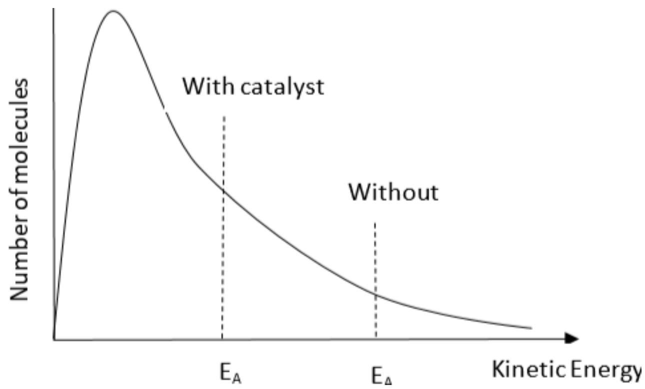


Figure 3.3 The graph showing that when a catalyst is used, the number of molecules with energy greater than E_A increases.

3.7.6 Effect of Surface Area (Particle Size) of a solid reactant on reaction rate

If one of the reactants in a chemical reaction is a solid, then increasing its surface area generally leads to an increase in reaction rate. This is because as surface area is increased more molecules of the reactant are exposed, which increases the collision frequency. When there are more effective collisions per unit time, the rate of reaction increases.

3.7.7 Energy Profile Diagrams

For an elementary reaction, the reactants are not instantly changed to products as energy is required to pass from reactants to products. The system follows a path defined by the energy of the system. The system passes through a maximum which is between the initial state, represented by the reactants, and the final state, represented by the products (Connors, 1990:4). The position of the maximum is called the 'transition state' of the reaction. The term, transition state, also refers to the actual chemical species that exists at this point in the reaction which is also called 'activated complex' (Connors, 1990:4). The activated complex is the molecular species in which old bonds are breaking and new bonds are forming (Mortime r& Mortimer , 2002:21). The difference in energy between the transition state and the initial state represented by the reactants is the activation energy. An elementary reaction is a one-step reaction with a single transition state as shown in Figure 3.4.

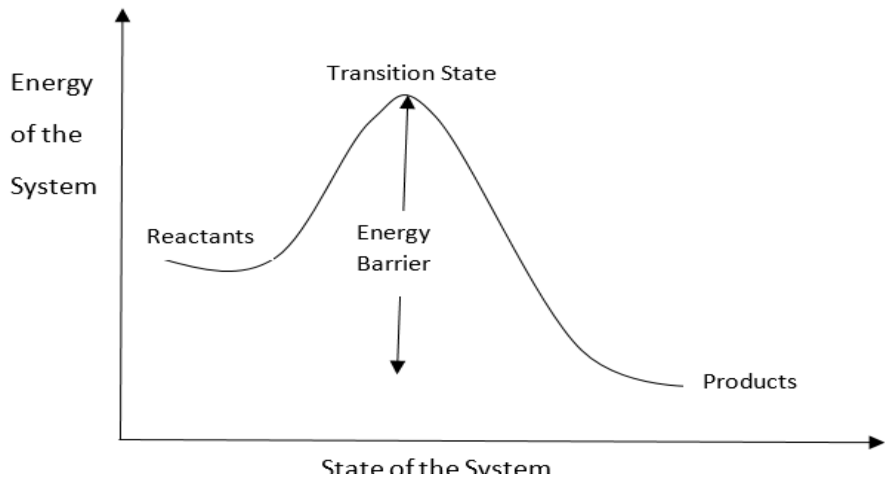


Figure 3.4 Energy of System against State of System for an elementary reaction. Adapted from Connors (1990:3).

Most reactions, however, consist of more than one step as they are a combination of elementary reactions and are known as complex reactions or composite reactions (Connors, 1990:3). For a complex reaction, the species at the minimum of the graph is an unstable intermediate. The intermediate is a product of the first elementary reaction and a reactant of the second elementary reaction (Connors, 1990:4). Complex reactions are beyond the scope of the Physical Sciences curriculum, hence, they will not be discussed further. The next section looks at difficulties encountered by learners in the understanding of these CRR concepts.

3.8 Difficulties and misconceptions of learners in Chemical Reaction Rate

CRR is considered an anchoring concept or one of the “big ideas” in chemistry (Bain & Towns, 2016:246). It is a unifying theme covering the whole of chemistry as it is related to many other concepts such as chemical change; ionic and chemical equilibrium; and chemical thermodynamics (Wright, 2005:2). CRR enables understanding of chemical processes in industrial, medical and environmental fields and in the chemical and pharmaceutical industries (Justi, 2003:293; Wright, 2005:2). Learners, therefore, are expected to perform well in CRR, as it will help them in furthering studies and in any future careers in Chemistry and related fields.

CRR, however, is considered a difficult concept in chemistry both by learners and teachers (Chairam *et al.,* 2015:937, Yan & Subramaniam, 2016:1114, Atabek-Yigit, 2018:746). It consists of abstract and complex concepts and demands understanding at the mathematical and conceptual levels as both quantitative and qualitative concepts are involved; in understanding these concepts, learners should also have good mathematical skills (Yan & Subramaniam, 2016:1114). Also, since this topic is related to many other concepts, it is essential that learners should understand CRR so that they may understand other related chemistry concepts. The learning difficulties in CRR may be due to the nature of chemistry and the three levels of thinking and representation in the subject.

3.8.1 Triplet Representation of Chemical Knowledge as a Source of Learning Difficulties in Chemical Reaction Rate

As mentioned above, thinking in CRR occurs at three levels. These levels are: macroscopic, sub-microscopic and symbolic (Taber, 2013:156). A triangle has been used as a model of this triplet representation of chemical knowledge as shown in Figure 3.5. The macroscopic level is made up of everyday experiences or observable phenomena; the sub-microscopic level includes atoms, molecules, ions and electrons; the symbolic is the representational level consisting of symbols, formulae, equations, molarity, algebraic and computational forms (Johnstone, 2000:11, Treagust, 2013:382). During instruction in CRR, phenomena experienced at the macro level are explained using the sub-micro level and represented by the symbolic level.

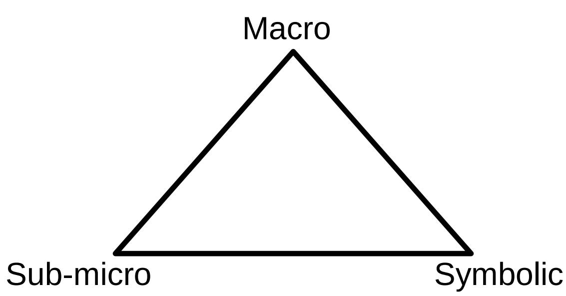


Figure 3.5 The three conceptual levels of chemistry. Adapted from Johnstone, (2006:59).

As stated by Johnstone (2000:11), to understand chemistry, what is observed and experienced at the macro level should be explained at the sub-micro level and recorded using a representational language and notation. This means that what is seen during an experiment when chemicals react is explained in terms of the unobservable at the particulate level in terms of atoms, molecules, and ions. This is the strength of chemistry as it gives the subject its explanatory power, however, it is also its major weakness when learning the subject. While the teacher can manipulate all three levels shifting from one level to another, the learner often finds this difficult to do.

Many difficulties encountered when learning chemistry concepts like CRR are due to the introduction of these concepts, at all levels of chemistry thinking, simultaneously (Johnstone, 2000:11). Chemistry educators, therefore, have suggested that chemistry concepts, such as CRR should be taught at the macro level before attempts to explain them at the sub-micro level (Tsaparlis, 2009:110). Tsaparlis (2009:110) continues that the introduction of the other two levels to learners should be gradual, however, it is noted that most learning of chemistry concepts occurs at the symbolic level.

Learning difficulties and some misconceptions arise when learners switch from the macro to the sub-macro level leading Barke (2015:417) to suggest that misconceptions may be ameliorated by explicitly differentiating the 3 levels of representation. When switching from the macro to the sub-micro level, the teacher may use concrete models such as sphere packing lattice models for giant structures or molecular models for structures. By making use of these concrete models, Barke (2015:417) argues that learners will develop suitable mental models. Use of computer simulations in teaching CRR has the same purpose of making abstract concepts concrete with the added advantage of enabling three-dimensional, dynamic visual representation of chemical phenomena (Justi, 2003:310).

3.8.2 Textbooks as a Source of Learning Difficulties in Chemical Reaction Rate

Textbooks used at secondary school level have been identified as a source of some learning difficulties and misconceptions in CRR (Cakmakci, 2009:31, Gegios *et al.,* 2017:151). Cakmakci (2009:31) found that the learning difficulties emanate from imprecise use of terms, such as ‘reaction rate’ and the mismatch between different forms of representations in textbooks. Furthermore, textbooks fail to explicitly address the relationships between different forms of representations.

In CRR, reaction rate refers to change in reactant concentration per unit time or change in product concentration per unit time. Reaction rate may refer to initial reaction rate, instantaneous reaction rate or average reaction rate. Textbook analysis at school level has shown that no distinction is made among these different conceptions of reaction rate, hence, learners may fail to grasp whether the rate being referred to in a question is the initial, instantaneous or average rate (Cakmakci, 2009:33).

An example of a term not precisely defined in textbooks is the word ‘catalyst’. Some textbooks do not define the term at all, thus, learners fail to understand that a catalyst reacts with one or more of the reactants in homogeneous catalysis. An example of a vague textbook definition of catalyst given by Cakmakci (2009:33) is that “it is a substance that alters reaction rate without entering a reaction”. By the phrase ‘without entering the reaction’ the textbook is attempting to convey the concept that the catalyst is regenerated at the end of the reaction, therefore, the learner may, unfortunately, assume that a catalyst does not react with any of the reactants. This has implications for learners’ understanding of reaction mechanisms. A homogeneous catalyst reacts with one or more of the reactants; this changes the reaction pathway when compared to the uncatalyzed reaction. In so doing, the catalyst changes the reaction mechanism and the alternative reaction pathway will have a lower activation energy.

3.8.3 Misconceptions in Chemical Reaction Rate due to the learning difficulties

Learners in South Africa are required to be able to use the collision theory and the transition state theory to describe reaction rate qualitatively (DBE, 2011), however, problems arise when these two theories are then used to explain every chemical reaction without considering their limitations. The collision and the transition state theories are limited to elementary reactions where two reactants collide to form products (Gegios *et al.*, 2017:155). Each model has its strength as well as weaknesses and so may not have universal application in explaining all chemical reactions. As stated by Gegios *et al.,* (2017:155), the collision model helps to explain why reaction rate is proportional to the reactant concentrations and helps in explaining also the effect of temperature on reaction rate. The transition state model explains the role of activation energy in reaction rate; failing to understand these theories may lead to misconceptions.

Some misconceptions, which may arise from these learning difficulties in CRR, have been identified in the literature. CRR is defined as the change in the concentration of a reactant or product per unit time. Bain and Towns (2016:247) reviewed the literature on teaching and learning CRR the result of the review showed that learners have misconceptions about the concept of the reaction rate. Some of the misconceptions as revealed by the review of literature are - reaction rate is reaction time; reaction rate is time required for reactants to form products; reaction rate is the collision of A and B in a given time; increasing concentration increases reaction time; reaction rate depends on the concentration of both the reactants and products; and increasing surface area of a solid reactant increases the probability of collision and the kinetic energy of the particles (Bain & Towns, 2016:247). Also on the concept of reaction rate some learners think that, as the amounts of reactants increases, the reaction rate also increases (Atabek-Yigit, 2018:752).

Other learning areas of difficulty reported in the literature review, include the effect of temperature on the rate. Generally, increasing temperature leads to an increase in reaction rate for elementary reactions, however, some learners think that when the temperature is increased, the rate of the endothermic reaction increases but the rate of the exothermic reaction decreases (Atabek-Yigit, 2018:752). Other misconceptions on the effect of temperature, as stated by Bain and Towns (2016:247) are - increasing temperature decreases reaction rate; increasing temperature does not affect the rate of endothermic reactions; exothermic reactions occur faster than endothermic reactions; endothermic reactions occur faster than exothermic reactions. In addition, Yan and Subramaniam (2016:1122), state that some learners have a misconception that increasing temperature by 10˚C doubles the reaction rate. They attribute this misconception to textbooks which often state that increasing temperature by 10˚C doubles reaction rate, which is often only true for biological systems.

Literature on misconceptions in CRR also shows that learners confuse concepts in chemical thermodynamics and CRR. For example, if a reaction is reversible and exothermic, learners tend to believe that increasing temperature decreases the rate of the forward reaction and increases the rate of the reverse reaction (Yan & Subramaniam, 2016:1122). To justify this, learners reason that, consistent with Le Chatelier's principle, equilibrium shifts to the left, which is true but is wrongly applied to CRR. Learners need to understand that an increase in temperature increases the rates of both the forward reaction and the reverse reaction for such reactions (Yan & Subramaniam, 2016:1122). The reverse reaction is increased more than the forward reaction which justifies why the equilibrium shifts to the left.

Other misconceptions have been reported on the role of activation energy on reaction rate. It was reported in a review by Bain and Towns (2016:247) that some learners think that increasing temperature increases activation energy; increasing temperature decreases activation energy; and as temperature decreases the activation energy, it enables the reaction to increase its rate.

As discussed in Section 8.3.2, textbooks do not define the term 'catalyst' precisely resulting in learners having difficulties with the concept of catalysis. For example, some learners think that a catalyst does not affect reaction rate; a catalyst can initiate a reaction by lowering its activation energy; and a catalyst increases the activation energy of a reaction (Atabek-Yigit, 2018:752). Some learners have the misconception that reaction rate does not depend on the concentration of a catalyst (Yan & Subramaniam, 2016;1122). This misconception has been attributed to teachers who mention that only a small amount of catalyst is needed to increase reaction rate.

These misconceptions may be ameliorated by instruction that is learner-centred and use simulations which will help learners in visualisation of the processes at the particulate level.

3.9 Literature on improving the teaching of Chemistry concepts and Chemical Reaction Rate

In this section literature on improving the teaching and learning of CRR is reviewed and the identified methods include the use of laboratory-based instruction and use of simulations. These reviews lead to identification of the gap in this literature and the contribution that this study will make.

3.9.1 Laboratory Teaching and other strategies to improve learners' understanding of Chemical Reaction Rate Concepts

Research in science education has shown that instruction within the investigation cycle of generating questions; designing experiments; collecting data; drawing conclusions; and communicating findings has been associated with improved conceptual understanding (Minner *et al*, 2010:493). Some studies have demonstrated that appropriate laboratory activities using the investigation cycle can improve the understanding of CRR concepts. Consistent with this reasoning, Chairam *et al.,* (2015:937) used a case study approach to explore learners' understanding of chemical kinetics, through inquiry-based learning activities. They collected both qualitative and quantitative data and used a pre- and post-test one group design to collect quantitative data. Using independent sample *t*-test, they concluded that inquiry-based activities, substantially, increased learners' understanding of CRR.

Similarly, Demircioğlu and Yadigaroğlu (2011:509) studied the effects of laboratory method on high school learners' understanding of reaction rate. In this study a quasi-experimental design was employed in which the experimental group was taught by the laboratory method while the control group was taught by the traditional approach. The study showed a significant difference in achievement between the control group and the experimental group in favour of the experimental group. In this study learners were provided with the investigative question, the purpose, the materials and the procedure.

Kaya and Geban (2012:216) investigated the effect of conceptual change-oriented instruction through demonstrations on Grade 11 learners' understanding of rate of reaction concepts. Their findings were that learners who were taught through demonstrations had significantly better acquisition of scientific concepts on CRR than those taught by traditional method. In a related study Kurt and Ayas (2012:979) investigated the effects of activities developed based on a four-step constructivist approach to test learners' understanding and explaining of real-life problems about reaction rate concepts in chemistry. They concluded that the constructivist approach helped learners more in explaining real-life problems than the traditional approach. They claimed that CRR concepts have not been comprehensively investigated by researchers, hence, there is need for more research on CRR.

With the same aim, Yan and Subramaniam (2016:25), conducted a study to diagnose learners' misconceptions in CRR, using conventional teaching which included lectures and tutorials. The diagnostic test was administered after a topic was taught through conventional methods. The mean score was only 22%. This score was so low that they concluded that the conventional method had not managed to address learning difficulties in CRR concepts.

Kırık and Boz (2012:151) investigated the effect of Cased-Based Instruction on learners' alternative conceptions in CRR in Turkey. Their sample was 53 high school learners selected using convenience sampling. They used a non-equivalent pre-test/post-test control group design and Reaction Rate Concept Test and structured interviews to collect data; the data were analysed using the independent *t*-test. The data analysis showed that learners instructed with Cased-Based Instruction had better understanding of core concepts of CRR when compared to the control group. The experimental group had fewer misconceptions on CRR, hence, they concluded that Case-Based Instruction is an effective teaching method for challenging learners' misconceptions in the topic of CRR.

The above studies show that the laboratory method, if properly designed, may lead to conceptual understanding in the topic of CRR. It may be because the method makes abstract concept more concrete thereby aiding in conceptual understanding. Computer simulations may, thus, also be used to make abstract concepts concrete.

3.9.2 Use of Computer Simulations in teaching Chemistry Concepts

Most concepts in Physical Sciences are complex and abstract. Not surprisingly most researchers have turned to computer simulations to make these abstract concepts concrete. In most of these studies, the aim was to improve conceptual understanding. The same may be said about the concepts in CRR.

Al-Mashaqbeh (2014:1), for example, investigated the effect of computer simulation instruction on Grade 11 learners' achievements. The focus was carrying out chemical experiments to acquire chemical concepts. The study was quasi-experimental with a control group. The experimental group had 17 learners and was taught with computer simulation instruction while the control group had 17 learners but was taught using the traditional approach. The experimental group performed better than the control group in carrying out chemical experiments to acquire chemical concepts, hence, virtual experiments through simulations have the potential to assist learners in conceptual understanding in chemistry.

Similarly, Akpınar (2014:527) investigated the effects of using interactive computer animations based on Predict-Observe-Explain (POE). This study was done with primary school learners on the topic of 'static electricity'. A quasi-experimental pre-test/post-test control group design was used. The experimental group had 30 learners and the control group had 27 learners. The experimental group was taught using dynamic and interactive animations based on POE while the control group was taught through normal instruction. The data collection instrument used was a static electricity concept test and open-ended questions. It was reported that interactive animations were more effective on learners' understanding of static electricity concepts compared to normal instruction.

3.9.3 Literature on use of Computer Simulations to teach Chemical Reaction Rate

CSBI makes use of virtual laboratory experiments to enable learners to investigate reaction rates. Some researchers who have used the investigation cycle in laboratory activities have shown that it improves conceptual understanding. Since this study makes use of virtual laboratory activities to enable learners to carry out scientific investigations in CRR, it is hoped that this approach would lead to an improvement in learners' performance.

Some studies have also used different approaches in teaching CRR using computer simulations. In Nigeria, for example, Olakanmi (2015:630) used 'an activity' that supported learners to connect the micro, sub-micro and symbolic representations to help them to gain conceptual understanding of rate of reaction. In this study an experimental pre-test/post-test control group design was used and the research instruments were: a Rate of Reaction Knowledge Test, a Chemical Attitude Scale, and a Class Activity on Rate of Reaction. These instruments were developed for the research and the qualitative data were collected through observations and interviews. The results showed that learning using web-based computer simulations improved the academic performance scores of the experimental group when compared to the scores of the control group taught using the traditional teacher-talk-and-chalk approach. In addition, it was reported that the learners in the experimental group taught using the simulations had higher motivation to learn chemistry, compared to the control group.

Similarly, in Uganda, Odongo (2013:260) studied the effect of computer-plus-talk teaching sequence to enhance learners' understanding of chemical reaction rate concepts. A total of 247 learners participated in that study. The research was a quasi-experimental study in which the experimental group was taught using the computer-plus-talk while the experimental group received 'normal' teaching. The results of post-test scores showed that the experimental group demonstrated better understanding of reaction rate concepts.

3.9.4 Summary on Studies on improving Teaching of Chemical Reaction Rate

Most of the studies reviewed above focussed on using the laboratory to improve understanding of reaction rates, while, very few studies made use of computer simulations to improve understanding of CRR. Odongo (2013:260) focussed on effect of computer-plus-talk on learners' understanding of reaction rate. Olakanmi (2015:630) studied the effect of a web-based computer simulation on learners' conceptual understanding to enhance their understanding of reaction rate, focussing on an understanding of the connections of the different representations in Chemistry.

There are a few studies that have used simulations in attempting to improve learners' understanding of CRR concepts (Odongo, 2013, Olakanmi, 2015), however, the approach used in these studies differs from the present study. This study is unique in that it made use of cognitive theory as the lens through which the study is done. This has significant implications on the way the simulations were incorporated in the teaching of CRR. Virtually no studies that I am aware of investigated the effect of simulations supported with POE to improve learners' understanding of CRR. This is the gap that the present study attempts to fill. Research has shown that when laboratory investigations are accompanied by POE instructional practices, the investigations are more likely to increase conceptual understanding, hence, this study focused on the effect of computer simulations, accompanied by POE, on learners' performance in CCR. Bain and Towns (2016:259) reviewed the literature on the teaching and learning of chemical reaction rates and concluded that research on learners' alternative conceptions on CRR has been exhausted. In their opinion, more research is rather required to find out which approaches are effective in teaching and learning of CRR. Such approaches should lead to an improvement in the learners' attitudes and interest in learning CRR, if they are to be effective, hence, the next section reviews the literature on attitudes and interest of learners towards chemistry.

3.10 Attitudes of Learners towards Chemistry Lessons taught through Computer Simulation-Based Instruction

Apparently referring to motivation, Reyes *et al.,* (2014:84) write:

> *"it is the supreme art of the science teacher to awaken a child's curiosity and enkindle the eagerness to explore, to search for knowledge, truth and harmony."*

Mubeen and Reid (2014:129) describe motivation as an inner force that activates and provides direction to thoughts, feelings and actions; it is characterized by goal-directed behaviour and persistence. They identify attitudes as the most influential factor that affects motivation, thus, a positive attitude enables one to have the motivation to perform a task well.

Development of positive attitudes towards Chemistry in learners is one of the important outcomes of Chemistry teaching, just as academic achievement (Cheung, 2007). It is important to understand learners' attitudes towards CSBI as attitude is linked with academic achievement. Numerous researches have shown that there is a direct relationship between attitude and achievement, although researchers are reluctant to claim a cause-and-effect relationship between them (Simonson & Maushak, 1996:987).

Hofstein and Mamlok-Naaman (2011:91) claim that learners who are interested in science and understand scientific concepts will have more positive attitudes towards science compared to those with learning difficulties in science.

While it is unclear how attitudes and achievement are related, it is logical that learners are more likely to remember information, seek new ideas and continue studying when they react favourably to an instructional strategy, such as CSBI (Simonson & Maushak, 1996:987). Learners who like CSBI are more likely to stay after class to find more information about experiments and to read about CRR. Simply put, learners tend to do what they like and not what they do not like (Simonson & Maushak, 1996:987).

Learners' attitude towards CSBI serves to inform teachers about the impact of CSBI on the learning process in CRR. Attitudes should be measured to find out if CSBI had any effect on them and if so, what kind of affect it is. The reason for this is to evaluate this intervention and improve the quality of instruction. If CSBI can promote positive attitudes in learners then it can contribute to a healthy, positive learning environment. The other reason for determining attitudes of learners towards learning CRR by CSBI is that it has been shown that, based on attitudes, it is possible to predict the behaviour of learners; for example, choice of school subjects and future careers (Simonson & Maushak, 1996:993).

Given the importance of learners' attitudes towards science, it is not surprising that many researches have been done in this regard. It is, therefore, important to understand what the concept 'attitude' means. Eagly and Chaiken (1993:7) define an attitude as "a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour". Consistent with the multicomponent model, attitudes are defined as the overall evaluation of stimuli that are derived from the favourability of an individual's affects, cognitions, and past behaviours (Huskinson & Haddock, 2006:453). Affect-based attitudes refer to feelings an individual associate with an attitude object; cognitive-based attitudes refer to beliefs or knowledge about an attitude object, while behaviour-based attitudes refer to past behaviours or behavioural intentions relevant to an attitude object (Huskinson & Haddock, 2006:453). In the context of this study, attitude object refers to chemistry lessons on CRR taught using CSBI. It is, therefore, appropriate to look at other studies that investigated learners' attitudes towards simulations in learning chemistry.

3.10.1 Studies on Learners' Attitudes towards Simulations in Chemistry Lessons

Tüysüz (2010:37) studied the effect of the virtual laboratory on learner's achievement and attitude in chemistry, focusing on the topic "Separation of Matter". The participants were 341 Grade 9 learners. The study was quasi-experimental with pre- and post-test and a Chemistry Attitude Scale was used to measure learners' attitudes towards chemistry before and after instruction. Pre-test scores were not significantly different before instruction for both the Experimental Group (EG) and the Control Group (CG) ($p=.632$, $p>.05$). After instruction, the post scores were found to be significantly different ($p=.01$, $p<.05$). EG post-test mean scores were higher than those of CG (EG=103.64; CG=75.65). It was concluded that the simulations improved learners' motivation towards chemistry lessons.

In a similar study, Ozmen (2008:423) investigated the influence of Computer-Assisted Instruction on learners' understanding of chemical bonding and attitudes towards chemistry. The study sample consisted of fifty Grade Eleven learners randomly assigned to the EG and CG. The experimental group was taught using computer-assisted teaching approach while the control group was taught using traditional teaching methods and the learners' attitudes toward chemistry, were determined from the Chemistry Attitude Scale. Pre-test results showed no statistically significant differences between EG and CG (t = 0.55; $p>.05$) which means that the groups were similar before instruction. The post-test scores showed a statistically significant difference between the EG and CG in favour of the EG in their attitudes (t = 5.696; p = .001). It was concluded that the differences in attitudes were due to the fact that learners enjoy lessons when Computer Assisted Instruction was used.

Pyatt and Sims (2012:133) investigated attitudes and performance of first-year secondary chemistry learners in virtual and physical experimentation, in inquiry-based science laboratory. Learners' attitudes towards virtual experiences were measured using a Virtual and Physical Experimentation Questionnaire, the researchers had developed for the study. Factor analysis was conducted for the questionnaire data and its reliability was calculated; the results showed that the questionnaire was valid and reliable. Pyatt and Sims (2012:133) reported that learners showed positive attitudes towards physical and virtual experiences. These studies show that an instructional approach may influence learners' attitudes and interest in learning chemistry, hence it is possible that teaching CRR, using CSBI, may lead to an improvement in interest and attitudes of learners towards the chemistry lessons taught by CSBI. By investigating learners' attitudes, this study aims to find that out.

3.11 Summary on Review of Literature on Teaching Reaction Rates using Simulations

This review of the literature has shown that learners have difficulties in understanding reaction rate concepts. Various researchers have contributed to an understanding of why learners face these difficulties and have contributed to instructional strategies that make it better for learners to understand CRR concepts. Such strategies, like the use of the laboratory in teaching CRR concepts and using simulations have been shown to be effective. These methods have also been shown to lead to an improvement in learners' attitudes and interest in learning. The present work was designed to contribute to an ever-increasing understanding of how the use of computer simulations may help learners in alleviating learning difficulties. In the next Chapter, the research paradigm, design and methodology of the study are presented.

Chapter 4 Research Paradigm, Design and Methodology

4.1 Introduction

The purpose of this study was to examine the effects of Computer Simulation-Based Instruction (CSBI) on the academic achievement of learners in the topic CRR. To achieve this purpose, this Chapter provides the paradigmatic foundations of the study, the paradigm adopted for the study, the research design and the methodology. From the paradigm, the appropriate research design is identified and presented, followed by a detailed description of the methodology and methods followed in the study.

4.2 Paradigmatic Foundations of the Study

Guba (1990:17) explains a paradigm as a basic set of beliefs that guide action. Dills and Romiszowski (1997:10) concur as they state that paradigms consist of the collective beliefs of a community of practitioners on the metaphysical, ethical, epistemological and axiomatic assumptions in their field. Furthermore, they observe that paradigms determine the type of research questions to be asked and the methodologies used in answering them. A paradigm, thus, indicates the philosophical orientation of the researcher. It is the researcher's beliefs about the nature of knowledge, reality and theoretical underpinnings of the methodology employed in answering the research questions.

Guba and Lincoln (1994:104) identify three components of a paradigm - ontology, epistemology and methodology. Ontology is concerned with what constitutes reality, in other words, *"what is"* while epistemology is concerned with how knowledge can be created, acquired and communicated, or what it means to know (Scotland, 2012:9). A research methodology is the strategy used for answering research questions; it is the overall strategy outlining the general way research aims will be achieved including, methods of data collection and analysis informed by a theoretical perspective (Taber, 2017).

The paradigmatic assumptions in this study are largely influenced by three worldviews - positivism, post-positivism and constructivism. They are discussed in the following sections. After that discussion, the paradigmatic assumptions of the study are presented.

4.2.1 Positivism and Post-positivism

Positivism was the major paradigm in the social sciences from the 1930s to the 1960s (Gray, 2013:21). It is based on the rationalist, empiricist philosophy that originated with Aristotle, Bacon, Locke, Compte and Kant (Mertens, 2014:10). Positivism postulates that social reality exists external to the researcher and must be investigated through rigorous process of scientific enquiry (Gray, 2013:20). Positivists were of the view that since objective reality exists independent of the researcher, social reality could be investigated in the same way as in natural sciences, hence, they valued objectivity, measurability, predictability, controllability, patterning, the construction of laws and rules of behaviour, and the ascription of causality (Cohen *et al.,* 2007:26). In line with these values, emphasis was placed on experimentation and measurement of observation of social phenomena to discover general laws to describe relationships between variables (Mertens, 2014:11). Positivists, hence, aimed to discover objective laws and rules which could be agreed upon by all people and which could be used to govern human behaviour.

The features of positivism described above are discussed in this study because positivism was the foundation of its successor, post-positivism. This is the basis for detailing positivism as a foreground of post-positivism, for the study. Positivism has been criticized for regarding human behaviour as passive, essentially determined and controlled, thereby, ignoring intention, individualism and freedom (Cohen *et al*., 2007:18). Mertens (2014:12) concurs as he observes that in studying human experiences, there is much that cannot be observed, like feelings and thinking. Furthermore, positivism neglects hermeneutic, aesthetic, critical, moral, creative and other forms of knowledge thereby reducing human behaviour to technicism (Cohen *et al.,* 2007:18). The criticism of positivism, therefore, led to the rise of post-positivism.

In terms of ontology, post-positivists agree with positivists that an objective reality exists, however, unlike positivists they assume that all observations are inherently fallible and the "truth" can never be explained perfectly and completely (Gray, 2013:22). Post-positivists, hence, depend on probabilities and not certainties to describe findings. Guba and Lincoln (1994:105) posit that the ontology of post-positivism is critical realism as proponents of post-positivism argue that *"claims about reality must be subjected to the* *widest possible critical examination to facilitate apprehending reality as close as possible but never perfectly",* thereby, post-positivists make no claim to absolute truth (Guba & Lincoln, 1994:105).

In their epistemology, post-positivists hold a deterministic philosophy and study problems where there is need to identify and assess the causes that probably influence outcomes, such as in experiments (Creswell, 2009:7). Objectivity is valued as a state that strives to reduce bias as far as possible. Furthermore, the philosophy is described as reductionist and deductive as researchers begin with a theory, collect data that supports or does not support the theory, then necessary revisions may be done (Creswell, 2009:7). Replicated findings are considered probably true but are always subject to falsification (Guba & Lincoln, 1994:110).

In terms of methodology, post-positivists seek to understand causal relationships, hence, experimentation and correlational studies are used (Scotland, 2012:10). Guba and Lincoln (1994:110) describe the methodology of post-positivism as modified experimental or manipulative and they say it emphasizes critical multiplism as a way of falsifying, rather than verifying hypothesis, however, participants' perspectives, or emic viewpoints are often sought (Guba & Lincoln, 1994:110, Scotland, 2012:10). Furthermore, as knowledge is tentative, hypotheses are not proved but simply not rejected (Creswell, 2009:7). The scientific paradigm seeks predictions and generalizations; thus, methods often generate quantitative data and analysis involves descriptive and inferential statistics (Scotland, 2012:10). The methodology that emanates from this paradigm is quantitative in nature.

4.2.2 Constructivism/Interpretivism

From the foregoing discussion, it can be deduced that positivists regard social sciences and natural sciences as the same, hence, they focus on discovering natural and universal laws that regulate and determine social and individual behaviour (Cohen *et al.,* 2007:7). Taking a contrary position, constructivism (interpretivism) seeks to describe and explain human behaviour by emphasizing how people differ from inanimate natural phenomena, and from each other (Cohen *et al.,* 2007:7).

The basic tenet of constructivism, as a paradigm, is that knowledge is socially constructed hence, researchers should attempt to understand the complex world of lived experiences. In line with this notion, the ontology of constructivism regard reality as socially-constructed; that it is possible to have multiple mental constructions in conflict with each other and reality may change throughout the research process (Mertens, 2014:18). Constructivists reject the positivists' position that there is an objective reality, thus, the goal of research is to understand multiple social constructions of meaning and knowledge (Mertens, 2014:18). The epistemology of constructivism assumes that knowledge is value-laden, flexible, descriptive, holistic, and context-sensitive and it relies on an in-depth description from the perspectives of the people involved, resulting in thick descriptions of social phenomena (Yilmaz, 2013:312).

Constructivism (interpretivism/naturalistic enquiry) rejects the belief that human behaviour is governed by general, universal laws characterized by underlying regularities. Rather, constructivists believe that the social world can be understood only from the standpoint of the individuals who are part of the ongoing action being researched (Cohen *et al.,* 2007:19). Reality, hence, knowledge, is subjective.

Constructivism is supported by qualitative research. Yilmaz (2013:312) elucidates a qualitative research as an emergent, inductive, interpretive and naturalistic approach to the study of people, cases, phenomena and social situations. He further points out that qualitative research is carried out in the participants' natural settings to reveal, in descriptive terms, the meanings that they attach to their experiences of the world. The methodology of this paradigm is based on diverse forms of strategies such as descriptive study, case study, field research, ethnography, participant observation, biographical method, life history, oral history, narrative inquiry to phenomenological research, ethno-methodology, symbolic interactionist study, grounded theory and action research (Yilmaz, 2013:312). From the foregoing descriptions, positivism and constructivism lie at opposite poles of the continuum of research paradigms.

4.2.3 Pragmatism

Pragmatism asserts that there is a single "real world" and all individuals have their own unique interpretation of that world (Mertens, 2014:37). This means that pragmatists see no antagonism in the adoption and use of ideas of reality from post-positivism and constructivism.

Pragmatists regard quantitative and qualitative methods as compatible, hence, they can be used together in a single research study (Tashakkori *et al.,* 1998:12). In support of this, Johnson and Onwuegbuzie (2004:16) assert that research approaches should be mixed in ways that offer the best opportunities for answering important research questions. Furthermore, since pragmatists in their epistemology consider truth to be "what works" at the time of inquiry, they use multiple methods, different worldviews and different forms of data collection and analysis to provide the best understanding of a research problem (Creswell, 2009:11). The present study, hence, adopted pragmatism as the philosophical base guiding the research.

4.2.4 Paradigmatic Assumptions Adopted for the Study

As indicated above, pragmatism was the research paradigm guiding the research, hence, it can be assumed, the researcher accepts that reality exists "out there" and that there are multiple realities arising from subjective interpretations of social phenomena by individuals. In pragmatism, the researcher is guided by the research questions to decide the methodology that can best be used to answer these questions. In other words, "what works" is what guided the research, hence, the methodology of experimentation advocated by post-positivists was considered appropriate to answer Research Question 1 (RQ1) and Research Question 2 (RQ2). Experimentation is largely advocated by post-positivists, although, pragmatists accept the use of the approach if it is the best one in answering the research questions. A quasi-experiment was carried out in this study due to practical concerns when carrying out social research. Research Question 3 (RQ3) sought to explore the conceptual understanding of CRR by the learners taught through the traditional approach and those through CSBI, hence, the qualitative methodology, based on constructivism, was considered appropriate. This is accepted by pragmatists, who consider that individuals have their own subjective interpretation of social realties which can have multiple interpretations, therefore, the appropriate methodology for this study was the mixed-methods approach.

4.3 Research Design and Methodology

This section introduces the mixed-method approach adopted in the study.

4.3.1 Research Design: Mixed-Method Approach

As already mentioned, this study, informed by the pragmatic paradigm, was a mixed-method research. The study, firstly, sought to investigate a cause-and-effect relationship between instructional method, academic achievement and attitudes. Secondly, it sought to describe how the instructional method influenced the conceptual understanding of the learners of the topic CRR. The first part of the research was quantitative and the second part was qualitative. Johnson and Onwuegbuzie (2004:17) define a mixed-method research as:

> *"a class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts and language in a single study".*

The study used a mixed-method approach for several reasons. Firstly, Research Questions 1 and 2 (RQ1 and RQ2) sought to find cause-and-effect relationships between instructional approach and the learners' academic achievement and attitudes. Hence RQ1 and RQ2 are best addressed by the quantitative research method. RQ3 sought an in-depth investigation of the conceptual understanding of CRR of the participants taught through CSBI and through the traditional method, hence, the qualitative approach, involving interviewing participants, was used to answer RQ3.

Secondly, mixed-method approach was used because the quantitative and qualitative methods enabled me to take advantage of the strengths of both approaches, since each approach when used alone has limitations. This method provided a complete and better understanding of the research problem than would if either of the approaches was used alone (Creswell, 2017:8). This approach also enabled me to generalise to a larger population and to develop a comprehensive view of the learners' perception of CSBI.

Thirdly, the mixed methods enabled me to obtain quantitative data from a sample followed by qualitative data from a few partcipants to assist me in explaining the quantitative results in more depth (Creswell, 2009:121). The specific mixed-method design used in this research is the sequential explanatory design in which the quantitative data collected in the first phase was explained by in-depth exploration of the participants' views in the second phase - the qualitative research.

4.3.1.1 The Sequential Explanatory Design

In the sequential explanatory design, the collection and analysis of quantitative data was followed by the collection and analysis of qualitative data (Creswell *et al*, 2003:178). The purpose of the sequential explanatory design was to use the qualitative results to assist in explaining and interpreting the findings of the quantitative study (Creswell *et al*, 2003:178). In this study priority was given to the quantitative data; the two methods were integrated during the interpretation phase.

The sequential explanatory design is represented in Figure 4.1 (Creswell *et al*, 2003:180).

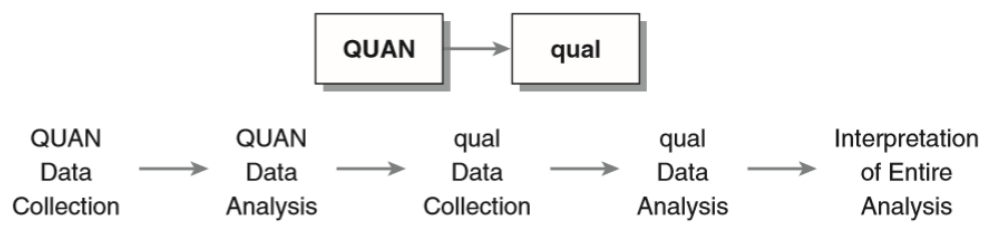


Figure 4.1The Sequential Explanatory Design

The arrow (→) shows that one form of data collection followed another; uppercase letters (QUAN) shows that the major emphasis in this study was on the quantitative form of data collection, and lowercase letters (qual) implies that less emphasis was given to the qualitative data collection (Creswell *et al*, 2003:180).

4.3.1.2 The Quantitative Phase

Creswell (2014:33) defines a quantitative research as:

> *"an approach for testing objective theories by examining relationships among variables. These variables, in turn, can be measured typically on an instrument, so that numbered data can be analyzed using statistical procedures."*

The quantitative phase aimed to investigate if a relationship existed between a teaching method, such as CSBI or traditional approach, and academic achievement/attitudes; and if it existed, the research targeted to establish the strength of the relationship. In other words, the quantitative phase investigated the cause-and-effect relationship with the intention of generalising from the sample to the population.

The quantitative phase of this research adopted a quasi-experimental methodology which used a Non-equivalent Control Group Design (NCGD) with a pre-test and post-test. The purpose was to collect data for answering the first and second research questions (RQ1 and RQ2) to find the effects of CSBI and traditional approach on the learners' academic achievement and attitudes. The independent variable was the method of instruction which was either the CSBI or the traditional method. The dependent variables were the learners' academic achievement as measured by scores obtained from the TCRRC and learners' attitudes as measured by the ATCLS.

The NCGD with a pre-test and post-test is represented as:

Experimental Group (EG):	NR	O	X	O
Control Group (CG):	NR	O		O

Figure 4.2 Non-equivalent Control Group Design (Cohen et al., 2007:283).

In this design NR represents Non-Randomization, O represents pre-test and post-test, X represents the treatment implemented (Cohen *et al.,* 2007:283).

4.3.1.3 The Qualitative Phase

A qualitative research is defined as research concerned with meanings that participants attribute to events which seek to describe and possibly explain events from the perspective of the participants (Willig, 2013:9). The qualitative phase of this research, carried out after the quantitative phase, sought an in-depth comprehension of the conceptual understanding of CRR by the participants and their views of CSBI.

The qualitative phase of the study collected data that were used to explain and interpret the quantitative results obtained in the first phase of the study (Creswell, 2009:211). The qualitative phase sought to answer RQ3 which was aimed at finding out if CSBI improves learners' conceptual understanding of CRR. The qualitative data was collected through semi-structured interviews.

4.3.2 Methodology: Data Collection Tools

This section is concerned with the description of data collection, the tools used and the pilot study implemented before the main study. There is a discussion on the collection of quantitative and qualitative data, the sampling procedure, measures of quality control as well as procedures for ensuring the validity, reliability and trustworthiness of the data collection instruments.

In this section, the data collection tools - Test on Chemical Reaction Rate Concepts (TCRRC) (Appendix 7), Attitude Towards Chemistry Lessons Scale (ATCLS) (Appendix 8), Interview Schedule for Learners (Appendix 10) and Interview Schedule for teachers (Appendix 9), are outlined. The TCRRC is the first data collection tool to be presented.

4.3.2.1 Data Collection Tools: Test on Chemical Reaction Rate Concepts

The TCRRC (Appendix 7) is a two-tier multiple-choice test with thirty items selected and developed from literature and from the National Senior Certificate (NSC) examinations. The ATCLS (Appendix 8) is an instrument that was developed by modifying an instrument that was used by other researchers. The following section describes the development of TCRRC and interview schedules.

4.3.2.1.1 Justification for using a two-tier multiple-choice test and interviews as data collection tools

A variety of research tools have been used by researchers in chemistry education to measure learners' conceptions to assess the effectiveness of instructional interventions. Among these tools are interviews, open-ended questions and multiple-choice tests (Gurel et al., 2015:991). The first two are qualitative and have the advantage of providing in-depth data resulting in a detailed description of the learner's thoughts. As stated by Gurel *et al.,* (2015:992) interviews are one of the best ways of obtaining a learner's view, however, interviews have been criticized for being time-consuming and hence may not be suitable for use in large classes (Chandrasegaran *et al.,* 2007:295).

The challenges of interviewing as a data collection strategy include: they need special training of the researchers to perform the interviews skilfully; they may result in interviewer bias which may taint the findings and they are associated with difficulties in data analysis and generalizability of the findings (Gurel *et al.,* 2015:992). Being aware of these challenges, steps were taken to mitigate them as described during the implementation phase and during data analysis. Since the present study is a mixed method research, both interviews and multiple choice questions were suitable for data collection. The interviews were used to gain an in-depth understanding of the conceptions of the learners on CRR after the implementation of the treatment as well as their views about CBSI and attitudes towards its use in instruction. This enabled me to present a detailed description of the learners' thoughts on CRR in the analysis and interpretation of results. The results of the interviews were also used to explain the findings in the quantitative phase of the study.

Multiple choice questions were also used in data collection. The advantages of using multiple choice include that they can be immediately scored and so can be applied to many learners in large classes. Furthermore, they can be used to measure different levels of learning and cognitive skills; they are objective in terms of scoring and are therefore more reliable; they are suitable for item analysis and they provide valuable diagnostic information (Gurel *et al.,* 2015:993). These are some of the considerations that led to the use of multiple-choice questions in the study.

One serious criticism of multiple-choice tests is that they do not provide enough insight into learners' thinking as it has been noted that learners may give correct answers for the wrong reasons. Multiple choice tests cannot differentiate correct answers due to correct reasoning from those that are due to incorrect reasoning (Gurel *et al.,* 2015:994). In other words, a learner may get the correct answer by simply guessing. Two-tier multiple-choice tests were developed to overcome some of these limitations of multiple-choice tests. The interviews during the qualitative phase of the study also aimed at mitigating the limitations of the multiple-choice test. Some of the interview questions included some from the TCRRC (Appendix 7). In the interviews, learners were asked to explain how they obtained their answers.

To differentiate correct responses by guessing and correct responses due to conceptual understanding, each multiple-choice test item consisted of two tiers. The first tier was a content multiple-choice question. The second tier measured the learner's confidence in his/her response, thereby, the learner had to choose from the following: *very unconfident*, *unconfident*, *confident* or *very confident*. To be considered correct the learners had to get the first tie correct and the second tie had to be either *confident* or *very confident*. Otherwise a correct response to the first tie but a rating of *very unconfident* or *unconfident*, meant that the learner was guessing and so was not considered correct. The two-tier TCRRC was used in this study as it helps to reduce guesswork, enables large-scale administration, can be objectively scored and offers insight into the learner's reasoning (Gurel *et al.,* 2015:995). The section that follows describes how the TCRRC (Appendix 7) was developed.

4.3.2.1.2 Procedure for Construction and Development of Test of Chemical Reaction Rate Concepts

Mutlu and Sesen (2015:630) suggest three phases in the development of a diagnostic test - 1) defining the content area; 2) determination of learners' alternative conceptions in reaction rate and 3) development and validation of the instrument.

- ***Phase 1: Defining the Content Area***

The content area and boundaries were determined from the Curriculum and Policy Statement (CAPS) document which is used to guide teaching and learning of Physical Sciences in South Africa (DBE, 2011:123). On the topic, CRR learners are expected to be able to: explain what is meant by reaction rate; list the factors which affect the rates of chemical reactions; explain in terms of the collision theory how the various factors affect the rate of chemical reactions; suggest suitable techniques for measuring the rate of a given reaction; define activation energy; use a graph showing the distribution of molecular energies to explain why only some molecules have enough energy to react and hence how adding a catalyst and heating the reactants affects the rate and explain how some catalysts function by reacting with the reactants in such a way that the reaction follows an alternative path of lower activation energy (DBE, 2011).

This is the content area used to demarcate the boundaries of the TCRRC (Appendix 7), therefore, all the questions were based on these concepts.

- ***Phase 2: Determination of learners' alternative conceptions***

After defining the content area, a review of literature was carried out to determine the known misconceptions in CRR. Test items chosen from different sources were selected on the basis that they contained distracters with these misconceptions. Since I could not find a single suitable research instrument suitable for the study, questions had to be adapted from a variety of sources. Ordinary multiple-choice questions suitable for this research were found from the South African NSC examination in Physical Sciences. Another source of suitable multiple-choice questions was the Alternative Conception Test in Chemical Kinetics (Ahiakwo & Isiguzo, 2015:117). I found three, two-tier multiple-choice questions suitable for the present study from the research by Supasorn and Promarak (2015:125) on enhancing conceptual understanding of chemical reaction rate. The distracters for the first tier were developed from the alternative conceptions identified in literature (Mutlu & Sesen, 2015:189).

- ***Phase 3: Development of Test of Chemical Reaction Rate Concepts (TCRRC)***

In Phase 3, the two-tier TCRRC (Appendix 7) was developed. The first tier consisted of ordinary multiple-choice questions selected from the South African final Grade 12 Physical Sciences Examinations, the ACT (Ahiakwo & Isiguzo, 2015:112) and from Supasorn and Promarak (2015:125). The second tier was the confidence rating. After these three phases, the TCRRC (Appendix 7) was ready for the next phase, which is content validation.

4.3.2.2 Data Collection Tools: Attitude Towards Chemistry Lessons Scale (ATCLS)

The original ATCLS was developed by Cheung (2011:1). The original scale had 20 items with four dimensions developed by considering psychological theories on attitudes. Initially it was administered to 777 chemistry learners and from that initial pilot, the scale was reduced to 12 items. It was then applied to a sample of 954 chemistry learners in 6 secondary schools in Hong Kong. The Cronbach's alpha showed that the scale had internal consistency and therefore, was reliable. Confirmatory factor analysis using

LISREL programme showed that the ATCLS had 4 dimensions as hypothesized. This scale was adapted for use in this study (Appendix 8). The dimension of *Liking Chemistry Laboratory Work* was changed to read - *Liking Chemistry Virtual Laboratory Work*. Except for that dimension, the scale was used for this study in its original form (Appendix 8).

4.3.2.3 Data Collection Tools: Interview Schedules for Learners and the teacher

The Interview Schedule for Learners (Appendix 10) was developed to collect data to obtain an in-depth understanding of the thoughts of learners in CRR concepts after treatment. The data would complement and clarify the results from the quantitative phase. Some questions were taken from the Test of Chemical Reaction Rates Concepts TCRRC (Appendix 7) and a few others were added. Seeking the same information and using two different research methods help in triangulation in the mixed-method research (Creswell, 1999:458). Triangulation was another reason for asking the same questions in the Test of Chemical Reaction Rates Concepts (TCRRC) with the learners during the interviews. In addition, the interview schedule also asked questions to find out if CSBI clarified the conceptual questions asked. The Interview Schedule for the Teacher (Appendix 9) was meant to collect the views of the teacher on aspects of CSBI and sought to find out if these different aspects were helpful.

4.3.3 Pilot Study

A pilot study was carried out before the main study to validate CSBI and to improve the data collection tools; two schools that were in a different circuit were chosen to participate in the pilot study. The pre-test was administered by ensuring that both the Experimental Group (EG) and Control Group (CG) sat for the test at the same time and for a period of one hour. Participants in both the EG and the CG indicated that they had no problems with understanding the vocabulary of the research instruments. During the implementation of the Computer Simulation-Based Instruction (CSBI) in the EG, one expert teacher was requested to observe while I taught. At the end of each lesson we discussed the lesson. Areas that needed improvement were noted and adjustments to the Lesson Plans (Appendices 28-31) were made. It was realized that if the virtual experiments were carried out in small groups the time needed was about twice the time required to teach the Control Group (CG). To prevent this problem the virtual experiments in the Experimental Group (EG) were conducted as a demonstration for the entire class but group discussions were only done for tasks that did not involve the experiments. Using this approach CSBI was implemented in four lessons. Each lesson was one hour long. After the post-test, two participants from the EG were interviewed using the interview schedule for learners. A few adjustments, such as addition of questions that probed participants on how Computer Simulation-Based Instruction helped them in conceptual understanding were made to the schedule. It was agreed at the end of the implementation that CSBI was valid. The main study was implemented after the pilot study.

4.3.4 Quantitative Data Collection: Main Study

Quantitative data was collected through pre-test, treatment, followed by post-test.

4.3.4.1 Pre-test

TRRC (Appendix 7) and the ATCLS (Appendix 8) were administered as a pre-test two weeks before interaction with both the CG and the EG. The TCRRC is a two-tie multiple-choice test covering all the concepts in CRR, at all the cognitive levels which I developed using information from literature and the Grade 12 final examinations on CRR. This pre-test was administered two weeks before the treatment to allow time to reduce test-recognition at the post-test stage. The purpose of the pre-test was to determine the learners' prior knowledge and to establish whether the EG was like the CG. The TCRRC was administered to both groups on the same day at the same time. The learners sat for the test for one hour. All question papers were collected at the end of the test in both groups to avoid contamination of results in the post-test. Learners completed the Attitudes Towards Chemistry Lessons Scale (ATCLS) immediately after completing the TCRRC (Appendices 7 & 8).

4.3.4.2 Teaching in the Experimental Group

The EG was taught by me using Computer Simulation Based Instruction (CSBI) (Appendix 27). Animations, visualizations and interactive virtual laboratory experiences were selected from simulations on CRR that are freely available on the internet. The reason for this is that the simulations should be readily available to other researchers and teachers. In selecting the simulations, I followed the principles used to reduce cognitive overload, guided by the Cognitive Theory for Computer Simulation-Based Instruction presented in Chapter Two. For example, some of the principles include the *pre-training effect, the modality effect*, and *the segmentation effect* (Mayer, 2010:548). Each lesson was one-hour long and four lessons on CRR were planned as shown in the scheme in Appendix 27 and the Lesson Plans (Appendices 28-31). The teaching sequence in Appendix 27 was validated by an expert teacher during the pilot study before using it in the primary data collection phase of the research. This was done by presenting the lessons to a sample of learners who did not participate in the study (Section 4.4.2). The teaching sequence was modified along the findings of the pilot study. The teaching sequence was used to produce four detailed lesson plans (Appendices 28, 29, 30 & 31), therefore, the total number of lessons was four, each lesson was one hour; this translated to four hours of teaching.

Computer Simulation-Based Instruction (CSBI) make use of the Predict-Observe-Explain (POE) strategy to engage learners during the demonstrations. POE was used for both simulations and virtual experiments. For example, during Stage 5, of Lesson Plan 2 (Appendix 29), POE was used when learners were investigating the effect of particle size on reaction rate by carrying out a virtual experiment. Figure 4.3 shows a screenshot of the virtual experiment.

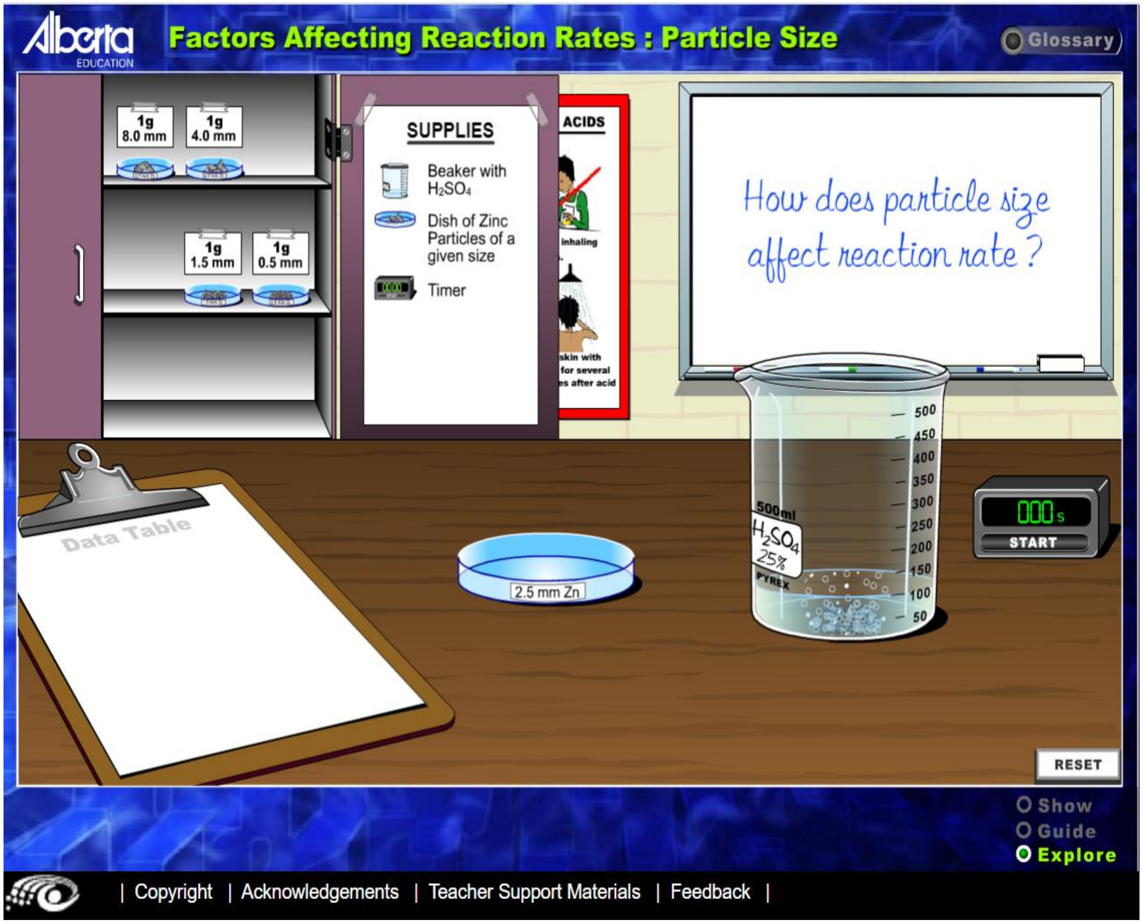


Figure 4.3 The effect of surface area on reaction rate (Alberta Education, 2006).

In Stage 5 of Lesson Plan 2, the learners investigated the effect of temperature on reaction rate using a demonstration of a virtual experiment. The screenshot in Figure 4.4 shows this experiment.

Figure 4.4 The effect of temperature on reaction rate (Alberta Education, 2006).

The factors that affect reaction rate were also investigated using simulations so that the learners could understand the reactions at the molecular level. Figure 4.5 shows the screenshot of the simulations of factors affecting reaction rate.

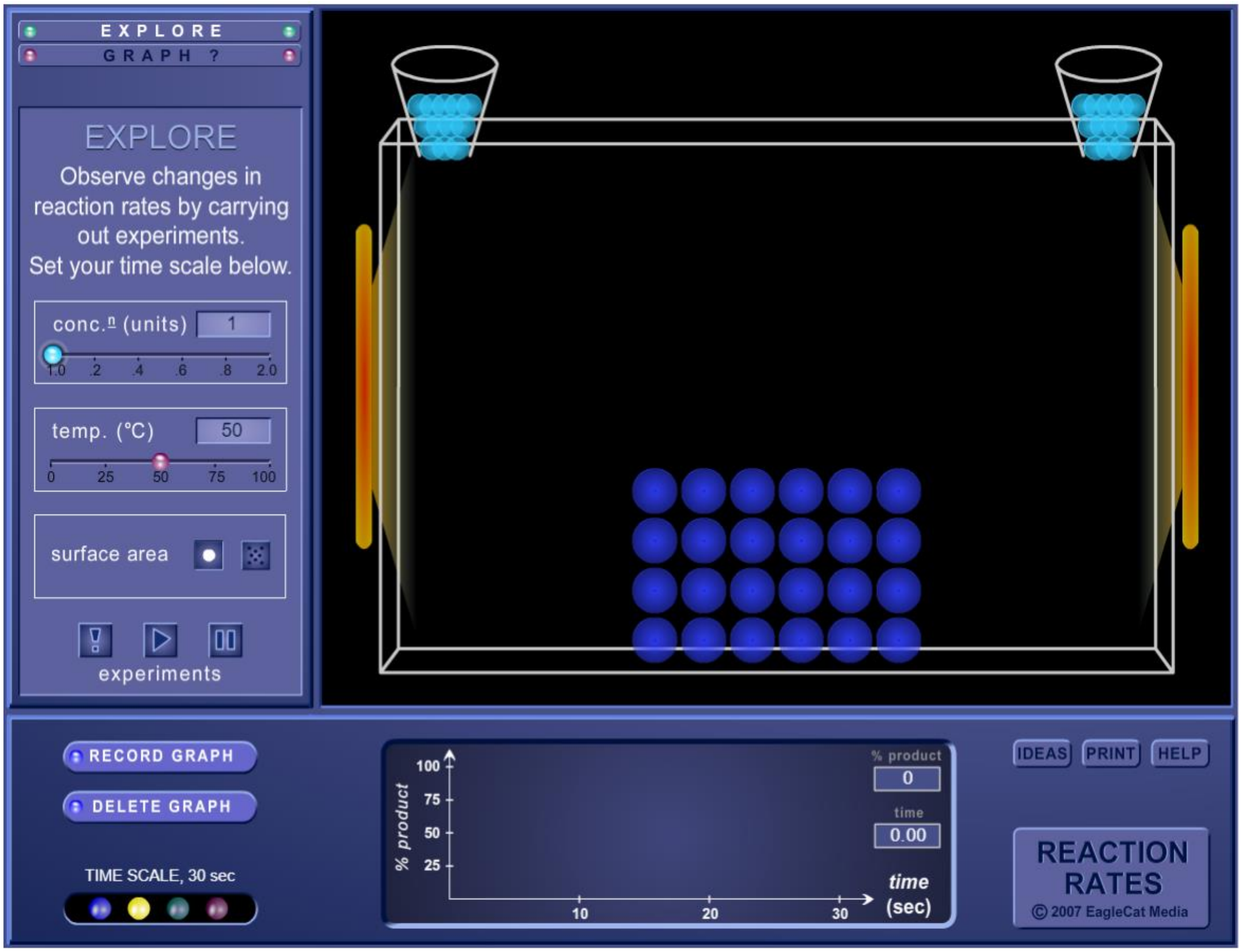


Figure 4.5 Factors affecting reaction rates (Barassi, 2007).

It was argued in Section 2.5.1 of Chapter 2 and Section 3.5 of Chapter 3 that it is not simply teaching Chemical Reaction Rates with simulations *per se* that can lead to conceptual understanding. What is required is to engage learners in cognitive processes when teaching with simulations. The Predict-Observe-Explain strategy was one of the cognitive tools that was identified to scaffold the learning of Chemical Reaction Rates with demonstration of experiments. Since traditional instruction did not involve the use of experiments, but reflect the way teachers normally teach Chemical Reaction Rate concepts, it was not necessary to use the Predict-Observe Explain strategy as this strategy is often used in carrying out experiments (Chapter 3, Section 3.5).

4.3.4.3 Teaching in the Control Group

I also taught the Control Group (CG) for the same period but using the Traditional Instruction approach (see Chapter 1 for the definitions of Traditional Instruction and Computer Simulation-Based Instruction). All the concepts of CRR were explained without engaging learners, therefore, these lessons were not learner-centred. The only difference in the teaching between the two groups was that the Control Group (CG) was taught using the traditional Instruction while the Experimental Group was taught using CSBI but the content that was taught was the same. As explained in Chapter 3, the Computer Simulation-Based instruction was not purely learner-centred as any questions learners had were answered and they also answered questions in the textbook as classwork. The teaching of both the EG and the CG by the researcher was a possible source of contamination of the results but the researcher attempted to limit this possibility by teaching the CG using the traditional approach and the EG using CSBI as outlined above.

4.3.4.4 Post-test

Learners sat for the post-test two weeks after teaching of both the EG and the CG as detailed above. The same test, given as pre-test was administered as a post-test, two weeks after treatment, but the sequence of the questions was changed to reduce test recognition. The test was administered under the same conditions as the pre-test - the Test of Chemical Reaction Rates Concepts (TCRRC) was administered to both groups on the same day, at the same time; the learners sat for the test for one hour; immediately after completing the TRRC the learners also completed the Attitudes towards Chemistry Lessons Scale (ATCLS) and all question papers were collected at the end of the testing session.

4.3.5 Qualitative Data Collection: The Interview

As stated by Denzin (2008:14) a qualitative research:

> *"explores qualities of entities putting emphasis on processes and meanings that are not experimentally measured in terms of quantity, but instead are socially constructed."*

Denzin (2008:14) further explains that qualitative research answers questions that stress how social experience is created. Petty *et al.,* (2012:380), opine that interviews are used extensively in qualitative research as a method of data collection, therefore, to answer RQ3, semi-structured interviews were used.

Morse (2012:199) notes semi-structured interviews as a qualitative method of interviewing used when the researcher knows a reasonable amount about the topic, enough to identify the domain and questions to be asked, but does not know enough to anticipate the participants' responses; semi-structured interviews provide form to the data collection. All participants were asked the same questions in the same order but had the option to respond to the questions as they chose. The interviews were recorded using a digital device.

The interviews were conducted at the school where the participants were enrolled. I requested for a quiet room from the principal to use for the interviews and at the beginning informed the participants about the purpose of the study and the anticipated duration of the interview. Each participant was also given a copy of the interview schedule (Appendix 10). Each interview lasted about twenty minutes; request was sought for permission to audio-record the interview using the recording capability of Samsung S10 cell phone. The Interview Schedule for Learners (Appendix 10) had three sections: Background information; Learners' conceptual understanding of CRR and their views on whether CSBI was helpful in conceptual understanding of CRR and Learners' attitudes towards lessons taught through CSBI.

4.4 Sampling

In this section, the population and sampling procedures are discussed.

4.4.1 Population

A population can be defined as all people or items with the characteristics that one wishes to study (Bhattacherjee, 2012:65). The population of interest in this study were all the Physical Sciences Grade 12 learners in Mopani District, Limpopo Province of South Africa.

The use of convenience sampling of schools that participated described in section 4.5.2 has implications for the generalisability of the results of the study. Caution should be exercised when generalising to the population, however, deliberate effort was made to ensure that the sampled schools and learners were comparable to the schools and learners in the Province, so that it may be possible to generalise to the population. Suter (2014a:31) identifies two types of generalisability - population and ecological. Population generalisability refers to how well the participants in the sample represents the persons in the population while ecological generalisability refers to how well the setting in which the data was collected mirror the setting in the wider population (Suter, 2014a:31). To safeguard ecological generalisability, caution was taken in ensuring that the sampled schools were like the schools in the population. These schools were like the others in the Limpopo Province, in terms of - the size of the Physical Sciences classes (as they are many schools with more than 20 learners in a Physical Sciences class); the location of the schools (with most of the schools in the Limpopo Province located in the rural areas); lack of laboratories equipped with sufficient materials for experiments; and lack of computer laboratories. Regarding population generalisability, the learners that participated in the study were like the learners in the population, in that they were approximately the same age of 16 to 20 years; they had similar socioeconomic background; they were all in Grade 12 doing Physical Sciences and learning the same concepts in Chemical Reaction Rate. Most of the learners in this district are enrolled in public schools in rural areas and this also applied to the learners who participated in the study.

4.4.2 Sample

Sampling is the statistical process of selecting a subset of a population of interest for purposes of making observations and statistical inferences about that population (Bhattacherjee, 2012:65). Singh and Masuku (2014:3) concur as they define sampling as the selection of a subset of individuals from within a population to estimate the characteristics of the whole population. In this study, non-probability convenience sampling was used for selecting schools for the quantitative phase of the research, while non-probability purposive sampling was used for the selection of learners and the teacher who participated in the qualitative phase; the selected schools were situated in the

Limpopo Province in South Africa. Schools were conveniently selected in terms of accessibility, location and the number of learners enrolled for Physical Sciences. As I was the one teaching both the Experimental Group (EG) and the Control Group (CG) it was necessary to have easy access to both the participating schools. While the schools had to be far enough from each other to avoid the possibility of learners from the same community interacting after treatment, the schools had to be easily accessible. The schools were along the major road and I could drive from one school to the other in less than one hour. Preference was given to schools with more than fifty learners enrolled for Physical Sciences.

4.4.3 Quantitative Sampling

The sampling procedure that was used was non-probability convenience sampling. Non-probability sampling is a sampling technique where the samples are gathered in a process that does not give all the participants in the population equal chances of being included (Etikan *et al.,* 2016:1). The learners who participated in the study were sampled in terms of ease of accessibility. The learners were not randomly assigned to the Experimental Group (EG) and the Control Group (CG) after convenient selection of schools but intact classes were used. In a quasi-experiment randomization of participants is not possible and, hence, pre-assigned groups were used (Levy, 2011:155). There was no control over the composition of the learners as they were put into those classes at the beginning of the school term, by the principals. Also, for ethical reasons, such as possible disruption to the curriculum activities of two different schools, randomization of learners from the two schools into the EG and CG was not possible. For these reasons the study was a quasi-experiment and not a true experiment.

The two classes in the conveniently sampled schools were then randomly assigned to be the EG or CG by the toss of a coin to minimize bias. Grade 12 Physical Sciences learners in one class formed the EG and those in the other class constituted the CG. The CG was selected so that it was like the EG, in terms of demographic characteristics. The learners had an age range of sixteen to twenty years. The EG had fifty-three learners and the CG had about sixty-five learners. The total number of learners, who participated in the study was one hundred and eighteen (118).

4.4.4 Qualitative sampling

Qualitative researchers are more interested in a small number of participants who represent the phenomena of interest (Beitin, 2012:248). Participants are purposively selected to provide rich knowledge about the research question. Purposive sampling is a method of sampling in which the researcher selects participants who have experience or knowledge of the issue/s being addressed in the research (Oppong, 2013:203). Purposive sampling may be defined as - selecting units based on specific purposes associated with answering a research study's questions (Teddlie & Yu, 2007:77). Beitin (2012:248) opines that when sampling in a qualitative study the researcher should ask - *"How can a sample include as many perspectives as possible on the topic?"* Sampling in the qualitative phase of this research, hence, sought to include learners who would provide different perspectives of the effects of CSBI on their performance. The purposively-selected sample consisted of five learners from the CG and five learners from the EG identified from statistical analysis of the results of the TCRRC. To confirm, enrich or challenge findings from the quantitative phase, the sample chosen had high performers and average performers, hence, the sample of learners was ten. There was one teacher who also participated as he had attended all the lessons that were provided to the Experimental Group (EG); he was also interviewed during the qualitative data collection.

4.5 Measures of Quality Control

This section discusses the validity and the reliability of quantitative data collection instruments, and the credibility and trustworthiness of qualitative data collection.

4.5.1 Validity and Reliability of Quantitative Research Instruments

This section discusses validity and reliability of the data collection instruments.

4.5.1.1 Validity

Validity refers to the accuracy of the research instrument (Lodico *et al.,* 2006:88). A research instrument is valid if it measures what it is supposed to measure (Yilmaz, 2013:318). The following paragraphs describe how the research instruments for the quantitative phase were validated. Content validity was the type of validity that was considered for the research instruments.

Content validity concerns the degree to which a sample of items taken together constitutes an adequate definition of a construct (Polit & Beck, 2006:490). In ensuring content validity of the TCRRC, each test item was rated by three expert teachers and one Chief Examiner of Physical Sciences. Two of these four experts had a Master's degree in Chemistry Education, one had a Bachelor of Science degree in Chemistry and a Post Graduate Diploma in Education, and the other had a Bachelor of Education degree with Chemistry as a major. All the validators had more than 8 years' experience in teaching. Each item in the TCRRC was rated by these validators on a four-point ordinal rating scale where 1 = *not relevant;* 2 = *somewhat relevant;* 3 = *quite relevant and* 4 = *highly relevant* (Polit & Beck, 2006:491). Only those items with Content Validity Index (CVI) = 1.00 were accepted and those with less were modified or rejected as advised by Polit and Beck (2006:491).

The overall validity of the TCRRC was determined by the Scale-level CVI (SCVI). The TCRRC was considered valid as it had an SCVI of 0.90 (Polit & Beck, 2006:493). Initially the TCRRC consisted of 34 questions. After the initial validation, all expert teachers independently rated two of the test items either as a 1 or a 2. It was agreed during the discussion phase that these two items be removed altogether. The two questions were either too challenging or were beyond the scope of the specified content. Three questions received a rating of 2 or 3. These were modified to ensure that the questions or responses were not ambiguous. The experts then provided their final ratings. In the final rating, only two questions were rejected, thus, the final version of the test had 30 multiple choice questions.

Furthermore, a table of specification for the TCRRC was constructed (Table 4.1). The purpose of the table of specification was to improve validity; ensure that all content areas were covered and that all performance objectives in Bloom's Taxonomy (Bloom, cited in Krathwohl, 2002:213) were represented.

Table 4.1 Table of Specification for the TCRRC

Concepts and Skills	Questions	Total
Explaining concept of reaction rate, calculation of rate and its unit.	2, 4, 10, 15, 25, 29, 30	7
Identifying factors which affect reaction rate	1, 3, 21, 23, 24	5
Explaining factors in terms of the collision theory	20, 22, 26	3
Understanding of concept of activation energy and Heat of Reaction	5, 6, 8, 9, 11, 17	6
Understanding of concept of catalysts and how they function and Reaction Mechanisms	13, 16, 18, 19, 27, 28	6
Interpretation of graphs of distribution of molecular energies	7, 12, 14	3

Most of the questions in the TCRRC were in the *understanding* and *applying* level in the revised Bloom's taxonomy of educational objectives (Krathwohl, 2002:213) as shown in Table 4.2.

Table 4.2 Classification of Questions in the TCRRC into the Revised Bloom's Taxonomy of Educational Objectives (Krathwohl, 2002:213)

Domain Specific Cognitive Process	Questions
Remembering	2, 4, 7, 9
Understanding	3; 5; 8; 12; 13; 14; 15; 18; 19; 20; 21; 22; 23; 24; 27
Applying	10; 11; 17; 25; 29; 30
Analysing	6; 26; 28
Evaluating	16
Creating	1

After the content validation by the experts and construction of the table of specification, the TCRRC (Appendix 7) was considered valid for its purpose. Next to be considered were the interview questions for learners and the teacher.

The purpose of the Interview Schedules for Learners and for the Teacher (Appendices 9 & 10) was to determine the conceptual understanding of the learners of the CRR concepts. They contained, therefore, conceptual questions on CRR and questions on finding out if CSBI helped learners to understand the concepts. The four expert teachers were given both interview schedules and asked to rate them independently. They were asked to check the clarity of the questions in terms of the vocabulary, any ambiguity and appropriateness. They were also required to rate each of the items on a four-point rating scale (Polit & Beck, 2006:490). After they had rated the interview questions independently, there was a discussion between the validators and the researcher. Issues that came up in the discussion only involved the wording of some of the questions. This was resolved by changing some of the statements to increase clarity. The experts rated all items with a three or a four, thus, the interview schedules were considered valid.

The ATCLS had 12 items used to assess the attitudes of the learners. The expert teachers rated each of the 12 items on a four-point rating scale and they all independently rated all the items with a three or four. During the discussion, it was agreed that the items were appropriate in terms of culture, age, vocabulary, language and content level for Grade 12; the ATCLS (Appendix 8) was therefore, considered to be valid.

4.5.1.2 Reliability

In this section the reliability of the research instruments is discussed.

4.5.1.2.1 Reliability of the Test on Chemical Reaction Rate Concepts (TCRRC)

Reliability is the degree to which the measure of a construct is consistent or dependable (Bhattacherjee, 2012:56). It is concerned with the ability of an instrument to measure consistently (Tavakol & Dennick, 2011:53). In this study the reliability of TCRRC was determined through the test-retest process; this concerns the reliability of a test over time (Kline, 2013:7). It is measured by correlating the scores from a set of subjects who take the test on two occasions and the correlation coefficient measures the degree of agreement between the two scores on these occasions. The correlation coefficient runs from +1 which means complete agreement to -1 which means complete disagreement. As stated by Kline (2013:11), a test is reliable if its correlation coefficient is +0.8 or higher.

The test-retest reliability of the TCRRC was determined by administering the test to a sample of 76 learners who were not part of the main study. The same test was administered again after six weeks from the time of the administration of the first test and the test-retest reliability was determined using the Statistical Package for Social Sciences (SPSS) version 26. The minimum possible score was 0 and the maximum possible score was 30. The Pearson Correlation was used to examine the relationship between test scores from the first and the second test administrations. The mean score in the first test administration was 7.30 (*SD* = 2.46) and in the second administration was 8.53 (*SD* = 2.19). The relationship of the test scores in the first and second test administration was strong and statistically significant [$r(74) = .82$, $p < .01$]. The test was deemed reliable according to Kline (2013:11).

4.5.1.2.2 Reliability of the Attitude Towards Chemistry Lessons Scale (ATCLS)

The reliability of the ATCLS was determined using Cronbach's alpha (Cronbach, 1951:331). As observed by Vaske *et al.,* (2017:163), alpha is often used by researchers to determine the internal consistency of summated scales such as the ATCLS. Alpha (α) was determined from the sample of 76 learners who were not part of the main study. Using the Statistical Package for Social Sciences (SPSS) version 26 it was found that α = .89, with the number of participants, N = 76. This value of Alpha was adequate as it was above .80 (Vaske *et al.,* 2017:165), hence, the ATCLS was considered reliable for using in the main study.

4.5.1.2.3 Inter-rater Reliability of the coding of transcribed Interview transcripts for Learners

After I did the initial coding, the services of a second expert teacher were enlisted to do the second coding to ensure objectivity; it was therefore necessary to determine interrater reliability.

In the analysis of the transcribed interview transcripts for learners, qualitative content analysis was the strategy used. The learners' responses were put into three categories and the reliability of this process was assured through using inter-rater reliability. Inter-rater reliability is a measure of the extent to which data collectors assign the same score to the same variable and Cohen's kappa, k, can be used as the inter-rater's statistic (McHugh, 2012:276). I coded the ten transcribed interviews for learners, then, the transcripts were given to one of the expert teachers to independently code the transcripts using the same categories I had used. A kappa statistic was determined using SPSS version 26 for each of the transcribed interviews. The results are presented in Chapter 5.

4.5.2 Trustworthiness of qualitative Data

There are four criteria that should be addressed to ensure trustworthiness of qualitative research: credibility, transferability, dependability and confirmability (Shenton, 2004:63).

4.5.2.1 Credibility

Credibility means that the researchers had demonstrated that a true picture is being presented (Shenton, 2004:263). In this study, credibility was assured by using a relatively longer duration of time in the field to establish rapport and trust with the participants; peer debriefing by seeking support from the promoters and other members of the academic staff for scholarly guidance; and member checking by requesting the participants to read the transcribed interview data and confirm whether they are a true reflection of the interview (Anney, 2014:276-277). Triangulation in this study involved the use of a wide range of participants, by sampling average achievers and high achievers which also helped to gain multiple perspectives to ensure credibility of data (Shenton, 2004:66). This type of triangulation is called 'data source triangulation' as it sought to collect data from different types of participants (Carter *et al.,* 2014:545).

4.5.2.2 Transferability

Transferability implies that sufficient details of the context of the fieldwork is provided for other researchers to judge whether findings apply to other settings. Transferability in this research involved providing sufficient thick description of the study, to allow readers to have a proper understanding of it, so that they can compare it with similar settings (Shenton, 2004:70).

4.5.2.3 Dependability

Dependability was assured by providing sufficient details for other researchers to be able to repeat the study. Dependability was addressed by reporting in detail, so that any future researcher may be able to repeat the work (Shenton, 2004:270).

4.5.2.4 Confirmability

Confirmability means that researchers take measures to ensure that findings emerge from the data and not the researcher's predispositions (Shenton, 2004:63). To ensure, this I kept a reflexive journal, which included all events that happened in the field and personal reflections to deal with issues of confirmability (Anney, 2014:279). In this way, it can be seen how the interpretations of the findings were derived at from the data.

4.6 Conclusion

At the beginning of this Chapter, pragmatism was identified as the appropriate paradigm for the study. The sequential explanatory design was adopted as the methodology. The first quantitative phase was described as a pre-test/post-test NCGD. The second qualitative phase involved using semi-structured interviewing of the learners sampled from the CG and the EG to determine their conceptual understanding of CRR concepts. The research instruments used in data collection were discussed in terms of their development and how measures of quality control were assured for each instrument. The conducting of the pilot study was discussed as well as the implementation of the main study. In the next Chapter results are presented, analysed and interpreted.

Chapter 5 Data Analysis and Interpretation

5.1 Introduction

Chapter 4 described the rationale for adopting mixed-method approach for the study. From this methodology, the sequential explanatory design was identified as suitable for the research and in line with this, the presentation and analysis of quantitative data, in this Chapter, is done first followed by qualitative data. Lastly, the integration of quantitative and qualitative data is presented during the interpretation of the results.

5.2 Presentation and Analysis of Results of Test of Chemical Reaction Rates Concepts

Descriptive and inferential statistics were used in the analysis of the data. The aim was to answer Research Question 1 (RQ1).

Research Question 1: How effective is the use of CSBI compared to the traditional instruction on the academic achievement of learners in CRR concepts?

Firstly, the independent samples *t*-test was used to find out if the Experimental Group (EG) and Control Group (CG) were similar before treatment by comparing the means in the pre-test. Secondly, the independent samples *t*-test was used to find out if there was a significant difference between the means of the CG and EG in the post-test. Then, the related samples *t*-test of the scores of the EG in the pre-test and post-test was performed to determine the effect of treatment on this group. The same test was performed to find if there was a significant difference in performance of learners in the pre-test and post-test in the CG. Then, the effect sizes were calculated to determine the practical significance of the observed differences. Finally, a summary of the findings on the results of the TCRRC is provided.

The *t*-test is a parametric test and for it to be used there are certain assumptions that must be satisfied. These are: the dependent variable should be measured on a ratio scale; observations should be independent of each other; the population from which the samples are taken are normally distributed; samples are taken from populations of equal variances and scores are obtained from random samples of the population (Pallant, 2005:197-198). An inspection of the data before the use of each test in sections 5.2.1 and 5.2.2 shows that the first four assumptions were satisfied, however, the last assumption was not satisfied as convenience sampling was used. Section 4.5 provided justification as to why the results of the study can be generalised to the larger population, despite using convenience sampling.

5.2.1 Pre-test Results Presentation and Analysis

In this section results from the TCRRC for the EG and CG are presented and analysed.

5.2.1.1 Pre-test Results and Independent samples t-test

The TCRRC had a total of 30 multiple choice questions. The lowest possible score was 0 and the highest possible score was 30 (Appendix 11). The pre-test raw scores (Appendix 11) were analysed to determine the normality of the distribution of the scores using the Statistical Package for Social Sciences (SPSS) version 26. The raw scores are shown in Appendix 11.

A Shapiro-Wilk's *t* ($p > .05$) (Razali & Wah, 2011:25) and a visual inspection of the histograms (Figure 5.7), normal Q-Q plots (Figure 5.8) and box plots (Figure 5.9), showed that the pre-test scores were, approximately, normally distributed for both the EG and CG. The EG scores had a skewness of 0.457 (*SE* = 0.327) and a kurtosis of -0.269 (*SE* = 0.644). For the CG, the skewness was 0.128 (*SE* = 217) and the kurtosis was -0.575 (*SE* = 0.586) (Doane & Seward, 2011b:1).

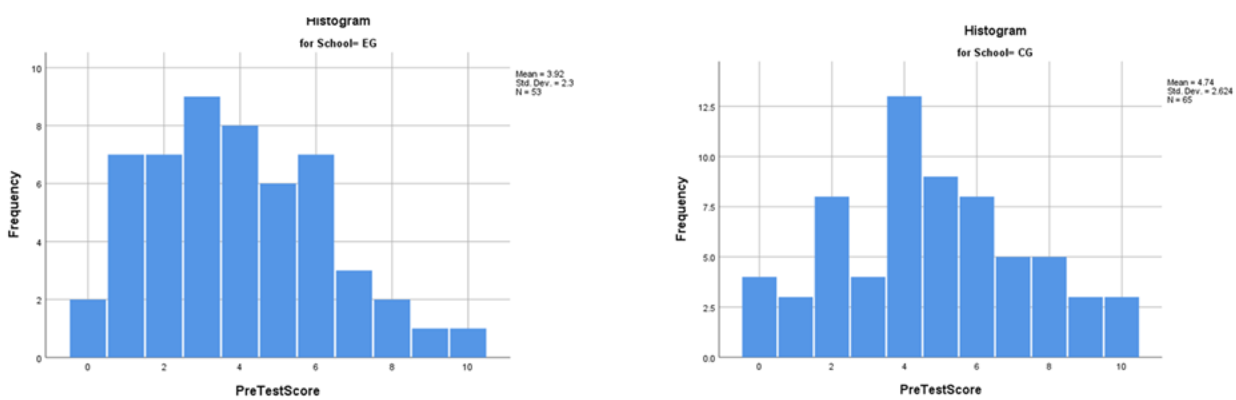


Figure 5.1 Histogram of the Pre-test Scores of the Experimental Group (EG) and Control Group (CG)

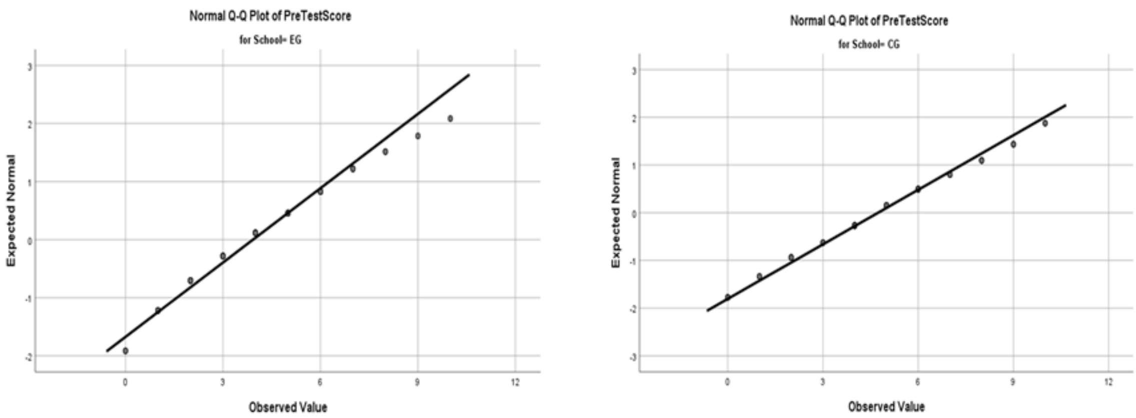


Figure 5.2 Normal Q-Q Plots for the Pre-test Scores of the Experimental Group (EG) and the Control Group (CG)

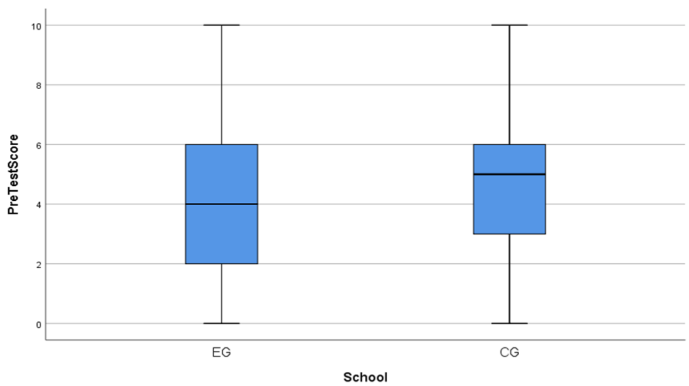


Figure 5.3 Box Plots of the Pre-test Scores of the Experimental Group (EG) and the Control Group (CG)

The EG (*N* = 53) had a pre-test score of M = 3.92 (*SD* = 2.34) while the CG had a score of M = 4.74 (*SD* = 2.62). To test whether the EG and CG had scores that were not statistically different in the pre-test, an independent samples *t*-test was conducted. This was appropriate as the distribution of scores of both the EG and CG were sufficiently normal for conducting a *t*-test. In addition, the assumption of homogeneity of variance was tested and satisfied by the use of Levene's F test, F(116) = 0.67, p = 0.42 (Gastwirth *et al.,* 2009:343), therefore, an equal variance was assumed.

The results of the *t*-test were *t*(116) = -1.758, *p* = .081, p > .05 indicating that the scores of the EG and the CG were not statistically different in the pre-test, hence, the academic achievement of learners before treatment was the same for both the EG and CG.

5.2.2 Post-Test Results Presentation and Analysis

5.2.2.1 Data Characteristics

The EG (N = 53) had a mean post-test score of M = 10.70 (*SD* = 4.06), and the CG (N = 65) had a mean score, M = 7.85 (*SD* = 3.08). To test the hypothesis that the scores of the EG in terms of academic achievement were statistically significantly different from the scores of the CG, an independent *t*-test was performed. Before performing this independent *t*-test, it was necessary, however, to find out if the post-test scores were normally distributed. A Shapiro-Wilk's test ($p > .05$), histograms (Figure 5.10), normal Q-Q plots (Figure 5.11) and box plots (Figure 5.12) showed that the post-test scores were, approximately, normally distributed for both the EG and the CG (Razali and Wah, 2011:25). The EG had a skewness of 0.48 (SE = 0.33) and a kurtosis of 0.23 (SE = 0.64). The CG had a skewness of 0.22 (SE = 0.30) and a kurtosis of -0.09 (SE = 0.59) (Doane & Seward, 2011a:3). In addition, the assumption of homogeneity of variance was tested and found to satisfy Levene's F test, $F(116) = 3.43$, $p = .07$ (Gastwirth *et al.,* 2009:345).

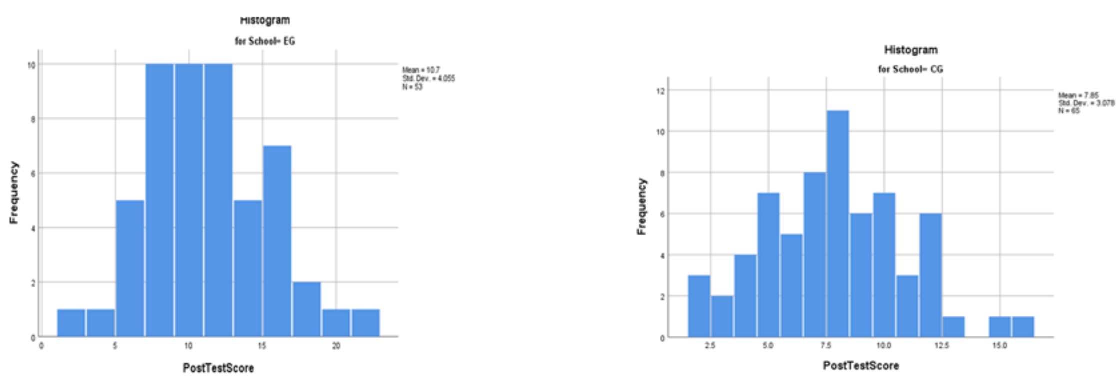


Figure 5.4 Histograms of the Post-test Scores of the Experimental Group (EG) and Control Group (CG)

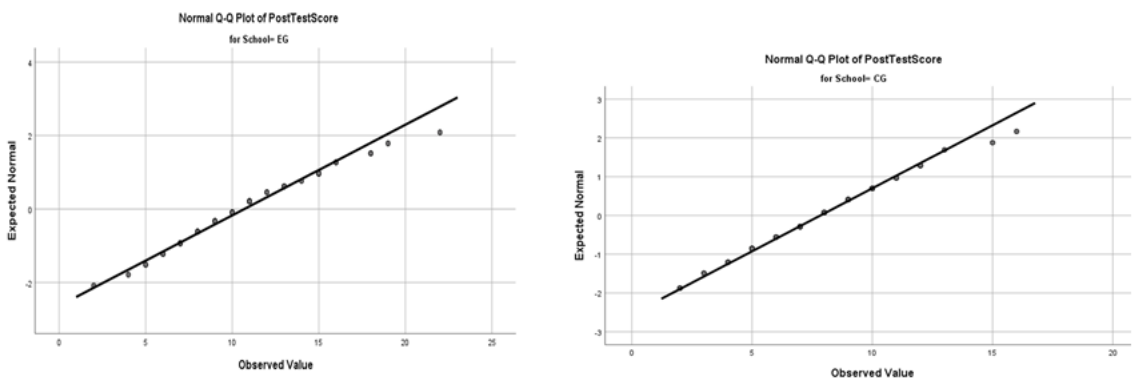


Figure 5.5 Normal Q-Q Plots of Post-test Scores of the Experimental Group (EG) and the Control Group (CG)

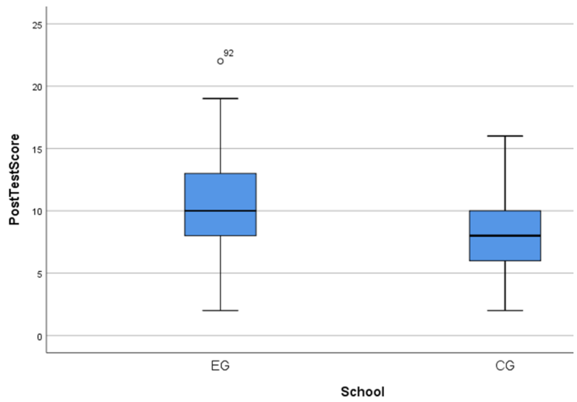


Figure 5.6 Box Plots of Post-test Scores of the Experimental Group (EG) and the Control Group (CG)

5.2.2.2 Post-test Independent samples t-test and Effect Size

An independent samples *t*-test was conducted to compare the post-test scores of learners taught through Computer Simulation-Based Instruction (CSBI) and learners in the Control Group (CG), taught through traditional instruction. There was a statistically significant difference in the scores of the EG (M = 10.70, SD = 4.06) and CG (M = 7.85, SD = 3.08); $t(116) = 4.34$, $p < .005$. These results suggested that CSBI influenced learners' academic achievement in CRR. Specifically, the results of the study suggested that when learners were taught CRR using CSBI, their academic achievement improved more than when they were taught using the traditional approach.

Research Question 1 (RQ1) sought to find out how effective the use of CSBI was, as compared to the use of traditional approach, on the academic achievement of learners in teaching CRR concepts. To answer this research question, it was necessary to determine the effect size of the treatment, for although the independent *t*-test showed that CSBI affected the academic achievement of learners in CRR, it does not, however, quantify the magnitude of the effect.

The mean score for learners taught CRR by CSBI, M = 10.70, was greater than for the learners taught through traditional approach, M = 7.85; d = 0.53. An effect size of 0.2 is considered as small, 0.5 is medium and 0.8 is large (Cohen, 1992:157). The d of 0.53, as determined in this study, indicated that CSBI had a medium effect size on the academic achievement of learners in CRR when compared with traditional instruction. De Winter (2013:7) opines that large effect sizes are not usually commonly observed in behavioural and psychological sciences, typically, the effect sizes ranges from 0.2 to 0.3. It is further noted in literature that even small effect sizes can have extensive consequences (Lakens, 2013:3). Mayer (2010:547) opines that for the effect size to have practical significance for improving academic achievement of learners, *d* should be equal to or greater than 0.5. The value of *d* was greater than 0.5, implying that the observed difference has practical significance for improving academic achievement, hence, it can be concluded that the CSBI was a more effective instructional approach than the traditional approach. This is further explored in the following section.

5.2.2.3 Paired Sample t-Tests and Effect Sizes

The paired samples *t*-test for the EG and CG is determined together with the effect sizes in this section. The reason is to establish if the learners' mean scores before and after instruction changed in a statistically significant way, and if they did, what the practical significance of the change is.

5.2.2.3.1 Experimental Group

Learners' performance in the pre-test was much lower than their performance in the post-test. This could be expected as pre-test scores were those obtained before treatment. To compare the academic achievement of learners before being taught by CSBI (pre-test) and after treatment (post-test), a two-tailed paired sample *t*-test was used.

The mean scores of the Experimental Group increased from 3.98 in the pre-test to 10.30 in the post-test. This was a statistically significant increase from the pre-test scores (M = 3.98; *SD* = 2.45; N = 53) to the post-test scores (M = 10.30; *SD* = 4.286); $t(52) = -11.47$; $p < .001$. The mean increase in test scores was 6.32 with a 95% confidence interval ranging from 5.22 to 7.43, however, to quantify the effect size of the treatment, the eta squared was calculated. Eta squared was determined as 0.68 indicating a large effect size, hence, the use of Computer Simulation-Based instruction was an effective instructional approach with huge practical significance. Based on these results, the use of CSBI in teaching Chemical Reaction Rates can be said to improve academic scores of learners.

5.2.2.3.2 Control Group

The academic achievement of learners improved after exposure to traditional instruction. There was a significant increase in test scores from pre-test (M = 4.74, *SD* = 2.62, N = 65) to post-test (M = 8.22, *SD* = 3.30); $t(64) = -10.45$, $p < .001$). The mean increase in test scores was 3.48 with a 95% confidence interval ranging from 2.81 to 4.14, however, it must be noted that this mean increase was lower than the mean increase for the EG (6.32). The eta squared statistic, 0.58, showed that the effect size of teaching using the traditional instruction was large, but less than the effect size observed for the Experimental Group.

5.2.3 Comparing Effect Size of Control Group and Experimental Group

The eta squared statistic showed that the effect sizes of both the Control Group (0.58) and the Experimental Group (0.68) were large. However, the CG had a lower effect size compared to the EG. This shows that the use of CSBI was more effective in teaching CRR compared to traditional approach.

5.2.4 Post-Test Analysis per Question

The TCCRC (Appendix 7) consisted of thirty, two-tier multiple-choice items. The first tier was a content question while with the second-tier learners, were required to indicate how confident they were with their answers. The purpose of the second tier was to ensure that only those responses where learners were confident of their answers were considered as correct. This helped to exclude those questions learners got correct by guesswork, however, it should be noted that although this reduced the learners' scores, it improved the extent to which the achievement of learners could be considered as actual achievement based on their knowledge. In the following analysis of the academic achievement of learners per question, the Correct Response (CR) refers to a correct answer in the first tier and an indication by the learner that he/she was *confident* or *very confident* in the second tier. Where the learner was correct in the first tier but chose *very unconfident* or *unconfident* in the second tier, then the response of the learner was considered incorrect in this analysis. The maximum possible score was 30; the lowest possible score was 0.

The multiple-choice questions (Appendix 7) were categorized into the six major concepts and skills in CRR as shown in Table 5.1. The questions were classified into the concepts and skills in which they fall and analysis of learners' academic achievement was done based on each of these concepts and skills (Table 5.1).

Table 5.1 Classification of Questions in TCRRC per the major concepts and skills in CRR

Concepts	Questions	Total
Reaction rate, calculation of rate.	2,4,10,15,25,29,30	7
Factors affecting reaction rate	1,3,21,23,24	5
Collision theory	20,22,26	3
Activation energy and Heat of Reaction	5, 6,8,9,11,17	6
Mechanism of Reaction and Catalysis.	13,16,18,19,27,28	6
Distribution of molecular energies	7,12,14	3

Table 5.2 shows the percentages of learners with correct response (CR) for each of the thirty multiple choice questions in the pre-test and the post-test for the Experimental Group (EG) and the Control Group (CG). The percentage of learners with correct responses was determined by dividing the number of learners with correct responses by the total number of learners for a question and expressing this as a percentage for the EG and the CG. The table also shows the percentage increase/decrease of learners with the correct response (CR) from the pre-test to the post-test for the EG and the CG. The analysis in this section is based on the data in Table 5.2.

5.2.4.1 Reaction rate concept and calculation of rate

The understanding of the concept of reaction rate and calculation of reaction rate were tested using questions 2, 4, 10, 15, 21, 25, 29 and 30. The percentage of learners' correct responses (CRs) to these questions are presented in Table 5.2. Figure 5.1 shows the percentage increase of CRs in the EG and CG. Greater increases in CRs were recorded in Q2, Q4, Q25 and Q30. The smallest increases were in Q10, Q15, Q21 and Q29 (Fig 5.1).

Table 5.2 Percentages of Correct Responses (CR) in Pre-Test and Post-Test, and percentage increase from Pre-Test to Post-Test for the EG (N=53) and CG (N=65)

Question	Pre-Test		Post-Test		Increase	
	EG	CG	EG	CG	EG	CG
1	9.4(5)	3.1(2)	37.7(20)	6.2(4)	28.3(15)	3.1(2)
2	28.5(15)	20.0(13)	77.4(41)	63.1(41)	48.9(26)	43.1(28)
3	11.3(6)	12.3(8)	49.1(26)	49.2(32)	37.8(20)	36.9(24)
4	11.3(6)	6.2(4)	41.5(22)	13.8(9)	30.2(16)	7.6(5)
5	7.5(4)	12.3(8)	26.4(14)	24.6(16)	18.9(10)	12.3(8)
6	1.9(1)	6.2(4)	13.2(7)	12.3(8)	11.3(6)	5.9(4)
7	15.1(8)	13.8(9)	54.7(29)	33.8(22)	39.6(21)	20(13)
8	11.3(6)	15.4(10)	24.5(13)	13.8(9)	13.2(7)	-1.6(-1)
9	20.8(11)	13.8(9)	26.4(14)	16.9(11)	5.7(3)	3.1(2)
10	18.9(10)	27.7(18)	22.6(12)	26.2(17)	3.7(2)	-1.5(-1)
11	11.3(6)	9.2(6)	13.2(7)	15.4(10)	1.9(1)	6.2(4)
12	17.0(9)	29.2(19)	56.6(30)	43.1(28)	39.6(21)	13.9(9)
13	32.1(17)	46.2(30)	56.6(30)	56.9(37)	24.5(13)	10.7(7)
14	34.0(18)	26.2(17)	54.7(29)	49.2(32)	20.7(11)	23.0(15)
15	9.4(5)	0(0)	17.0(9)	15.4(10)	7.6(4)	15.4(10)
16	5.7(3)	4.6(3)	20.8(11)	9.2(6)	15.1(8)	4.6(3)
17	7.5(4)	10.8(7)	9.4(5)	6.2(4)	1.9(1)	-4.6(-3)
18	22.6(12)	47.7(31)	41.5(22)	46.2(30)	18.7(6)	-1.5(-1)
19	15.1(8)	21.5(14)	32.1(17)	30.8(20)	17(9)	9.3(6)
20	13.2(7)	13.8(9)	35.8(19)	41.5(27)	22.6(12)	27.7(18)
21	41.5(22)	30.8(20)	49.1(26)	46.2(30)	7.6(4)	15.4(10)
22	9.4(5)	16.9(11)	54.7(29)	49.2(32)	45.3(24)	32.3(21)
23	11.3(6)	13.9(9)	18.9(10)	9.2(6)	7.6(4)	-4.7(-3)
24	9.4(5)	12.3(8)	47.2(25)	9.2(6)	37.8(20)	-3.1(-2)
25	13.2(7)	21.5(14)	54.7(29)	33.8(22)	41.5(22)	12.3(8)
26	17.0(9)	18.5(12)	28.3(15)	21.5(14)	11.3(6)	3(2)
27	3.8(2)	6.4(4)	26.4(14)	6.2(4)	22.6(12)	-0.2(0)
28	5.7(3)	10.8(7)	17.0(9)	12.3(8)	11.3(6)	1.5(1)
29	9.4(5)	10.8(7)	20.8(11)	6.2(4)	11.4(6)	-4.4(3)
30	3.8(2)	9.2(6)	41.5(22)	24.6(16)	37.7(20)	15.4(10)

EG is the Experimental Group; CG is the Control Group; CR is Correct Responses excluding responses that were correct but had low confidence ratings by the learners. Number in brackets is the actual number of learners (absolute frequency) with the CR while the percentage is the first number (outside the brackets).

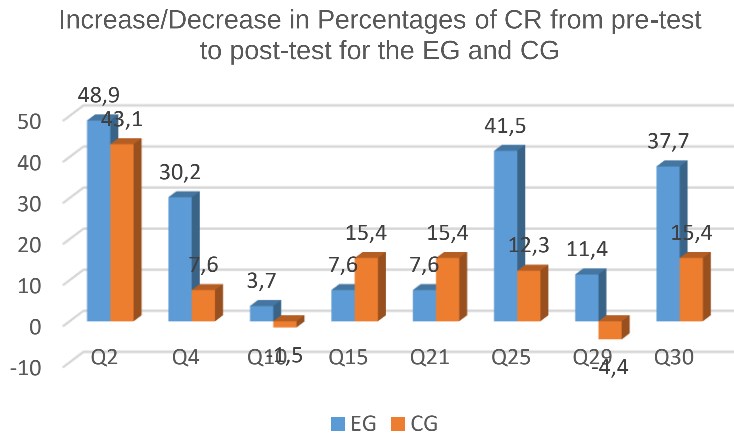


Figure 5.7 Graph of Percentage increase/decrease of CR in EG and CG on Reaction Rate and Calculation of Rate from pre-test to post-test.

Questions 2 and 4 (Q2 and Q4) required learners to understand the concept of reaction rate. Reaction rate is defined as change in concentration of a reactant or product per unit time, but it can also be expressed in other quantities per unit time. Whichever quantity, the rate is always change in that quantity per unit time. Learners in the Experimental Group seem to have grasped this concept better than the learners in the Control Group. There was a greater increase in Correct Responses (CR) from the pre-test to the post-test in the Experimental Group compared to the Control Group in both questions 2 and 4 (Table 5.2). This means the CSBI was more effective in helping learners to comprehend the concept of reaction rate compared to learners taught through the traditional instruction.

Questions 10, 29 and 30 (Q10, Q29 and Q30) tested the learners' ability to calculate reaction rate from given information, however, Q10 and Q29 required the understanding of stoichiometry to calculate the rate at which a product is formed given the rate at which a reactant is consumed or vice versa. In Q10 there was a slight increase in the percentage of learners who could answer this question from the Experimental Group, from the pre-test to post-test, while the Control Group had a decrease in percentage (Figure 5.1). It appears the teaching approach did not influence learners' performance in questions that involve stoichiometric calculations. Question 30 required learners to calculate an average reaction rate, but it did not involve stoichiometric calculations; it only required learners to determine change in amount and to divide by change in time. The learners who understood questions 2 and 4 had no problems with Question 30 (Q30). The percentage of learners who could give the CR in Q30 increased much more in the Experimental Group than in the Control Group from pre-test to post-test (Figure 5.1).

Questions 15 and 25 (Q15 and Q25) required learners to understand that during a reaction, the rate of reaction decreases with time. This information was displayed using graphs. In Q15 the percentage of learners with the Correct Response increased from 9.4% in the pre-test to 17.0% in the post-test in the EG and in the CG; it increased from 0% to 15.4%. In Q25, the EG had 54.7% and CG had 33.8% in the post-test (Table 5.2). Generally, the data suggests that the CSBI was a better instructional approach than traditional instruction in the teaching of Reaction Rate and Calculation of Rate.

5.2.4.2 Factors Affecting Reaction Rate

The factors that affect reaction rate were assessed by questions Q1, Q3, Q21, Q23 and Q24. Figure 5.2 shows the percentage increase/decrease in Correct Responses (CR) for these questions from pre-test to post-test in the EG and the CG.

In question 1 (Q1), learners were given a graph of volume of hydrogen gas [H_2(g)] against time for the reaction of 100 cm^3 of a 0.1 $mol.dm^{-3}$ hydrochloric acid with excess magnesium powder. They were required to identify the graph that would be obtained for the reaction of 100cm^3 of a 0.1 $mol.dm^{-3}$ ethanoic acid with excess magnesium powder. A higher percentage of learners in the Experimental Group, more than in the Control Group, answered the question correctly in the post-test (Table 5.2), thus, there was a greater increase in the percentage of learners with the CR in the EG from pre-test to post-test (Figure 5.2). This may be attributed to the fact that learners in the EG carried out virtual experiments on factors that affect reaction rate in which graphs were generated from the simulation, when conditions were changed. This question further required that learners understand the difference between a strong and a week acid. Hydrochloric acid, being a strong acid, is completely ionized in solution producing a high concentration of hydrogen ions (H^+) ions. This high concentration of H^+ ions made the reaction to have a high reaction rate. On the other hand, ethanoic acid, being a weak acid, is only partially ionized in water producing a low concentration of H^+ ions, which made the reaction slower, although the concentrations of both acids were the same. This shows that learners in the Control Group had little understanding of how concentration affect reaction rate.

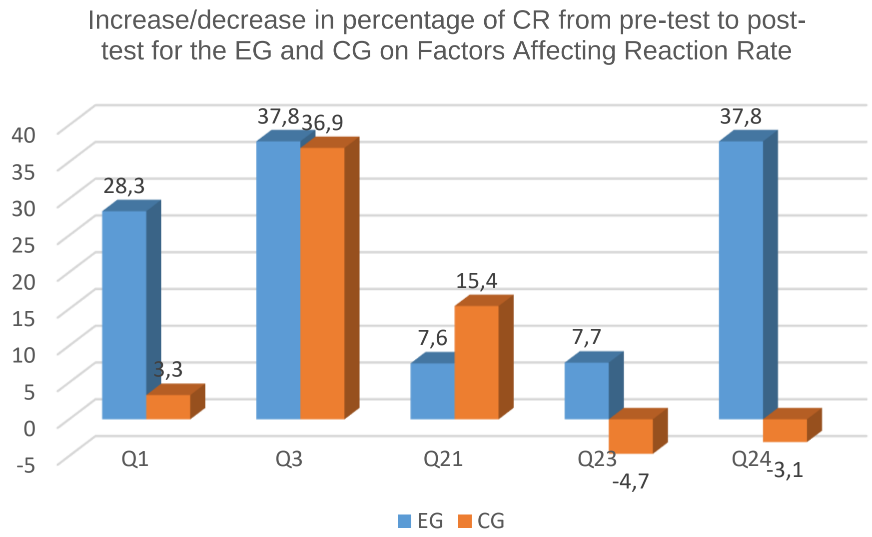


Figure 5.8 Percentage increase/decrease in CR from pre-test to post-test for the EG and the CG on Factors Affecting Reaction Rate

In Q3, learners were provided with a balanced equation for the decomposition of calcium carbonate. Calcium carbonate is a solid, therefore, factors such as pressure, concentration, and even mass do not affect the rate of its decomposition. The only factor that could affect the rate of its decomposition is temperature. The percentage of the Correct Responses (CR) were higher for the EG (49.2%) compared to the CG (37.8%) in the post test as shown in Table 5.2, although the percentage increase from pre-test to post-test was almost identical as shown in Figure 5.2. It may, therefore, be deduced that neither traditional teaching approach nor CSBI was better for Q3.

In Q21, learners were required to identify an incorrect statement about reaction rate. The incorrect statement was that the bigger the particles of a solid reactant, the faster the reaction rate. While learners were most probably aware that increasing surface area increases reaction rate, it appears they thought increasing surface area is the same as “bigger particles”. The percentage of CR from the EG was marginally higher than in the CG (Table 5.2) in the post-test, but the CG had a moderately higher increase from the pre-test to the post-test (Fig 5.2).

Both Q23 and Q24 assessed the learners’ understanding of the effect of temperature on reaction rate. Q23 involved a reversible reaction which reached an equilibrium in a closed vessel. Learners were then asked what would happen if temperature was increased. The correct response was that the rate of both the forward and reverse reactions would increase and the forward reaction was shown as exothermic. This was a challenging question for most learners as can be seen in Table 5.2 which indicates that the percentage of correct responses was only 18.9% for the EG and 9.2% for the CG in the post-test (see Table 5.2). This is in line with empirical studies conducted in other countries (Atabek-Yigit, 2018:752), showing that learners have challenges with regards to how temperature affects reaction rate. As shown in this current study, using CSBI may reduce the proportion of learners who have these challenges.

Question 24 (Q24) tested learners on the effect of temperature on exothermic and endothermic reactions; increasing temperature increases reaction rate for both exothermic and endothermic reactions. There was a considerably higher percentage of Correct Responses (CR) in the post-test for the EG compared to the CG as shown in Table 5.2. There was also a substantial increase of 37.8% in CR in the EG from pre-test to post-test. For the CG the percentage of CR decreased by 2% from pre-test to post-test indicating that the traditional approach was not successful in assisting learners to understand the effect of temperature (Figure 5.2), however, CSBI was helpful in assisting learners to understand the effect of temperature on reaction rate.

5.2.4.3 Collision Theory

Collision Theory was assessed through questions Q20, Q22 and Q26. Figure 5.3 shows the change in percentage of correct responses on the questions on Collision Theory.

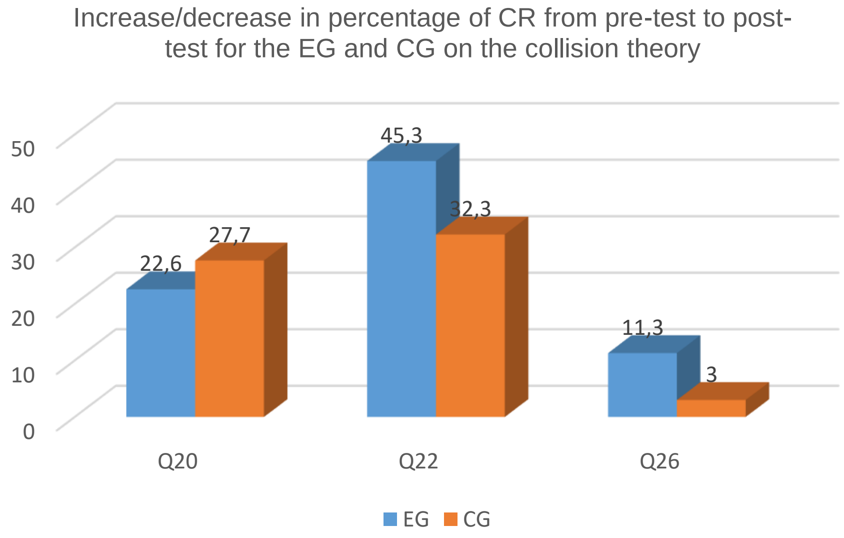


Figure 5.9 Percentage change in CR from pre-test to post-test for the EG and the CG on Factors Affecting Reaction Rate.

Question 20 (Q20) tested the concept in Collision Theory that, increasing temperature increases the number of effective collisions per unit time. Only 35.8% of learners in the EG had correct responses as compared to 41.5% in the CG in the post-test (Table 5.2). The Control Group had a slightly higher increase of correct responses from the pre-test to the post-test as compared to the Experimental Group (Figure 5.3). While the difference was not large, it should be noted that learners taught through traditional instruction performed better than those in the EG in Q20. Like Q20, Q26 was about temperature where learners were asked the effect of increasing temperature on the rate of collision of gas particles and rate of effective collisions. Rate of collisions and rate of effective collisions increase if temperature increases, however, most learners thought that only the rate of effective collisions increases, which may explain why only a small proportion of learners in both the EG and the CG could answer correctly. Only 28.3% of the responses in the EG were Correct Responses (CR) compared to only 21.5% of those in the CG, in the post-test (Table 5.2). The increase in the percentage of the CR from the pre-test to the post-test was also marginally higher in favour of the EG (Figure 5.3). The slightly higher percentage of the EG could be attributed to learners' exposure to simulations of the Collision Theory.

Question 22 (Q22) assessed the two concepts in the Collision Theory. They are that: particles must collide with the correct orientation and that colliding particles must have a certain minimum amount of energy. The EG had a significantly higher increase in percentage of Correct Responses from the pre-test to the post-test compared to the CG (see Figure 5.3). This difference may be explained by the fact that learners in the EG were exposed to simulations of the collision theory which may have led to improvement in their understanding. Consistent with the Cognitive Theory for Computer Simulation-based Instruction (CTCSI) (Section 2.7), the use of scaffolding tools such as simulations and Predict-Observe Explain (POE) increases conceptual understanding. This may explain the observed differences.

5.2.4.4 Activation Energy and Heat of Reaction

Concepts on Activation Energy and Heat of Reaction were assessed in questions Q5, Q8, Q9, Q11 and Q17. Fig 5.4 shows a bar graph of the increase/ decrease in percentages of CR from the pre-test to the post-test for the EG and the CG, on the questions on Activation Energy and Heat of Reaction.

Questions 5, 6 and 11 (Q5, Q6 and Q11) were concerned with activation energy. In Q5, learners were asked to choose a statement that best describes activation energy from the given statements. The required response was that activation energy is the minimum energy required by reactant molecules for effective collision. From Table 5.2, 24.6% of the responses of learners in the CG were correct, as compared to 26.4% for learners in the EG in the post test. The graph also shows that there was a greater increase in percentage of CR from the pre-test to the post-test for the EG compared to the CG (Fig 5.4). This data implies that CSBI was a more effective approach in assisting learners to comprehend the concept of activation energy when compared to the traditional approach.

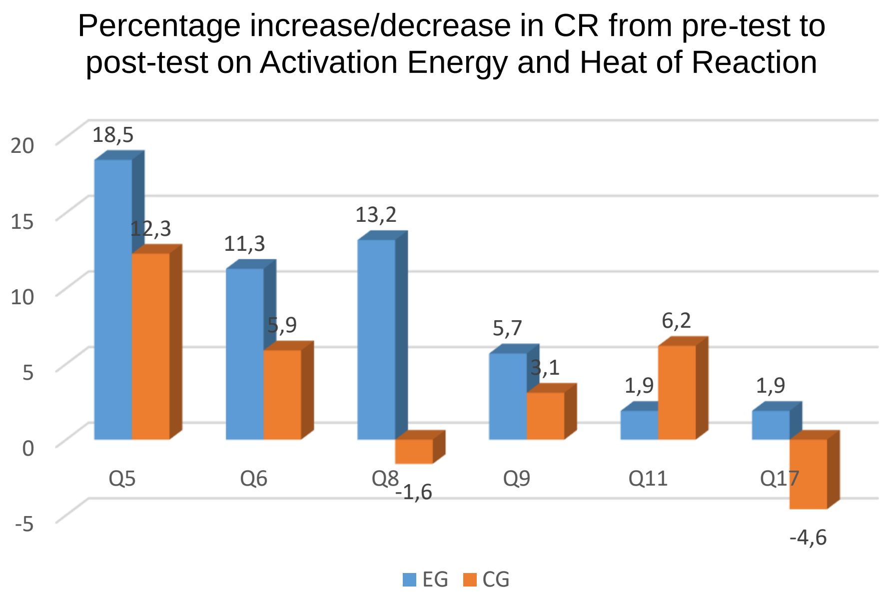


Figure 5.10 Percentage change in CR from pre-test to post-test for the EG and the CG on Activation Energy and Heat of Reaction.

Question 6 (Q6) assessed the understanding of learners of the effect of a catalyst on activation energy and heat of reaction for a specific reaction. The catalyst decreases the activation energy but has no effect on heat of reaction. The proportion of learners whose responses were correct is 13.2% for the EG and 12.3% for the CG in the post-test (Table 5.2), however, in terms of the gain in percentage from pre-test to post-test, the EG had a moderate gain (11.5%) as compared to the CG (5.9%) (Figure 5.4). The percentages are low for both groups indicating that the concept of activation energy was not well understood.

In question 11 (Q11), learners were provided with a potential energy diagram with potential energy values on the Y-axis for an endothermic reaction. They were then asked to calculate the energy change and the activation energy from the graph. Only 13.2% of the responses of learners in the EG were correct, when compared to 15.4% for the CG in the post-test (Table 5.2). The proportion of correct responses was low in both groups, implying that the calculation of activation energy and heat of reaction from potential energy diagrams was not well understood.

Concepts in chemical energetics are linked and related to concepts in chemical kinetics. Literature has also shown that learners develop misconceptions in reaction rates due to misunderstanding of chemical energetics concepts (Cakmakci, 2010), hence, two questions that test the basic concepts of enthalpy change of reaction were included in the Test on Chemical Reaction Rate Concepts (TCRRC). In question 8, learners were required to recognize that the enthalpy change of a reaction is the difference between the potential energy of the products and the potential energy of the reactants. In the EG, 24.5% of learners' responses were correct as compared to 13.8% of those in the CG in the post-test (Table 5.2). The EG had a moderate increase in CR percentage from pre- to post-test, but the CG had a decrease in CR (Fig 5.4). Q9 was also on enthalpy change, but learners were simply required to recognize that the heat of reaction is the energy change during a chemical reaction. In the EG 26.4% of the responses of the learners were CR as compared to 16.9% in the CG in the post-test (Table 5.2). Conceptual understanding of chemical energetics was, therefore, low in both EG and CG. Q17 asked learners to identify a graph that showed the relationship between activation energy and temperature from given graphs. The learners were supposed to realize that increasing temperature does not change the activation energy, however, very few learners understood this concept, from both the EG and CG, even after instruction (Table 5.2). The EG had a slight increase in percentage of CR after treatment and the CG had a noticeable decrease in percentage of CR (Figure 5.4). This may imply that the traditional approach was not helpful at all in assisting learners to understand this concept.

5.2.4.5 Catalysis

Mechanism of reaction and catalysis was assessed through questions 13, 16, 18, 19, 27 and 28 (Q13, Q16, Q18, Q19, Q27 and Q28). The concept tested in in these questions was that, catalysts speed up the rate of a reaction by lowering the net activation energy. Catalysts do this by providing an alternative reaction pathway or reaction mechanism of lower activation energy than the mechanism for the same reaction without a catalyst. These concepts were tested using graphical representations or directly using words as explained in the analysis of these questions that follows. Figure 5.5 shows the percentage gain in CR from pre- to post-test for the EG and CG on these questions.

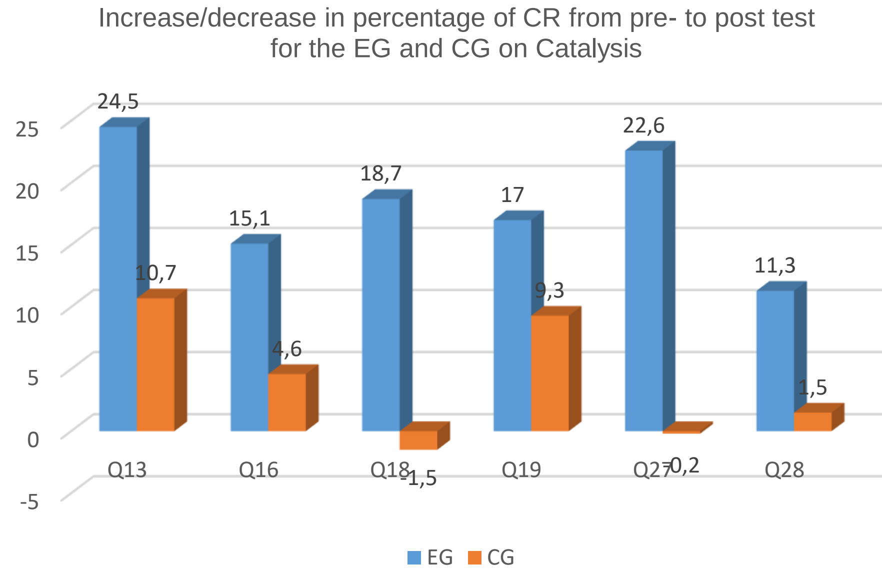


Figure 5.11 Percentage increase/decrease in CR from pre-test to post-test for the EG and the CG on Catalysis

In Q13, learners were provided with a potential energy diagram for an exothermic reaction with labels for - enthalpy change, activation energy, potential energy of reactants and potential energy of products. They were asked which quantity would change if a catalyst was added. The item was assessing learners to find out if they understood that a catalyst lowers the activation energy of a reaction, hence increases reaction rate; this was a simple recall question. Learners in both the CG (56.9%) and in the EG (56.6%) performed at about the same level in the post-test (Table 5.2), however, the EG made a significant gain from the pre- to the post-test when compared to the CG (Figure 5.5).

Question 16 (Q16) was challenging for most learners as the performance in both the EG and the CG was not good. In the question, learners were provided with a graph of concentration of a reactant against time. They were then asked to identify the graph that would be obtained if a catalyst was added. Only 9.2% of the learners in the CG could identify the Correct Response (CR) as compared to 20.8% in the EG in the post-test (Table 5.2). This was the case, even though most of the learners in the CG had shown a good understanding that a catalyst lowers the activation energy of a reaction in question 13. To identify the correct response, learners had to realize that the graph of concentration of a reactant against time for a faster reaction is shifted to the left and should have a greater gradient but must level off at the same level as that without a catalyst. The better performance by the EG could be attributed to the fact that simulations on factors affecting reaction rate, generated graphs as the reaction occurs. This freed their cognitive resources which most likely enabled them to understand the effect of concentration and catalysts on reaction rate. This is consistent with the findings from the CTCSI (Section 2.7). Learners were also able to change different conditions and observe changes on these graphs.

Question 18 (Q18) was related to Q13 in that learners were provided with a potential energy diagram. They were asked which change in reaction conditions would change the activation energy, labelled as P, and the difference between the potential energy of the activated complex and potential energy of products, labelled R, on the graph. Only 41.5% of learners in the EG could identify the correct answer compared to 46.2% of learners in the CG in the post-test (Table 5.2). The EG, however, made a significant gain from the pre- to the post-test while the CG had a decrease in percentage of CR (Figure 5.5).

In Q19, learners were asked the same concept assessed in Q13 and Q18. They were asked to identify a statement which explains why a catalyst causes a reaction to proceed faster. The correct answer from the statements provided was that, the catalyst lowers the activation energy. This item showed clearly that neither the CG nor the EG understood this concept well. Only 32.1% of learners in the EG and 30.8% of learners in the CG answered the question correctly in the post-test (Table 5.2). Figure 5.5 shows that the EG made a significant gain after treatment compared to the CG.

In Q27, learners were asked to identify a statement that describes how a catalyst increases the reaction rate; the correct response was that a catalyst provides an alternative reaction pathway. The other alternatives are well known misconceptions that other researchers have unearthed in this topic (Cakmakci, 2010, Cakmakci & Aydogdu, 2011). The percentage of Correct Responses for the Experimental Group was 26.4% while it was only 6.2% for the Control Group in the post-test (Table 5.2). The EG made a much bigger gain in percentage of CR after treatment, compared to the CG (Figure 5.5), hence, teaching through CSBI seemed to remedy some of the strongly-held misconceptions that learners have in the concepts in catalysis.

Question 28 (Q28) asked learners what happens to the rate during a reaction, if a catalyst is present. It is well known that generally for elementary reactions, the reaction rate decreases with time during the reaction. Even in the presence of a catalyst, a reaction rate decreases as reaction proceed as concentration of reactants decreases with time. The presence of a catalyst confused many learners, resulting in a very low performance in this question. Only 17.0% of learners in the EG and 12.3% of learners in the CG managed to answer the question correctly, after treatment. The EG made a moderate gain in percentage of CR after treatment as compared to the CG, indicating that CSBI was a better approach in assisting learners to understand this concept when compared to traditional instruction (Figure 5.5).

5.2.4.6 Distribution of molecular energies

Distribution of molecular energies was assessed through Q7, Q12 and Q14. Figure 5.6 shows the percentage increase in CR after treatment, in the EG and the CG.

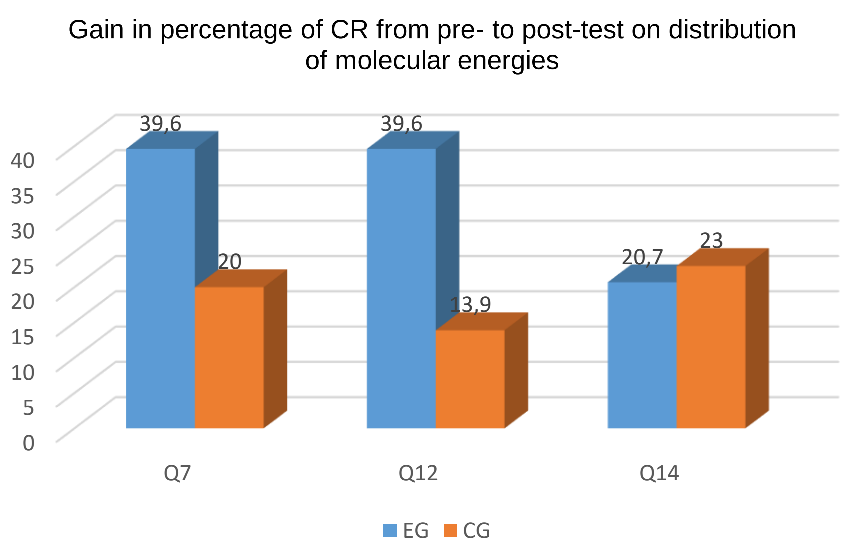


Figure 5.12 Percentage increase/decrease in CR from pre-test to post-test for the EG and the CG on distribution of molecular energies

Question 7 (Q7) required learners to identify temperature as a measure of the average kinetic energy of molecules, from the given options. In the post-test, 54.7% of the learners in the EG could identify the CR as compared to 33.8% in the CG (Table 5.2). The percentage gain after treatment for the EG was about twice that of the CG (Figure 5.6).

In Q17 learners were provided with graphs representing the molecular distribution, for a reaction at different temperatures. They were then asked to identify the graph with the reaction at the highest temperature. In the post-test 54.7% of the EG could identify the correct graph as compared to 43.1% of the CG (Table 5.2). The EG had more than twice in percentage gain from pre-test when compared to the CG (Figure 5.6). In Q17 the learners were provided with the same graph in Q12 but were asked to identify the graph for the reaction at the lowest temperature. Table 5.2 shows that 54.7% of the EG could identify the CR compared to 49.2% of the CG. Figure 5.6, also, shows that the CG made a slight gain after treatment when compared to the EG. The results on distribution of molecular energies indicate that CSBI was a more effective instructional approach than the traditional instruction.

5.2.5 Findings on the effectiveness of the use of CSBI as compared to the traditional instructional approach, on the academic achievement of learners in CRR concepts

- The results of the independent t-test showed that there was a statistically significant difference in the academic achievement of the EG (M = 10.23, *SD* = 4.30) and CG (M = 8.22, *SD* = 3.30); $t(116) = 2.87$, $p = .005$. The independent *t*-test means that the differences in the academic achievement of the EG and CG were not due to chance but were due to treatment effects.

- The mean score for learners taught CRR by CSBI, M = 10.23, was greater than for the learners taught through traditional approach, M = 8.22; d = 0.53. The value of Cohen's *d* implies that the effect size was moderate.

- The findings of this study therefore are that CSBI is more effective than the traditional approach in teaching CRR, with a moderate effect size.

5.3 Presentation and Analysis of Results of Attitudes Towards Chemistry Lessons Scale

The Attitudes Towards Chemistry Lessons Scale (ATCLS) was administered to answer Research Question 2 (RQ2).

Research Question 2 (RQ2): What are the effects of CSBI and the traditional instructional approach on learners' attitudes towards the chemistry lessons in CRR?

As discussed in the literature review, attitudes are psychological constructs that cannot be measured directly. ATCLS (Appendix 8) is a modified Likert type scale that was used to measure the attitudes of learners towards the Chemistry lessons on CRR taught by CSBI and traditional approach in the EG and CG respectively. ATCLS had four dimensions with three items for each dimension. In this study, non-parametric tests were used to analyse the data.

5.3.1 Attitudes Toward Chemistry Lessons Scale Results before Treatment

Mann-Whitney U test, a non-parametric test, was used to test the difference between the EG and the CG, before and after treatment. Before conducting the Mann-Whitney U test, SPSS version 26 was used to determine whether the data met the assumptions of the test. Independent variable should have two levels, independent observations while the dependent variable should be measured at ordinal level or greater; and the dependent variable distribution must have the same shape. Inspection of the data showed that the first three assumptions were met. Inspection of the histograms of the data for the EG and the CG (Figure 5.13) indicated that both data sets had approximately the same shape. Their box plots were also similar in shape (Figure 5.4), hence, it was deduced that the data met the assumptions for the Mann-Whitney U test.

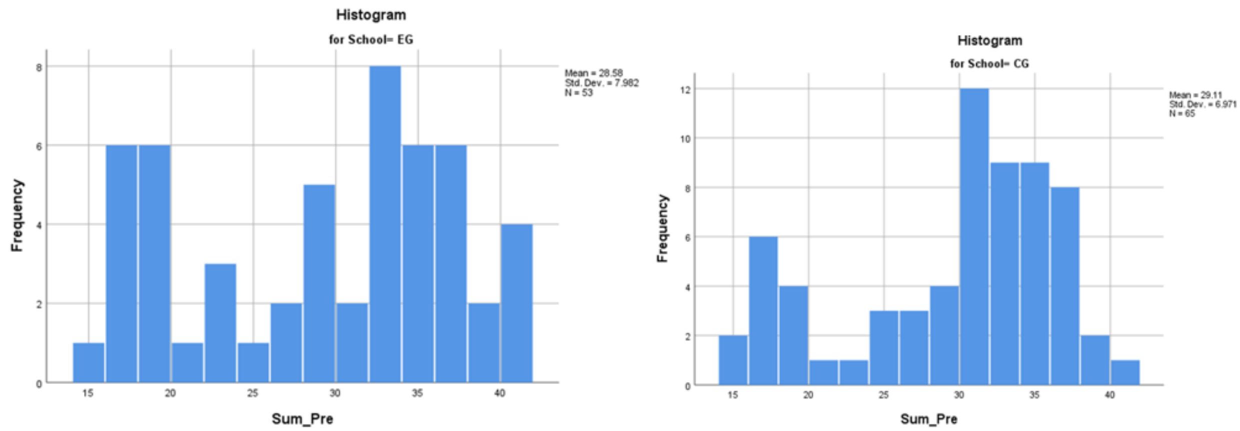


Figure 5.13 Histograms of summated Attitude Pre-test Scores (Sum_Pre) of the Experimental Group (EG) and Control Group (CG).

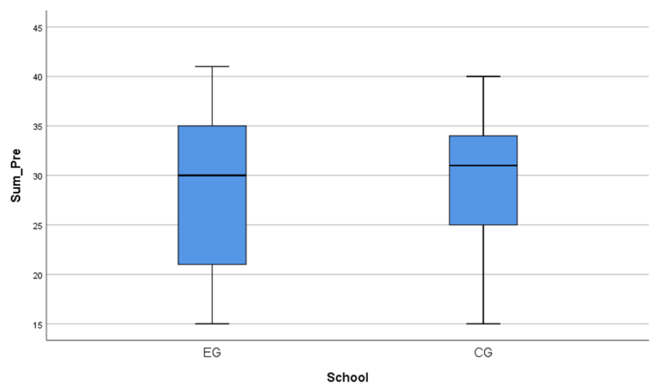


Figure 5.14 Box Plots of the summated Pre-test Attitudes Scores (Sum_Pre) of the EG and the CG

An independent sample Mann Whitney U test was performed from the data collected using ATCLS, to find out if the attitudes of the learners were similar before treatment. The Mann-Whitney U test indicated that there was no statistically significant difference in the attitudes of learners in the CG (Mean Rank = 60.05, N = 65) and EG (Mean Rank = 58.83, N = 53) before treatment, U = 1 758, z = 0.034, *p* = .853, two tailed. This implies that the attitudes of learners towards Chemistry lessons were approximately the same before treatment.

5.3.2 Attitudes Toward Chemistry Lessons Scale Results after Treatment

To find out if the scores on ATCLS had similar shapes in terms of their distributions, SPSS version 26 was used. Visual inspection of the histograms of the EG and CG data show that the data sets had approximately similar shapes (Figure 5.15). Visual inspection of the Box plots confirmed that the data had similar shape (Figure 5.16), hence, it was deduced that the assumptions of the Mann-Whitney U test were not violated.

The independent sample Mann-Whitney U test performed after treatment indicated that there was statistically significant difference in the attitudes of learners in the CG (Mean Rank = 45.68, N = 65) and EG (Mean Rank = 76.45, N = 53), U = 824, z = -4.867, $p <$ .05, two tailed. The Mean Rank of the EG was higher than that of the CG implying that the Attitudes of the EG improved when compared to the CG.

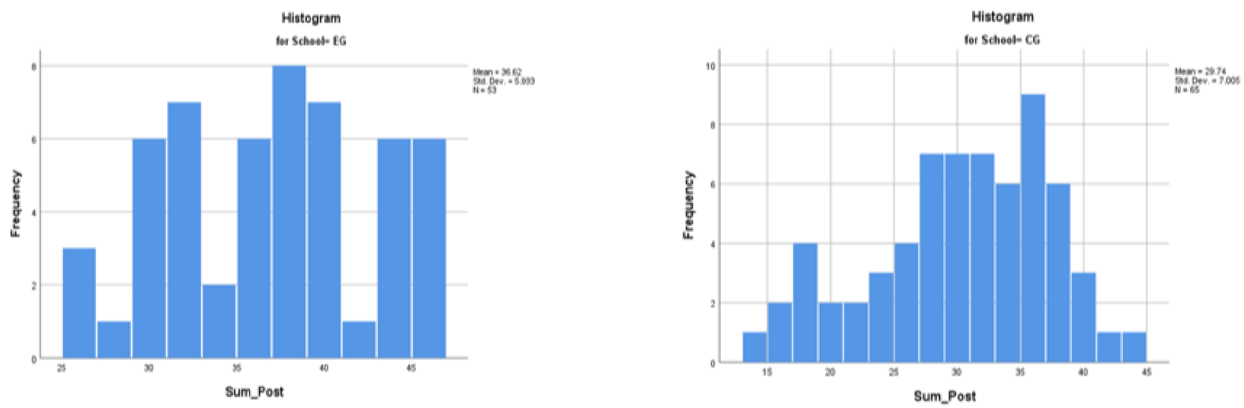


Figure 5.15 Histograms of Post-test Attitude Scores (Sum_Post) of the EG and the CG

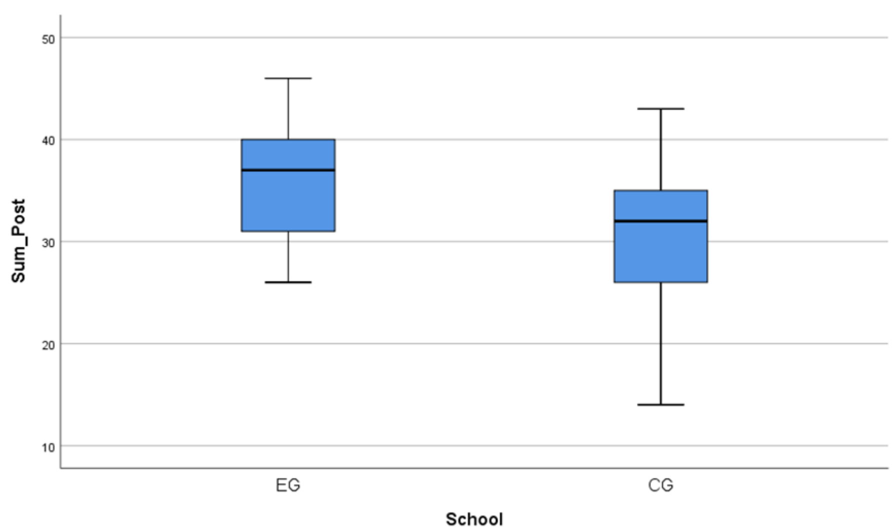


Figure 5.16 Box Plots of the Post-test Attitudes Scores (Sum_Post) of the EG and CG

5.3.3 Effect size Partial eta squared for the difference between the CG and EG after treatment

To determine the percentage of variability that was accounted for by the independent variable (CSBI/Traditional Instructional approach) partial eta squared was determined. Partial Eta squared was found to be 0.20, which means that 20% of the variance in the Attitudes as measured by ATCLS could be explained by the instructional method used to teach the EG. A partial eta squared of 0.01 indicates small effect, 0.06 indicates medium effect and 0.14 indicates large effect (Cohen 1988, cited in Wagner, 2019:7). The partial eta squared from this study was of 0.20, therefore, a large effect size, hence, it can be concluded that CSBI had a large effect on improving the learners' attitudes towards the lessons on CRR.

5.3.4 Comparison of the attitudes of the Experimental Group and Control Group Pre- and Post-Treatment

The ATCLS had twelve items with four sub-dimensions: Liking for chemistry theory lessons; liking virtual chemistry laboratory work; evaluative beliefs about school chemistry and behavioural tendencies towards learning chemistry. Table 5.3 shows that the EG learners' positive attitudes increased much more for all the four dimensions when compared to the CG learners' attitudes from Pre- to post-treatment. Analysis of the dimension, *liking for chemistry theory lessons*, shows that there was significant increase in the EG learners' liking of chemistry lessons after exposure to CSBI. The proportion of learners in the EG who found chemistry lessons interesting more than doubled after treatment while no change occurred in the CG. The proportion of learners in both the EG and CG who regarded chemistry as one of their favourite school subjects was similar before treatment and they were no huge gains after treatment for both groups. The percentage of learners who reported that they liked chemistry more than any other school subject increased significantly (26% to 42%) in the EG while it remained almost unchanged in the CG.

Table 5.3 Percentages of Positive Responses Before and After Treatment for the EG and CG

Sub-Scale	Items	Percentage of Positive Responses			
		Pre-Treatment		Post-Treatment	
		EG	CG	EG	CG
Liking chemistry theory lessons	Q1. I like chemistry more than any other school subject.	26	17	42	20
	Q5. Chemistry lessons are interesting.	42	62	87	62
	Q9. Chemistry is one of my favourite subjects.	74	60	79	63
Liking virtual chemistry laboratory work	Q2. I like to do virtual chemistry experiments.	64	55	87	68
	Q6. When I am working on the virtual chemistry lab, I feel I am doing something important	51	58	83	52
	Q10. Doing virtual chemistry experiments in school is fun.	51	54	79	52
Evaluative beliefs about school chemistry	Q3. Chemistry is useful for solving everyday problems.	39	34	64	37
	Q7. People must understand chemistry because it affects their lives	57	52	85	65
	Q11. Chemistry is one of the most important subjects for people to study.	47	55	79	43
Behavioural tendencies towards learning chemistry	Q4. I am willing to spend more time reading chemistry books.	47	51	91	51
	Q8. I like trying to solve new problems in chemistry.	47	63	83	72
	Q12. If I had a chance, I would do a project in chemistry.	62	52	83	51

Note: Positive responses are the responses where the learner chose *agree* or *strongly agree* with each statement

In the dimension, *liking virtual chemistry laboratory work,* there were significant gains in all the three items in the EG compared to the CG. In the EG there was a significant increase in percentages of learners who liked doing virtual chemistry experiments; who felt that working on the virtual chemistry laboratory is something important and who thought that doing virtual chemistry experiments in school was fun. In contrast to this, the proportion of learners in the CG who felt that doing virtual chemistry experiments is important decreased from 58% before treatment to 52% after treatment; the proportion of learners who thought that doing virtual chemistry experiments is funny decreased from 54% before treatment to 52% after treatment.

This trend was also observed for the dimension, *evaluative beliefs about school chemistry.* Before treatment there was a fewer proportion of learners who believed that: *chemistry is useful for solving everyday problems*; *people must understand chemistry because it affects their lives* and *chemistry is one of the most important subjects for people to study* in the EG. There was a higher proportion of learners in the EG with much more positive beliefs in the three items after treatment as compared to the CG (Table 5.3).

In the last dimension, *behavioural tendencies towards learning chemistry,* 47% of learners in the EG were willing to spend more time reading chemistry books, but this increased to 91% after exposure to CSBI. This is important as it shows that the tendency towards exerting more effort in learning increased, most likely due to exposure to CSBI. The proportion of learners in the CG willing to spend more time reading chemistry books did not change after exposure to traditional instruction. The proportion of learners who liked to try to solve new problems increased much more for the EG than the CG. Also, the proportion of learners willing to do a chemistry project was much greater in the EG, after treatment. The CG experienced almost no change in percentage of learners for this item (Table 5.3). The increase in behavioural tendencies towards learning chemistry in the EG is important as it indicate that after exposure to CSBI the learners were willing to exert more effort in learning chemistry.

5.3.5 Findings on effects of Computer Simulation-Based Instruction and the traditional approach on learners' attitudes towards the chemistry lessons in Chemical Reaction Rates

- There was statistically a significant difference in the attitudes of learners between the CG (Mean Rank = 45.68, N = 65) and EG (Mean Rank = 76.45, N = 53), U = 824, z = -4.867, $p < .05$, two tailed as determined using Mann-Whitney U test after treatment. The Mean Rank of the EG was higher than that of the CG implying that the Attitudes of the EG improved as compared to the CG. This means that the difference in attitudes was not due to chance but were due to exposure of the EG to CSBI.

- The effect size was large as determined by eta squared. The value of eta squared was 0.20 - a very large effect size. This effect size means that 20% of the variance in Attitudes between the CG and EG can be explained by exposure to treatment; in other words, 20% of variance in Attitudes was due to CSBI.

5.4 Presentation and Analysis of Data from Interviews on learners' Conceptual understanding of Chemical Reaction Rate

Data from interviews was collected to answer RQ3.

Research question 3: Does Computer Simulation-Based Instruction improve learners' conceptual understanding of Chemical Reaction Rate as compared to traditional instruction?

Qualitative data was collected through semi-structured interviews (Appendix 10). While the first part of the question was a closed question with a correct or wrong response the participants were asked to explain their reasoning to understand how they arrived at their answers.

5.4.1 Demographic Information of Participants

Eleven participants were interviewed. The sample was made up of ten learners and one male teacher. Eight of the learners were males and two were females. The youngest learner was 16 and the oldest was 19 years old. Five of the learners were sampled from the EG class and the other five from the CG class. The interviewed teacher had attended all the lessons taught through CSBI to the EG. The teacher had a Bachelor of Education degree with Chemistry as a major; in addition, he had a Bachelor of Science degree in Computer Science. The learners from the EG and CG were purposively sampled to include those with average to high marks in the post-test. The five learners from the CG had scored 8, 9, 12, 12, and 15 marks in the post test. Those from the EG had scored 9, 9, 11, 11 and 15 marks in the post test. For purposes of data analysis, the participants were coded depending on whether they were from the EG or CG and whether they were Males (M) or Females (F). For example, the participant coded **EGM01** is a learner who was from the EG and was a male; participant coded **CGF09** was a learner from the CG and a female. The teacher was coded **ED11**.

5.4.2 Transcription

After each interview, I transcribed the interviews using a free Application on Google Play Store called 'Live Transcribe'. Each interview was listened to twice before checking the transcription for errors. After this I listened again pausing the audio and correcting any parts that were not correctly transcribed; this was in addition, to correcting grammatical errors in the transcription.

5.4.3 Member Checks

After all the interviews were transcribed, I took the transcribed interviews to the participants and each participant was given a copy of his/her transcribed interview. The participants were asked to carefully read their transcribed scripts (to confirm what was said) in my presence. Only two indicated a few minor changes which were effected in their presence. After they were satisfied with their responses, all the scripts were collected on the same day. After this process of authentication through member checking the transcribed interviews (Appendices 12-21 & 23) were ready for analysis.

5.4.4 Data Analysis

This study as indicated earlier, is a mixed-method research. In this section, Qualitative Content Analysis (QCA) is used to analyse the interview data. QCA is a rule-based method, performed by making coding frames or guides that consist of categories with relevant meanings and involves assigning passages to these categories (Schreier, 2019:3, Mayring, 2014:10). Some of the reasons for using QCA are - it helps to condense the data; it provides an overview of key concepts; it is not fixed to any specific ontology or epistemology and it is highly flexible (Schreier, 2019:3). QCA is a mixed-method approach where the assignment of categories to text is a qualitative step and the analysis of frequencies of categories is a quantitative step (Mayring, 2014:10).

The study followed the seven steps of the deductive category assignment in structured QCA as suggested by Mayring (2014:96), which are:

1. Formulating the research question.
2. Defining of the category system: Responses to interview were categorized into Sound Understanding (SU), Partial Understanding (PU) or Lack of Knowledge (LK).

3. Defining of the coding guideline: scientifically correct answers to the interview questions, anchor examples and coding rules.
4. Preliminary coding, adding anchor examples and coding rules.
5. Revision of the categories and coding guideline.
6. Final working through the material.
7. Analysis, category frequencies and contingencies interpretation.

The analysis did not follow in that order, as the steps are iterative (Schreier, 2019:6). The results of the analysis conducted by following these steps are summarized in the tables for the coding guide for each analytic unit for CRR that follows in this section. The results for the coding of all the transcripts for learners is provided in Appendix 22.

The deductive categories are developed *a priori* from theory, previous studies, and even from the interview guide (Schreier, 2019:3, Mayring, 2014:97). In this study the questions on CRR concepts in the interview guide formed units of analysis (Mayring, 2014:99). The questions (units of analysis) are categorized into the main concepts and skills which are: Reaction rate and calculation of rate; Factors Affecting Reaction Rate; Collision Theory; Activation energy and Heat of Reaction; Catalysis; and Distribution of Molecular Energies.

The participants' conceptual understanding of each unit of analysis was categorized as Sound Understanding (SU), Partial Understanding (PU) or Lack of Knowledge (LK). The categories are defined in Table 5.4 by following ideas from previous researchers (Cakmakci, 2010:450, Cakmakci & Aydogdu, 2011:22, Kurt & Ayas, 2012b:984).

Table 5.4 Definition of Categories

Category	Definition of Category
Sound Understanding	Responses that included scientifically-accepted ideas.
Partial Understanding	Partly correct responses; may include some scientifically-incorrect ideas.
Lack of Knowledge	Incorrect, unintelligible ideas or no response or where a learner indicated that he/she had no idea.

Questions on the interview guide (Appendix 10) for learners were used as the units of analysis. The conceptual questions included some of the questions in the TCRRC (Appendix 7). For each question participants were required to explain the concepts or explain how they obtained the answers. The purpose was to establish their conceptual understanding and provide further evidence by triangulation of the quantitative results from TCRRC (Appendix 10). The participants' responses were categorized using the coding guides which provide a summary of the qualitative part of the analysis; its function is to reduce and summarize the interview data (Schreier, 2019:6).

The coding guides were used to code the responses of the participants. After the initial coding was completed, I re-coded and determined intra-rater agreement. There was strong intra-rater agreement as determined by Cohen's kappa, however, to improve reliability of the results, one expert teacher was given the interview transcripts and the coding guides and was requested to code independently. Cohen's kappa was determined for every interview transcript by comparing my ratings and those of the expert teacher. There was strong inter-rater agreement, ranging from strong agreement to perfect (McHugh, 2012:279) as shown in Table 5.5. The summary of the coding of all the learners' transcripts is provided in Appendix 22.

Table 5.5 Cohen's Kappa for interrater reliability for coding of interview transcripts

Transcript	Kappa (k)	Significance	Interpretation
EGM01	.88	P < .001	Strong
EGM02	1.00	P < .001	Perfect
EGM03	.93	P < .001	Almost perfect
EGF04	.91	P < .001	Almost perfect
EGM05	.81	P < .001	Strong
CGM06	.87	P < .001	Strong
CGM07	.89	P < .001	Strong
CGM08	.91	P < .001	Almost perfect
CGF09	.93	P < .001	Almost perfect
CGM10	.86	P < .001	Strong

There was a discussion between the expert teacher and I, on a few questions where there was no agreement. After reaching an agreement, the results of the final coding are presented in the next sections.

5.4.4.1 Reaction Rate and Calculation of Rate

In the Reaction Rate and Calculation of Rate, the concepts include, the definition of reaction rate, calculations of average reaction rate and instantaneous reaction rate. Reaction rate needed to be defined precisely as - the change in concentration of a reactant or product per unit time. At this level a general statement, such as – *a rate is how fast a reaction occurs* - at best can only be categorized as partial understanding. The coding guides for Reaction Rate and Calculation of Rate are shown in Table 5.6 and Table 5.7.

The coding guide for questions on describing what happens to reaction rate during a reaction in the absence or presence of a catalyst is shown in Table 5.7. In general, the reaction rate decreases with time for the reactions that learners are exposed to, at this level. Since the concentration of the reactants are greatest at the beginning of the reaction, reaction rate is fastest at the beginning. As time progresses the reactants are converted to products and their concentration decreases, therefore, the reaction rate decreases.

In the remainder of this section on Reaction Rate and Calculation of Rate, a detailed question-by-question analysis is provided.

Question 2.1*: Tell me what you understand by the term "rate of a chemical reaction."*

Some of the responses in which the participants demonstrated SU are: Reaction Rate …

> *"Is the change in concentration of the reactant whereby it is divided by the time for the reaction,"* participant EGM01.
>
> *"….. is the change in concentration of a product or reactant per unit time,"* Participant EGM02.

Table 5.6 Coding Guide for defining of Rate and calculation of rate

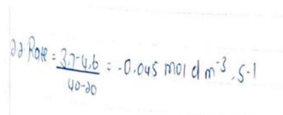
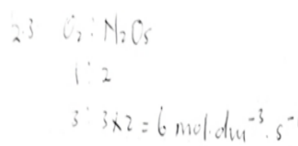
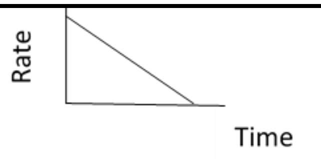
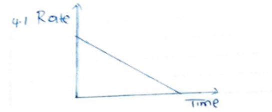
Unit of Analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
2.1 Defining rate	Reaction rate is change in concentration/amount of a reactant/product per unit time.	SU	*"Is the change in concentration of the reactant whereby it is divided by the time for the reaction,"* participant EGM01.	Rate defined in terms of concentration or amount
		PU	*"is the speed at which the reaction takes place,"* participant CGM07.	Partly correct
		LK	I don't know	No part of response correct
2.2 Calculating rate	$Rate = \frac{\Delta[R]}{\Delta t} = \frac{3.7 - 4.1}{40 - 20} = -0.045$	SU		Participant shows all the steps
		PU		Partly correct
		LK	*we are going to say the average of 40 sec minus the average of consumption of 20 seconds we are going to say 3.7-4.6 it will give us 0.9 divide by 2. 0.45.*	No correct part
2.3 Using stoichiometry	O_2:N_2O_5 1:2 3:x x=3×2=6mol.dm^3.min^{-1}	SU		All steps shown
		PU	*"If I say 2X3 this represents the moles. It will be 6 moldm3min^{-1},"* Participant EGM08	Correct answer, no working.
		LK		Completely incorrect.

Table 5.7 Coding Guide for Interview questions on reaction rate against time

Unit of Analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
IQ4.1 Rate against time	 Reaction rate decreases with time	SU		Correct shape of graph and correct labels for axes. Correct explanation
		PU	*"…the concentration will be decreasing with time the gradient will be less steeper,"* participant EGM03.	Correct graph; incorrect explanation.
		LK		Incorrect shape and incorrect explanation.
IQ6.5 Describing rate against time	Reaction Rate decreases with time	SU	*"It decreases with time,"* participant EGM02.	Completely correct.
		PU		Include incorrect information
		LK	*I can say. This graph shows that … the reaction rate will be equalized to time and this is how I understand it,"* participant CGM06.	Completely incorrect response.

Responses where participants showed PU are:

> *"According to my understanding it talks about how the reaction happen per unit time … how fast a reaction is to make product,"* participant EGM03.
>
> *"Rate of a reaction is the speed at which a reaction takes place,"* participant CMG06.

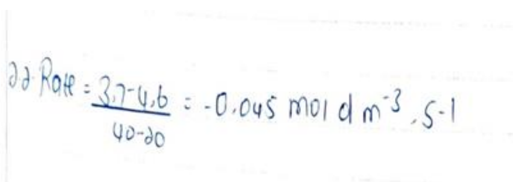
Four of the participants in the EG had SU in defining reaction rate with only one showing LK. Only two participants in the CG had SU in defining reaction rate (Table 5.8).

Question 2.2: *During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained:*

Time (s)	*0*	*20*	*40*	*60*	*80*	*100*
[A]/mol.dm^{-3}	*5.6*	*4.6*	*3.7*	*3.0*	*2.4*	*2.0*

The average consumption rate of A, in mol.dm^{3}.s^{-1} during the time interval between 20 s and 40 s is ….

Question 2.2 required participants to calculate reaction rate given the concentration of a reactant at various time intervals. Those participants who had LK of the concept of reaction rate as demonstrated in question 2.1 had problems in calculating reaction rate from given information. An example of a response that showed SU of calculation of reaction rate given by Participant EGM02 is as follows:



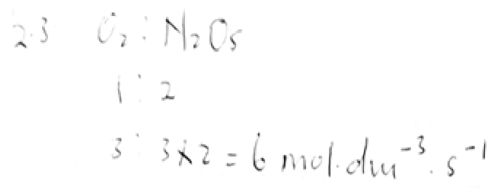
An example of a response showing LK, from participant CGM07, is as follows:

> *We are going to take the average consumption rate. We are going to say in 40 sec we are going to say the average of 40 sec minus the average of consumption of 20 seconds we are going to say 3.7-4.6 it will give us 0.9 divide by 2. 0.45.*

Three participants in the CG had LK of calculation of Reaction Rate while all the participants in the EG had SU (Table 5.8).

Question 2.3: *During the course of the reaction: $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$. At time t, instantaneous rate of formation of O_2 was found to be 3 mol.dm^{-3}.min^{-1}. The average consumption rate of A, in mol.dm^{3}.s^{-1} during the time interval between 20 s and 40 s is ….*

With question 2.3, Participants were supposed to use stoichiometric coefficients of the balanced reaction to determine reaction rate. Participant EGF04 gave the following response, which showed SU:

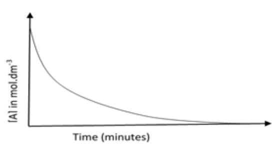


The participants who were coded as LK are those that stated that they did not know how to solve this problem. For example, participant CGM06 stated the following:

> *"I don't understand this question,"* participant CGM06.

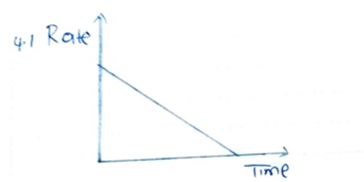
All the participants in the EG had SU while 3 participants from the CG had LK of this concept (Table 5.8).

Question 4.1: *Two chemicals A and B react to form C as shown in the equation A(aq) + B(aq) → C(aq). The graph shows how the concentration of A changes with time*



Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

An example of a response coded as SU, from participant EGM03, is:



For the reason for the shape of the graph, participant EG03 said:

> *"My graph says that the rate will be decreasing with time…"*

An example of a response, coded as LK, from participant CGM06, is:

When asked to explain the shape of the graph this is what participant CGM06 said:

> *"This graph shows that … the reaction rate will be equalized to time and this is how I understand it,"* participant CGM06.

Apparently by '*equalized to time'* the participant implied that the reaction rate remains constant. This confirmed the participant's LK. One participant from the CG had SU while 4 participants from the EG had SU (Table 5.8).

Question 6.5: *The elementary reaction A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.*

This concept in this question is the same concept asked about in question 4.1. An example of a correct response was:

> *"It decreases with time,"* participant EGM02.

Incorrect responses are noted when participants had nothing to say or just indicated that they did not know. All learners in the EG had SU of the concept while only one participant in the CG had SU. Table 5.8 provides a summary of the frequencies of the participants' responses in each of the three categories - SU, PU and LK.

Table 5.8 Frequencies of responses of participants per category to interview questions on Definition of Reaction Rate and Calculation of Rate (EG, N=5; CG, N=5)

Recording Unit	Frequency					
	EG			CG		
	SU	PU	LK	SU	PU	LK
2.1 Defining rate	4	1	0	2	2	1
2.2 Calculating rate	5	0	0	2	0	3
2.3 Stoichiometry in calculating rate	5	0	0	1	1	3
4.1 Rate against time	4	1	0	1	0	4
6.5 Rate against time with catalyst	5	0	0	1	0	4

Comparison of the EG and CG on conceptual understanding of Reaction Rate

A comparison of the frequencies of SU and LK of the EG and the CG in Table 5.8 reveals that the EG had a better understanding of the concepts in defining - Rate and Calculating Rate. There were more participants in the EG who could define reaction rate correctly when compared to the CG. In calculating of rate, all the responses in the EG had SU as compared to 2 in the CG; in using stoichiometry to calculate reaction rate, all the participants in the EG had SU compared to only 1 in the CG; in drawing graph and describing of rate against time, 4 participants in EG had SU compared to 1 in the CG and in describing what happens to reaction rate in the presence of a catalyst as time passes, all the responses in the EG were coded SU as compared to only 1 in the CG. Participants from the EG had SU of Reaction Rate and Calculation of Rate.

5.4.4.2 Factors Affecting Reaction Rate

Factors Affecting Reaction Rate involves an understanding of the effect of temperature, surface area, pressure and concentration on reaction rate. The Coding Guide for questions on effect of surface area on reaction rate and identifying temperature and concentration as factors affecting the rate of a reaction, is presented in Table 5.9.

Table 5.9 Coding guide for effect of surface area on reaction rate and identifying factors

Unit of Analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
3.1Surface area	B/ Reason: Smaller pieces of Mg have a larger surface area	SU	*"B will be (more) faster. The surface area on this diagram it has been increased as the particles have a smaller size. The surface area that was increased was the Mg surface area,"* participant EGM01.	Correct answer and correct reason
		PU	*"B, the molecular size in B is smaller therefore has a higher surface area,"* participant EGGM10.	Reason not clearly stated
		LK	*"… I think it is B … those molecules are not attached to each other so they just got less potential …,"* participant CGM06.	Incorrect reason.
3.2Surface area	No/ Reason: Bigger particles of solid reactant means smaller surface area	SU	*"No. Because the bigger the particles the reaction will be slow because bigger particles have small surface area,"* participant EGF004.	Correct answer and correct reason
		PU	*"No the learner is not correct because the bigger the particles of the solid reactant the reaction is going to be slower. If the size of the solid is bigger so there won't be enough movement …,"* participant EGM05	Reason not clearly stated.
		LK	*"No. Because when the substance is bigger, it will too much time to react,"* participant CGM06.	Reason incorrect
3.3.1 Identifying temperature	Temperature. Reason: Temperature affect the rates of almost all reactions	SU	*"It will be temperature … temperature affect all the reactions in every phase,"* participant EGM05.	Correct factor and reason
		PU	*"…temperature. … If the temperature is increased the rate of reaction will increase because the temperature is the controlling variable"* Participant CGM06	Correct factor, reason incorrect
		LK		Reason incorrect
3.3.2 Identifying concentration	Concentration of H^+ ions: Because H^+ ions are in aqueous solution	SU	*"…so concentration affect the reactions in aqueous and mass of magnesium does not have an effect at all,"* participant EGM05.	Correct factor and reason.
		PU	*"Concentration. It's difficult,"* participant CGM07.	Correct factor; reason incorrect.
		LK		Reason incorrect

The Coding Guide for questions on explaining effect of temperature and concentration on reaction rate is shown in Table 5.10.

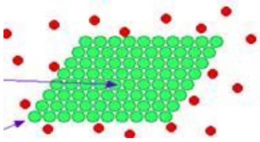
Table 5.10 Coding Guide for questions on explaining effect of temperature and concentration on reaction rate

Unit of Analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
3.4 Explaining effect of temperature	Increasing temperature increases rate of reaction/ If temperature is increased, then average kinetic energy of reactant molecules increases and more reactant molecules have $E_K \geq E_A$. More effective collisions (per unit time).	SU	*"Rate of reaction is increased … the kinetic energy of the particles inside the reaction increases thus resulting in more effective collision,"* participant EGM03.	At least one point explained
		PU	*"Temperature because as we increase temperature increases heat and has got greater effect,"* participant EGM01	Correct relationship; incorrect reason.
		LK	*"when temperature is increased … also the reaction will increase because it will be heated with the catalyst,"* participant CGM08.	Incorrect explanation
3.5 Explaining concentration	Increasing concentration increases rate of reaction. If concentration is increased, then there are more reactant molecules per unit volume and more effective collisions per unit time (Any **one** of these 2 points)	SU	*"If concentration is increased the reaction rate will increase. Firstly, because there are more reactant molecules per unit volume, which means that more molecules with higher kinetic energy per unit volume. Secondly, more effective collisions occur per unit time,"* participant EGF04.	At least one point explained
		PU	*"As concentration is increased the rate of reaction also increase. As we increase the volume of our molecules we are decreasing ….,"* participant EGM01.	Correct relationship; incorrect reason.
		LK	*"…concentration will increase the rate of reaction because when we increase the hydrochloric acid (concentration) the rate of reaction will increase,"* participant EGF04.	Incorrect explanation.

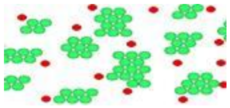
The remaining part of this section, looks at the responses of the participants for each of the questions on factors affecting reaction rate.

Question 3: *The reaction of magnesium and hydrochloric acid can be represented by the equation:* $Mg_{(s)} + 2H^{+}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + H_{2(g)}$

Diagram A (Centre for Distance Learning and Innovation [CDLI], 2007) shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ion.



A (CDLI, 2007)



B (CDLI, 2007)

Question 3.1: *Which of these two reactions will be faster? Explain why.*

This question tested the participants' conceptual understanding of the effect of surface area of a solid reactant on the rate of reaction. An example of a response that was coded as SU is:

> *"B will be (more) faster. The surface area on this diagram it has been increased as the particles have a smaller size. The surface area that was increased was the Mg surface area,"* participant EGM01. This participant understood the effect of surface area on reaction rate.

While most of the participants could identify that reaction B would have a faster reaction rate, most of the participants in the CG could not give a plausible reason. For example, the response from participant CGM06 showed that the participant could give the correct answer but with an incorrect reason.

> *"According my perspective I think it is B. Because those molecules are not attached to each other so they just got less potential the reaction will be faster because the molecules are not attached to each other so they do not have too much potential. I am talking about … I can say let me say potential energy they don't have that energy to can overpower the reaction or to take time to react,"* participant CGM06.

This showed that the participant lacked conceptual understanding of the effect of surface area on reaction rate, therefore, this response was coded as, LK. All the participants in the EG showed SU, while only one participant in the CG has SU of effect of surface area on reaction rate.

Question 3.2: *A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct? Please explain.*

This question further explored the conceptual understanding of the participants on effect of surface area on reaction rate. The participants who had shown an understanding of this concept in Question 3.1 had no problems in answering this Question. For example, participant EGF04 said:

> *"No. Because the bigger the particles the reaction will be slow because bigger particles have small surface area,"* participant EGF04.

Participants who had given an incorrect reason in Question 3.1, could not give a plausible reason in Q3.2. For example, participant CGM06 said:

> *"No. Because when the substance is bigger, it will take much time to react,"* participant CGM06.

No reference to surface area of the solid reactant was made by the above participant. This may imply lack of conceptual understanding of the effect of surface area on reaction rate. Three participants in the EG had SU on the effect of surface area on the rate of the reaction in question 3.2 as compared to only one in the CG.

Question 3.3: *Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: Pressure; Temperature: Concentration; or mass of Mg? Please explain.*

The question intended to find out if the participants understood the effect of other factors on the reaction of magnesium and hydrochloric acid, apart from surface area explored in questions 3.1 and 3.2. They were required to identify temperature and concentration as the two factors that could affect this reaction from the four variables provided, then explain their choices.

Participant EGM03 showed SU for temperature but showed PU on why concentration is a factor that affects the rate of reaction between Mg and $HCl_{(aq)}$. The participant said:

> *"I will say both concentration and temperature. Firstly, I will talk about temperature. Temperature increases the rate … in a way that the kinetic energy is equal to or greater than the activation energy which will make (increase) the effective collisions per unit time. Secondly I am going to talk about the concentration. Concentration …. I am not adequate on that,"* participant EGM03.

The participant understood the effect of temperature on reaction rate but lacked conceptual understanding of the effect of concentration on reaction rate. Participant EGM05 showed SU of both concentration and temperature. The participant stated that:

> *"It will be temperature. Pressure affect the substances or reactants in gaseous state and temperature affect all the reactions in every phase so concentration affect the reactions in aqueous and mass of magnesium does not have an effect at all,"* participant EGM05.

In summary, three participants from the EG showed SU of temperature and two participants had SU of concentration as factors that affect the reaction between $Mg_{(s)}$ and $HCl_{(aq)}$. One participant from the CG showed SU of temperature and none of them had any understanding of concentration (Table 5.11).

Question 3.4: *State and explain what happens to reaction rates of most reactions if temperature is increased.*

Question 3.4 was a follow up question to question 3.3. Some participants in the EG who had SU responded as follows:

> *"Rate of reaction is increased … the kinetic energy of the particles inside the reaction increases thus resulting in more effective collision,"* participant EGM03.

"When temperature is increased there will be much effective collisions the reaction will be faster in a way that particles will be colliding faster," participant EGM02.

"Reaction rates increase as temperature is increased … the average kinetic energy of the molecules will also increase as the temperature is increased. For the reaction to occur the activation energy must either be equal or less than the kinetic energy," participant EGM01.

In contrast to this the participants in the CG struggled to explain how temperature affects reaction rate as exemplified by the following.

"… if we increase the temperature then the reaction also increase. If the temperature is increased the rate of reaction will increase because the temperature is the controlling variable of this I can say this investigation. It means that the temperature controls the reaction. The reaction rate is controlled by the temperature," participant CGM06.

There was, no mention from anyone in the CG of the following: the fact that increasing temperature increases average E_K, which would imply that more reactant molecules have $E_K \geq E_A$, hence there will be more effective collisions per unit time. This suggests that the participant lacked conceptual understanding of effect of temperature on reaction rate. The same pattern of responding was shown by other participants in the CG. For example, participant CGM08 said:

"when temperature is increased the reaction also, the reaction will increase because it will be heated with the catalyst," participant CGM08.

In conclusion, four participants in the EG showed SU of effect of temperature on reaction rate while only one of the participants in the CG showed understanding of effect of temperature on reaction rate (Table 5.11).

Question 3.5: *State and explain what happens to reaction rates for most reactions if concentration is increased.*

The following are the responses of the participants in the EG. Participant EGM01 did not fully understand the effect of concentration on reaction rate.

> *"As concentration is increased the rate of reaction also increase. As we increase the volume of our molecules we are decreasing …."*

Participant EGM02 had a better conceptual understanding and the response was coded as SU.

> *"If it is increased rate of reaction increases. Increasing concentration will increase the particles, number of particles that can collide and make the reaction; increase the number of particles that have a high kinetic energy,"*

Participants EGM03 and EGF04 had not comprehended the effect of concentration on reaction rate.

> *"Concentration I don't know about concentration,"* participant EGM03.

> *"…concentration will increase the rate of reaction because when we increase the hydrochloric acid (concentration) the rate of reaction will increase,"* participant EGF04.

The participant in the CG, CGF09, stated that if concentration is increased then there will be

> *"more reactants per unit volume, the more the effective collisions per unit volume,"* participant CGF09. This was coded as SU.

One participant in the EG stated that:

> *"If concentration is increased the reaction rate will increase. Firstly, because there are more reactant molecules per unit volume, which means that more molecules with higher kinetic energy per unit*

volume. Secondly, more effective collisions occur per unit time," participant EGF04. The response was coded as SU.

Two participants in the EG and one participant in the CG had SU of the effect of concentration on reaction rate.

A summary of the frequencies of the participants' responses in each category for the EG and CG, on factors affecting reaction rate is presented in Table 5.11.

Table 5.11 Participants' Responses on Interview Questions on Factors Affecting Reaction Rate

Unit of analysis	**Frequency**					
	EG			**CG**		
	SU	**PU**	**LK**	**SU**	**PU**	**LK**
3.1 Surface area	5	0	0	1	0	4
3.2 Surface area	3	1	1	2	0	3
3.3.1 Identifying Temperature with reason	3	2	0	1	1	3
3.3.2 Identifying Concentration with reason	2	3	0	0	2	3
3.4 Effect of temperature on reaction rate	4	1	0	1	3	1
3.5 Effect of concentration on reaction rate	2	1	2	1	2	2

Comparison of EG and CG on conceptual understanding of Factors Affecting Reaction Rate

A comparison of the frequencies of the responses coded as SU and LK in Table 5.11 suggests that the EG had a better understanding of factors affecting reaction rate. All the participants from the EG showed some ability to identify and describe how surface area affect reaction rate as compared to only 1 participant from the CG. In a further question on describing how surface area affect reaction rate, 3 participants in the EG showed SU compared to 2 participants from the CG. On identifying temperature, with reason, as a factor, 3 participants from the EG showed SU compared to only 1 for the CG. On explaining the effect of concentration on reaction rate, 2 participants from the EG showed SU and for the CG only one showed SU. In summary, participants from the EG had a greater conceptual understanding of factors affecting reaction rate when compared to participants from the CG.

5.4.4.3 Heat of Reaction and Activation Energy

The Coding Guide for Heat of Reaction and Activation Energy is shown in Table 5.12. Presented below are the responses of the participants to the questions on Heat of Reaction and Activation Energy.

Question 5: *Look at this picture.*


(Shutterstock, 2020)

Question 5.1: *Why do you think the person needs to use the match stick to start the fire? Please explain.*

All the participants in the EG could state that the use of the match stick was to provide activation energy (E_A) which showed that they had SU of the tested concept compared to only three participants in the CG.

Question 5.2: *Is the reaction occurring in the picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.*

All participants in the Experimental Group (EG) had Sound Understanding (SU) compared to 3 in the Control Group (CG). An example of a response coded as SU from participant EGM01 in the EG is:

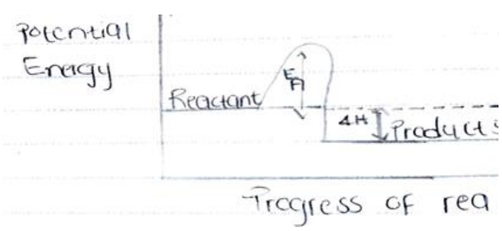
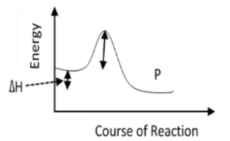
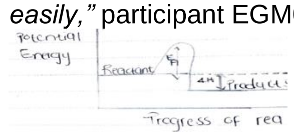
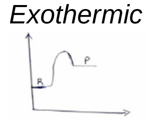
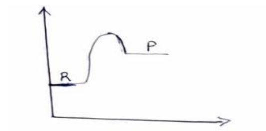


Table 5.12 Coding Guide for Activation Energy and Heat of Reaction

Unit of Analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
5.1 Need for E_A	It provides the activation energy to the reactants.	SU	*"… for the fire to start there must be the activation energy and this activation energy …,"* participant EGM01.	Clearly explain need for E_A
		PU		Partly correct response
		LK	*"Because between the match stick and that sketching area of the match box there is a collision … because a match stick is wooden hence it catches the fire so easily,"* participant EGM06.	Incorrect response
5.2 Energy profile diagram	Exothermic 	SU	 *Exothermic* EGM01	Graph should be for an exothermic reaction correctly labelled
		PU	*Exothermic* Participant CGM06.	Graph incorrect
		LK	 EGM008	Incorrect labels and incorrect graph
5.3 Heat of reaction	Difference between the energy of the products and the energy of the reactants.	SU	*"The heat of reaction is the change in enthalpy it is difference between the energy of products and the energy of reactants,"* participant EGM02.	Definition completely correct
		PU	*"It is the change between the heat of product and energy of reactants,"* participant EGM01	Imprecise language
		LK	*"Is when a reaction is heated then it produces heat,"* participant EGM08.	Any other response
5.4 Defining E_A	Minimum amount of energy needed for a reaction to occur.	SU	*"Activation energy is the minimum amount of energy required for a reaction to occur," participant*	Completely correct
		PU		Omitting some important words
		LK	*"I don't know this one,"* participant EGM08.	No meaningful attempt at defining

An example of a response coded LK from participant CGM08, is as follows:



Question 5.3: *What do you understand by the term 'heat of reaction'?*

Two participants in the EG showed SU of the concept, while only one participant in the CG could define, heat of reaction. Participant EGM02 defined heat of reaction as

> *"The heat of reaction is the change in enthalpy it is difference between the energy products and the energy of reactants,"* participant EGM02.

This can be contrasted with the response of participant CGM08 who said:

> *"Is when a reaction is heated then it produces heat,"* showing LK of heat of reaction.

Generally, the participants in the EG had a good understanding of heat of reaction compared to those in the CG.

Question 5.4: *What do you understand by the term 'activation energy'? Can you tell me more?*

Four of the participants in the EG could define E_A, while only two participants from the CG could define E_A correctly. Participant EGM01 from the EG defined E_A as

> *"Activation energy is the minimum amount of energy required for a reaction to occur."*

The participant had SU of E_A. This contrasts with participant EGM08 who said:

> *"I don't know this one,"* showing that the participant had LK of E_A.

A summary of the frequencies of the participants' responses in the different categories for questions on Heat of Reaction and Activation Energy is provided in Table 5.13. Table 5.13 is followed by a comparison of the conceptual understanding of the EG and CG of the concepts in Heat of Reaction and Activation Energy.

Table 5.13 Participants' Responses on Interview Questions on Heat of Reaction and Activation Energy

Unit of Analysis	Frequency					
	EG			CG		
	SU	PU	LK	SU	PU	LK
5.1 Need for E_A	5	0	0	3	0	2
5.2 Energy profile diagram	5	0	0	3	2	0
5.3 Heat of reaction	2	1	2	1	0	4
5.4 Activation Energy	4	0	1	2	0	3

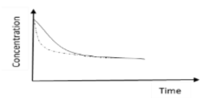
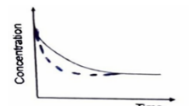
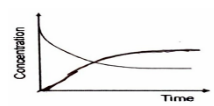
Comparison of EG and CG on conceptual understanding of Heat of Reaction and Activation Energy

The frequencies of the participants' responses in Table 5.13 show that the participants from the EG had a much better understanding of concepts on Heat of Reaction, Activation Energy and catalysis. The responses of the participants from the EG showed SU of these concepts. All participants in the EG had SU of the need for E_A to start a reaction and drawing of an energy profile diagram. In these two questions, only 3 participants had SU of both, in the CG. Learners in both the EG and CG had problems in defining heat of reaction (Table 5.13). There were more participants in the EG who could define E_A than in the CG (Table 5.13), therefore, it can be deduced that the EG had SU of concepts on Heat of Reaction and Activation Energy as compared to CG.

5.4.4.4 Catalysts

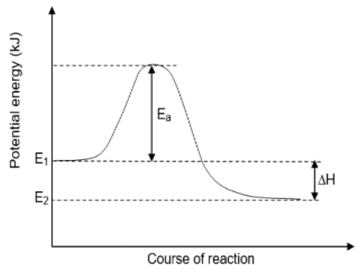
The main concept of catalysis is that positive catalysts increase the reaction rate. They do this by way of an alternative reaction mechanism or reaction pathway with a lower activation energy. When the activation energy has been lowered, there will be more effective collisions per unit time, thus, the reaction rate increases. The coding guide for questions in catalysis is shown in Fig 5.14.

Table 5.14 Coding Guide for questions on Catalysis

Unit of Analysis	Value	Definition	Anchor Sample	Encoding Rules
6.1 Change in E_A	SU	EA/ A catalyst lowers the E_A	*"…catalyst is to speed the reaction and when the catalyst is added it decreases the activation energy,"* participant EGF004.	
	PU	E_A; incorrect reason		Correct answer; incorrect reason
	LK		*"I can say delta H will change. Because delta H is the change of heat"* participant CGM006.	Incorrect answer and incorrect reason
6.2 Conc. Against time graph	SU		 CGM05 *"…, the catalyst …, so this one will be much steeper."*	Correct graph and correct reason
	PU	Correct graph; incorrect reason		Correct graph and incorrect reason
	LK	Incorrect graph and incorrect reason	 CGM07 *The shape of the graph, when a catalyst is added, the concentration will increase with time,"* participant CGM007.	Both graph and reason incorrect
6.3 Effect of catalyst	SU	Addition of a catalyst/ Catalyst lowers the E_A		Answer correct reason correct
	PU	Addition of catalyst; no reason or incorrect reason	*"By adding a catalyst. … reduced of the reactant molecules that will decrease the reactant molecules …,"* participant CGM006.	Correct answer and reason incorrect
	LK	Incorrect response		
6.4 How catalyst work	SU	Catalyst lowers E_A/More reactant molecules have $EK \geq E_A$/More effective collisions per unit time (Any **two**).	*"It makes the reaction faster by lowering the peak of the activated complex in a way of an alternative reaction mechanism … will be lowered,"* participant EGM003	At least two valid points
	PU	Catalyst lowers E_A; no further explanation	*"It decreases the activation energy,"* participant EGM001	Only **One** point
	LK	No explanation	*"the catalyst heats the reaction so that the reaction can occur faster,"* participant EGM008.	No correct explanation

The responses of the participants on catalysis are discussed in the remaining part of this section.

Question 6.1: *Look at the potential energy diagram*



Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added? Please explain.

All the participants in the EG could identify E_A as the quantity that would change compared to only two in the CG. One participant in the EG could not provide a good reason for the correct answer and was coded PU. Participant EGF04 responded as follows:

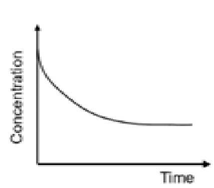
> *"Activation energy. Because when the catalyst is added the catalyst is to speed the reaction and when the catalyst is added it decreases the activation energy."*

The participant showed a SU of how a catalyst acts in speeding up a reaction. In contrast to this, participant CGM06 said:

> *"I can say delta H will change. Because delta H is the change of heat. Because the catalyst is added to speed the reaction and then when a catalyst is added it started to speed the reaction and … there will be too much heat ..."*

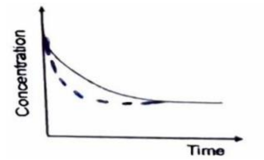
This demonstrated LK and a lot of misunderstanding of how a catalyst work.

Question 6.2: *Look at the graph of concentration against time*



On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

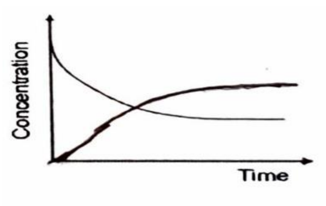
All the five participants from the EG showed SU of this concept while one participant from the CG had SU. Participant EGM05 responded as follows



As for the reason for the shape of the graph the participant said:

> *"So the graph will be like this, the catalyst will fast the reaction rate so it will decrease the time, so this one will be much steeper."*

This showed that the participant had a SU of how a catalyst functions. Participant CGM07 from the CG presented the following response:

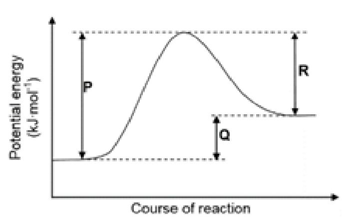


When asked to explain the shape of the graph, the following was the participant's response:

> *"The shape of the graph, when a catalyst is added, the concentration will increase with time."*

The participant showed LK of how a catalyst work. The participant was also confused about the concentration as the first graph clearly shows the concentration decreasing against time implying that it was the concentration of a reactant.

Question 6.3: *Look at the potential energy diagram:*



What change can be used to decrease both P and R but leave Q unchanged? Please explain your answer.

Three participants from the EG could state that adding a catalyst would change P and R and that this is since the catalyst lowers E_A. No participant from the CG showed SU of the concept in this question. For example, participant EGM03 explained as follows:

> *"A catalyst. It brings an alternative reaction mechanism with a lower activation energy".*

The participant had SU of the concept. In contrast to this, CGM06 said:

> *"By adding a catalyst. Because when a catalyst is added the reaction will be more faster and then there will be a reduced of the reactant molecules that will decrease the reactant molecules that's why P and R will be decreased"*

While the participant could state the necessary change, the participant had LK of how a catalyst work, thus, the response was deemed to be PU.

Question 6.4: *Explain how a catalyst works to make a reaction faster.*

Three participant from the EG demonstrated SU of the concept of catalysis while no participant from the CG showed SU. Participant EGM02 responded as follows:

> *"It lowers the activation energy … well, the number of effective of collisions are increased when the activation energy is lowered."*

This showed that the participant had a SU of how catalysts work. Participant EGM03 explained as follows:

> *"It makes the reaction faster by lowering the peak of the activated complex in a way of an alternative reaction mechanism. (Activation energy) will be lowered."*

This again showed a SU of the way catalysts work. Participants from the EG had a much better understanding of how catalysts work. In contrast to this participant, CGM08 in the CG said:

“The catalyst heats the reaction so that the reaction can occur faster”.

The participant had LK of how catalysts work; in other words, the participant knew that catalysts increase the rate of a reaction without knowing why. The participant also seemed to confuse the effect of temperature on reaction rate with how catalysts work as he said a catalyst heats the reaction.

A summary of the frequencies of the participants’ responses in each category on the concepts in catalysis, is presented in Table 5.15.

Table 5.15 Frequencies of participants’ responses on questions on catalysis

Interview Question	**Frequency**					
	EG			**CG**		
	SU	**PU**	**LK**	**SU**	**PU**	**LK**
6.1 Change in E_A	4	1	0	2	1	2
6.2 Conc. against time graph	5	0	0	1	1	3
6.3 Effect of Catalyst	3	2	0	0	3	2
6.4 How a catalyst work	3	2	0	0	2	3

Comparison of the EG and CG on understanding of Catalysis

Most of the responses of the participants in the EG on catalysis were in the SU category while most of the responses of the CG were in the LK category (Table 5.15). This suggests that the EG had better conceptual understanding of catalysis.

5.4.4.5 Collision Theory

The Collision Theory included concepts such as - for a reaction to occur reactant particles must collide; particles must collide with the correct orientation and the colliding particles must have energy equal to or greater than the activation energy. The Coding Guide for the participants’ responses for questions on the Collision Theory is shown in Table 5.16.

Table 5.16 Coding Guide for Collision Theory

Unit of Analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
4.3.1 Explaining Collision Theory	A theory that states that for a reaction to occur reactant particles must collide: with kinetic energy, equal to or great than E_A/with the correct orientation (all points)	SU	*"Collision theory is when a reaction happens due the collision of particles colliding in a way that they might have a minimum energy and they should be in the right orientation,"* participant EGM03.	Any one correct point
		PU	*"Atoms must collide, that's what it says,"* participant CGM08	Incomplete explanation
		LK		No correct point
4.3.2 Applying Collision Theory	C atom must collide with the O_2 molecule. C atom and the O_2 molecule must have $E_K \geq E_A$ C atom must collide with the O_2 molecule with the correct orientation (Any **one**)	SU	*"The carbon and oxygen must collide with the right orientation and the energy of particles must be greater or equal to the activation energy,"* participant CGM09.	Any one correct point
		PU		Incomplete explanation
		LK		No correct point

The following is a discussion of the responses of the participants to the questions on the collision theory.

Question 4.2: *The reaction for burning of wood may be represented by this equation.*

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

Question 4.2.1: *What do you understand by the term "Collision Theory"?*

All the participants from the EG had SU of the collision theory. Only one participant from the CG had sound understanding of this concept and the other four had LK. For example, participant EGM03 responded as follows:

> *"Collision theory is when a reaction happens due to the collision of particles colliding in a way that they might have a minimum energy and also they should be in the right orientation,"* participant EGM03.

The participant from the CG who had SU of the concept of collision theory stated it as follows:

> *"The term Collision Theory … the particles of the reaction collide require the minimum energy for the reaction to form a product and the reactants to form a product they must collide with the right orientation,"* participant CGF09.

The other participants from the CG indicated that they had limited understanding of the collision theory. For example, participant CGM08 responded as follows:

> *"Atoms must collide, that's what it says,"* showing PU.

Question 4.2.2: *Explain how this reaction occurs in terms of the collision theory.*

Three participants from the EG and none of the participants from the CG had SU of the application of the collision theory in explaining the reaction between C atoms and O_2 molecules. The participants from the EG who had SU of the concept explained as follows:

> *"As they are colliding, the oxygen collides with the C atom as they collide they are in the right orientation because they are not the same atom …. The energy of the molecules is actually equal to or greater that the E_A of the molecules,"* participant EGM01.

> *"The carbon and oxygen must collide with the right orientation and the energy of particles must be greater or equal to the activation energy,"* EGM05.

Table 5.17 is a summary showing the frequencies of the responses of participants in the different categories on conceptual understanding.

Table 5.17 Reponses of participants in Interview Questions on Collision Theory

Unit of Analysis	Frequency					
	EG			CG		
	SU	PU	LK	SU	PU	LK
4.2.1Explaining Collision Theory	5	0	0	1	1	3
4.2.2Applying Collision Theory	3	0	2	0	0	5

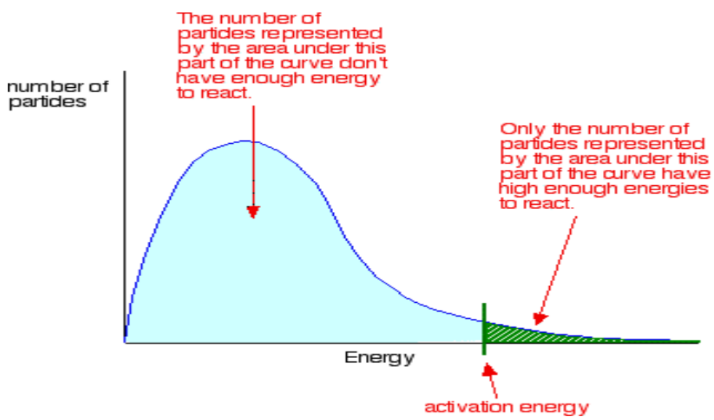
Comparison of EG and CG on conceptual understanding of Collision Theory

All the responses of participants in the EG showed SU in explaining the collision theory and 3 showed SU for application of collision theory (see Table 5.16). Only 1 response of the CG was coded as SU in explaining collision theory and all the responses were coded LK for application of the collision theory. This shows that the EG had a much better understanding of the collision theory.

5.4.4.6 Distribution of Molecular Energies

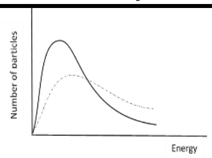
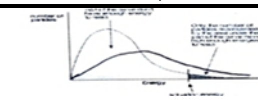
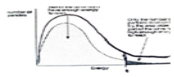
Learners are required to be able to use the Maxwell Boltzmann distribution curve to explain the effect of temperature and catalysts on reaction rate. At a higher temperature, the curve has a lower peak and it shifts to the right implying that there are more molecules with greater kinetic energy, then, there will be more effective collisions per unit time which increases reaction rate. Adding a catalyst lowers the activation energy and more molecules will have sufficient energy. The frequency of effective collisions increases, increasing reaction rate. The questions that examined the participants' conceptual understanding of the Maxwell-Boltzmann Distribution Graph and Catalysis are questions 7.1, 7.2 and 7.3. The coding guide is shown in Table 5.18.

Question 7: *The diagram shows the distribution of speed of molecules in a reaction mixture sample.*



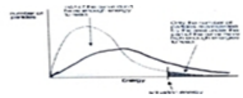
(Clark, 2002)

Table 5.18 Coding Guide for Maxwell-Boltzmann Distribution Graph

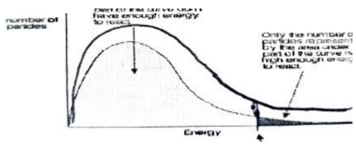
Unit of analysis	Scientifically accepted ideas	Category	Anchor Sample	Encoding Rules
7.1 Distribution graph at higher temperature		SU	 Participant EGF05	Graph should have lower peak and shifted to the right.
		PU	 Participant CGM06	Graph same peak but shifted to the right; higher peak shifted to the right
		LK		Any graph not shifted to the right or has a higher peak
7.2 Explaining effect of temperature using graph	Area under the graph represents number of molecules: At a higher temperature, they are more molecules with $E_K \geq E_A$/They are more effective collisions per unit time.	SU	*"So, temperature actually increases the rate of the reaction. If temperature is increased it will increase the kinetic energy making the kinetic energy greater or equal to the activation energy,"* participant EGF005.	At least one point from the definition column
		PU		Response partly correct
		LK		Response has no mention of effective collision and $E_K \geq E_A$
7.3 Explaining effect of catalyst using graph	Catalyst lowers E_A/They are more molecules with EK≥EA/They are more effective collisions per unit time	SU	*"There is fewer (less) energy needed for the reaction to start; lower energy needed for the reaction to start. … the number of particles with more average kinetic energy increase right that's meaning the effective collision will occur more,"* participant EGM002.	At least one of the points in definition
		PU		Response partly correct
		LK		Response has no mention of effective collision and $E_K \geq E_A$

Question 7.1: *Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.*

All the participants from the EG showed SU of the concept, while only one participant from the CG showed SU. An example of a response coded SU is, participant EGM05:



An example of a response coded LK is, participant CGM06:



Question 7.2: *Use the graph to explain the effect of temperature on reaction rate.*

Only one participants from the EG and none of the CG participants could use the distribution graph to explain the effect of an increase in temperature on reaction rate. Participant EGM05 used his graph and explained as follows:

> *"So, temperature actually increases the rate of the reaction. If temperature is increased it will increase the kinetic energy making the kinetic energy greater or equal to the activation energy."*

This indicated that the participant had SU of what happens to reaction rate when temperature is increased. Participant CGM06 showed that he could not explain correctly the effect of temperature on reaction rate:

> *"Because the temperature was increased and then that increased the rate of reaction that's why the graph looks like that. The number of particles were added in the … to speed up the reaction and the temperature was also increased,"* participant EGM06.

Question 7.3: *Use the graph to explain the effect of a catalyst on the rate of reaction.*

Only two participants from the EG showed SU in using the distribution graph to explain the effect of a catalyst on reaction rate. All the participants from the CG showed LK. One participant from the EG explained as follows:

> *"There is fewer (less) energy needed for the reaction to start; lower energy needed for the reaction to start. … the number of particles with more average kinetic energy increase right that's meaning the effective collision will occur more,"* participant EGM02.

Most other participants indicated that they did not know or simply stated that the catalyst lowers the activation energy. A summary of the concepts on Distribution of Molecular Energies showing the frequencies of the participants' responses in each category is presented in Table 5.19.

Table 5.19 Participants' Responses on Interview Questions on Maxwell-Boltzmann Distribution Graph and Catalysis

Unit of Analysis	Frequency					
	EG			CG		
	SU	PU	LK	SU	PU	LK
7.1 Graph at higher temperature	5	0	0	1	0	4
7.2 Temperature effect from graph	1	1	3	0	1	4
7.3 Catalyst effect from graph	2	2	1	0	0	5

Comparison of the EG and CG on conceptual understanding of Distribution of Molecular Energies

All participants from the EG could draw the graph of distribution of molecular speeds at a higher temperature while only one participant from the CG could do this. One participant from the EG could use the graph to explain the effect of temperature and the effect of a catalyst on reaction rate using the graph. Four participants from the CG showed LK on using the graph to explain the effect of temperature and catalysts on reaction rate. This data suggests that CSBI is better than traditional instruction in improving learners' conceptual understanding of Maxwell-Boltzmann distribution graph and its use in explaining the effect of temperature and catalysts on reaction rates.

5.4.4.7 Comparison of Computer Simulation-Based Instruction and Traditional Approach in assisting learners in conceptual understanding of Chemical Reaction Rate

The last step in QCA involves analysing category frequencies and contingencies interpretation (Mayring, 2014:96). In line with this, the data in Tables 5.8, 5.11, 5.13, 5.15, 5.17, and 5.19 were used to construct frequency contingency tables for the EG and the CG (Appendix 24). The tables were then converted into relative frequency contingency tables. Table 5.20 is the relative frequency contingency table for the EG.

Table 5.20 Relative Frequency Contingency Table for the EG

Interview Question	SU (%)	PU (%)	LK (%)	Total (%)
2.1	3.33	0.83	0.00	4.17
2.2	4.17	0.00	0.00	4.17
2.3	4.17	0.00	0.00	4.17
3.1	4.17	0.00	0.00	4.17
3.2	2.50	0.83	0.83	4.17
3.3.1	2.50	1.67	0.00	4.17
3.3.2	1.67	2.50	0.00	4.17
3.4	3.33	0.83	0.00	4.17
3.5	1.67	0.83	1.67	4.17
4.1	3.33	0.83	0.00	4.17
4.2.1	4.17	0.00	0.00	4.17
4.2.2	2.50	0.00	1.67	4.17
5.1	4.17	0.00	0.00	4.17
5.2	4.17	0.00	0.00	4.17
5.3	1.67	0.83	1.67	4.17
5.4	3.33	0.00	0.83	4.17
6.1	3.33	0.83	0.00	4.17
6.2	4.17	0.00	0.00	4.17
6.3	2.50	1.67	0.00	4.17
6.4	2.50	1.67	0.00	4.17
6.5	4.17	0.00	0.00	4.17
7.1	4.17	0.00	0.00	4.17
7.2	0.83	1.67	1.67	4.17
7.3	1.67	1.67	0.83	4.17
Total	**74.17**	**16.67**	**9.17**	**100.00**

Table 5.21 is the relative frequency contingency table for the CG.

The last rows of Table 5.21 and Table 5.22 shows the relative frequencies for each of the three categories. The percentage of the participants' total responses in the Sound Understanding (SU) category was much higher (74.17%) for the Experimental Group (EG) (Table 5.21) when compared to the Control Group (CG) which had 25.83% (Table 5.22). The percentages of responses In the Partial Understanding (PU) category were similar for the EG and the CG (Table 5.21 & Table 5.22). The percentage of responses in the Lack of Knowledge (LK) category, was 9.17% for the EG (Table 5.21) and 60.00% for the CG (Table 5.22).

Table 5.21 Relative Frequency Contingency Table for the CG

Interview Question	SU (%)	PU (%)	LK (%)	Total
2.1	1.67	1.67	0.83	4.17
2.2	1.67	0.00	2.50	4.17
2.3	0.83	0.83	2.50	4.17
3.1	0.83	0.00	3.33	4.17
3.2	1.67	0.00	2.50	4.17
3.3.1	0.83	0.83	2.50	4.17
3.3.2	0.00	1.67	2.50	4.17
3.4	0.83	2.50	0.83	4.17
3.5	0.83	1.67	1.67	4.17
4.1	2.50	0.00	1.67	4.17
4.2.1	0.83	0.83	2.50	4.17
4.2.2	0.00	0.00	4.17	4.17
5.1	2.50	0.00	1.67	4.17
5.2	2.50	1.67	0.00	4.17
5.3	0.83	0.00	3.33	4.17
5.4	1.67	0.00	2.50	4.17
6.1	1.67	0.83	1.67	4.17
6.2	0.83	0.83	2.50	4.17
6.3	0.83	0.83	2.50	4.17
6.4	0.83	0.00	3.33	4.17
6.5	0.83	0.00	3.33	4.17
7.1	0.83	0.00	3.33	4.17
7.2	0.00	0.00	4.17	4.17
7.3	0.00	0.00	4.17	4.17
Total	**25.83**	**14.17**	**60.00**	**100.00**

The CG had much higher percentage of responses in the LK category compared to the EG. The pattern that emerges from these data is that most of the responses of the EG were in the SU category while most of the responses of the CG were in the LK category, therefore, these data imply that the EG had greater conceptual understanding of CRR concepts as compared to the CG.

5.4.5 Views of learners and the teacher on Use of Computer Simulation-Based Instruction

Some of the questions on the Interview Schedule for Learners (Appendix 10) sought to understand how the participants viewed the use of CSBI in teaching CRR. These questions are Q8 to Q13. The views of the participants are presented in this section.

Question 8: *When you compare learning CRR using computer simulations or learning through the usual way the teacher teaches, which method do you think leads to a better understanding?*

All the participants stated that learning using simulations lead to a better understanding of CRR compared to traditional instruction. They attributed this to the fact that simulations enabled them to view processes occurring at the sub-micro level. The responses of the participants were as follows:

> *"Computer simulations are better than what is taught in class because in computer simulations I can actually visually see the particles colliding and the rates of reaction increasing in the presence of a catalyst yeah things like that but when a teacher is teaching it becomes a little bit difficult for me to understand as I am unable to actually see so am forced to use my mind to do so in order for me to understand."* Participant EGM01.

> *"The computer simulations* … *When a teacher just talks, it is very hard to imagine something you've never seen and when you see the reactions and the particles on a simulation you actually get a good idea and I understand what is going on when they say temperature is increased the average kinetic energy increases surface, you know, those kind things. We'll have more understanding*." Participant EGM02.

> *"Using the computer, because normally those things let me say the science that talks about the particles and all those things for learners to understand its better they visualize it in a way that we see on how particles behave on one another like a when a teacher teaches talking about particles, particles but we as learners not seeing those particles so it's better we use the computer."* Participant EGM03.

> *"I can say simulations, things become clearer. For example, when the teacher says surface area is increased we could see what it means. And that it increases reaction rate, when we increased the surface area by using smaller size of particles in the experiments. Without experiments, how can we understand?"* Participant EGF04.

> *"Using computer leads to a better understanding because I could see pictures what is happening. When a teacher teaches, he doesn't actually show the structures but just explaining so I could not just memorize those structures. Looking at the … like a movie it enables me to recognize those structures on how do they work."* Participant EGM05.

The responses of the learners suggest that simulations aid understanding of CRR by making unobservable processes at molecular level visible. The expert teacher agreed with this notion but his response suggested that using simulations enables learners to switch from macroscopic, sub-microscopic and symbolic representations more effortlessly.

> *"Simulation is involving movement involving a picture. It's also involving a text and also involving sound. We are having these three modes of communication. We are trying to impart whatever we are teaching to the learners understanding and using modes I think is better than using text only so simulation is a better way of also assisting learners to understand." Participant ED11.*

The response of the teacher is consistent with the CTML which states that learning occurs better when learners are presented with dynamic pictures and verbal explanations than either verbal explanations or pictures alone (Mayer, 2003). The views of the participants are also consistent with the Cognitive Theory for Computer Simulation-based Instruction (Chapter 2) which regards simulations as scaffolding tools that ensure that learning CRR occurs within the ZPD. The Cognitive Theory for Computer Simulation-based Instruction further predicts that the use of such scaffolds leads to greater conceptual understanding as confirmed by the views of the participants and the analysis of the conceptual understanding of CRR in Section 5.5.4.

The POE strategy was another scaffolding tool that was used in the teaching of CRR to engage learners in cognitive processes in CSBI. This was important because as presented in Chapter 3, just exposing learners to simulations may not enhance meaningful learning, hence, strategies that promote cognitive engagement should be used. Question 9 presents the views of the participants on the use of the POE strategy.

Question 9*: In performing virtual experiments in computer simulation based instructions, you were given a worksheet that asked you to go through the process of predict-observe-explain. Was the predict-observe-explain experience helpful in your understanding of each of the experiments and reaction rate?*

All the participants indicated that the POE strategy helped them in understanding of CRR concepts. One participant noted that during POE, explaining was particularly helpful. The teacher pointed out that the ‘prediction’ part of POE helped learners to use their prior knowledge and the explanation helped the learners resolve any differences between what they observed and their predictions. The strategy helped them to understand factors affecting reaction rate as noted by participant EMG05. The responses of the participants are as follows:

> *“Yes it was a little bit of help because my predictions actually were correct or almost correct and the observations I made were recorded and marked. When explaining, I was able to grasp the correct ideas.”* Participant EGM01.

> *“Yes. When we predict write things that we expect to happen and then we observed on the simulations what was going on and then we got our answers and it was really helpful to see what was going on other than to see it in a textbook or just thinking yourself, to see on the screen.”* Participant EGM02.

> *“Yes it was but what I can say is that with the experiment that we had our experiment … was not clearly with the prediction because we didn’t use adequate values like ….”* Participant 03.

> *“Yes. The observations from the simulation helped me to see if my prediction was correct, then when I was wrong I could understand why I was wrong, then I corrected myself.” Participant EGF04*

> *“Yes it was helpful because I could eventually see that how concentration, the increased surface area, increasing molecular mass of a substance affect the rate of a reaction and temperature also.”* Participant EMG05.

The teacher also agreed with the sentiments of the learners as shown by the following responses:

> *“Yes, the tool itself was allowing the learner to engage, to interact, to ask, or to be asked and that communication part of it was somehow assisting the learner to comprehend better, so that the learner will be involved.”* Participant ED11.

When asked to elaborate on prediction he said:

> *“That’s the initial knowledge in learner’s mind. The learner will have what we call prior knowledge. Using that prior knowledge, the learner can predict what is expected basing on what the learner is the mind. That’s the prediction. Normally when you predict you are using what you have in your mind. Your previous experiences. So that previous experience tell you because of what I saw last time, I think it will be like this. Then after the experiment you say okay, what I saw is different from what I am seeing now, that means you're*

correcting your prediction basing on what you have wanted from the experiment." Participant ED11.

The literature review in Chapter 3 has shown that positive attitudes are important outcomes in chemistry education and having a positive attitude may help learners improve their understanding. The affective component of the participants' attitudes was explored through question 10.

Question 10: *You performed some experiments using computer simulations when you were learning CRR. Did you enjoy doing those experiments? Please explain.*

All the participants indicated that they enjoyed doing virtual experiments in CSBI. They claimed that the simulations made them to understand the concepts. The responses of the participants are presented below.

> *"Yes, I did enjoy the experiments like when doing experiments over computer simulations it is much better than being taught by a teacher without doing the simulations like, like doing the experiments in class, things like the reaction rate how the decrease with time. Changing variables was helpful as I could see that as temperature increases it also changed the kinetic energy of the reactant particles."* Participant EGM01.

> *"I enjoyed them because firstly we don't do much of computer simulations so it was a new thing for me, a new experience, it was a good experience I enjoyed it because I did it with my class, I learned something new and understand chemistry more."* Participant EGM02.

> *"Yes, for my case I enjoyed it because I saw those things like those particles reacting and also for the beside of understanding it was funny because when you increased the temperature those particles were going very fast like colliding effectively so I guess it was a better way."* Participant EGM03.

> *"Yeah because computer simulation was making more things clearer because when the teacher was explaining … collision theory some of us that thing we didn't understand it very well but when we saw it on the computer simulation we were shown that the molecules were colliding with sufficient energy those molecules will need to be in a correct orientation for them to collide …" Participant EGF04.*

> *"Yes, I really enjoyed that. Looking at those particles colliding and doing such things it was like that was for real it helped me a lot in improving my Chemistry. Yes it was helpful because I could see you*

teaching those things we, I could see what happens when the temperature is changed or when the concentration is changed." Participant EGM05.

The teacher's view was in agreement with those of the learners as he said:

> *"Yes our learners these days they like these things of seeing. So, if you bring it to learners they are getting more interested because that's their thing of seeing a lot of now it is it like seeing people not even listening but is same so even from the same part and also manipulation way asking them to do it again and stop and do it again and stop that's what they enjoy. That's their area they enjoy that very much."* Participant ED11.

The responses of the participants may help explain why the attitudes of the participants improved after CSBI, much more for the EG. In the Cognitive Theory for Computer Simulation-based Instruction, the ACM states that if learners assimilate the CRR concepts taught through CSBI, their attitudes would change, thus, the change in attitudes of the learners could be due to increased understanding because of the CSBI approach to learning. Question 11 explored the views of learners on different teaching approaches.

Question 10 *Which of the following methods do you prefer in learning CRR? (a) Teacher reading from a textbook. (b) Teacher writing notes on the board. (c) Teacher talking and explaining. (d)Teacher explaining using computer simulations. Please explain why you prefer the method you choose.*

All the participants indicated that they preferred to be taught with the teacher using simulations to explain. One of the participants also said that the teacher should also provide notes to summarize the concepts. The responses were as follows:

> *"Teacher explaining using computer simulations. Because in this format I will be able to understand what the teacher is actually referring to when he says the reaction rate decreases with time and the reason why for the reaction rate to increase it increases as temperature increases so that I can have an open mind." Participant EGM01.*

> *"Teacher explaining using a computer simulation. As I explained before, when you see something on the screen rather than reading in a book its easy, when you see the particles move and everything that goes on in action its more understandable than when written down you get a sense of what is going on*." Participant EGM02.

> *"I prefer the teacher writing notes on the board and secondly I prefer the teacher explaining using computer simulations, firstly for the teacher writing notes on the board, they will give me a way of studying don't want to take a textbook I will use those notes because they will be straight forward and secondly for the teacher explaining using computer simulations it will help me on how to know the behaviour of those particles we had been talking about to have some additional ideas to know what the teacher is talking about exactly."* Participant EGM03.
>
> *"Teacher teaching using computer simulation. Because everything the teacher is teaching we will be shown on the computer simulation and they won't be need for us to think what is going on with this … the computer simulation will be showing us … when the reactant collide will be forming product … there won't be need for the teacher to draw and show us what this type of reactant will be colliding with what. Only the computer simulation will show a good example."* Participant EGF04.
>
> *"Method number D, so this method actually makes us see some pictures of what is happening rather than listening to a teacher just explaining but not showing us pictures this method is great."* Participant EGMO5.

The participants stated that they preferred learning from using simulation rather than the teacher lecturing like what happens in traditional instruction. They claimed that the former helped them to understand the concepts in CRR. The last two questions aimed to obtain clarity on the participants' preferred method of learning CRR.

Question 12. *Which method do you find more interesting: CSBI or the usual way the teacher teaches?*

All the participants indicated that they found CSBI more interesting than the traditional instruction.

Question 13. *Do you think Physical Sciences teachers should use computer simulations to teach? If Yes, please explain.*

Four of the participants indicated that they think that Physical Sciences teachers should use computer simulations to teach. One indicated that both simulations and the traditional approach should be used together. They also indicated that the simulations make learners understand scientific concepts at the sub-microscopic level. Their responses were as follows:

> *"Yes because usually in Physical Sciences we are talking about things like particles and atoms, molecules and such things are not things one can actually imagine it becomes a little bit difficult for a person to come up with the structure of those things until they actually see them through the computer simulations."* Participant EGM01.
>
> *"It is more understandable and it's better to learn that way I think for me it's better it's like performing an experiment you always gain some more knowledge."* Participant EGM02.
>
> *"Yes because mostly of the Physical Sciences things we are talking about things that we don't see."* Participant EGM03.
>
> *"I prefer they use both methods. When we are doing this or when they want to show us the collision theory yeah but when coming to other modules … like when you need to explain what chemistry will need our teacher to explain in order to understand…."* Participant EGF04.
>
> *"Yes so that learners could see what they are talking about." Participant EGM05.*

In addition to the reasons mentioned by the learners the teacher indicated that simulations should be used in teaching CRR as they enable learners to attain SPS. This involve aspects such as changing variables, making observations and interpretation of the observations and making conclusions. The teacher said:

> *"When you are changing the temperature keeping the other variables constant actually the learner is learning that this is being changed and this one is fixed. Now knowing what it was the meaning of variables, then the other thing is the hypothesis, the prediction you are talking about. Sometimes you give a prediction which may not be the correct outcome or which may differ from the outcome that means a learner is also learning about the hypothesis. Then observation, what you see during the experiment what you see when the processes are happening in the chemical reaction that's the observation you record that, you record the time which the reaction took to get finished then at the end may now link your hypothesis to your results, interpretation, so that you evaluate your experiment." Participant ED11.*

The views expressed by the teacher suggest that the simulations in CRR had helped learners to attain SPS and enhance scientific reasoning. In summary, the views of the participants were - CSBI makes unobservable processes at the molecular level, visible which made them understand CRR concepts; POE strategy in CSBI helped learners use their prior knowledge to understand the virtual experiments and when their predictions did not match the observations they had to change the way they were thinking to accommodate the new knowledge; CSBI made them enjoy learning CRR concepts; and learners preferred learning CRR using CSBI rather than the traditional approach.

5.4.6 Findings on influence of CSBI on the learners' conceptual understanding of CRR compared to traditional approach

- The results of Qualitative Content Analysis (QCA) showed that learners taught through CSBI had a greater conceptual understanding of CRR compared to those taught through the traditional instruction. The learners who were taught using CSBI had 74.17% SU compared to 25.83% SU for those taught through the traditional approach.
- The views of the learners were that simulations enabled them to observe chemical processes at the sub-microscopic level and this is what helped them to have conceptual understanding of CRR.

5.5 Interpretation

In a mixed method, sequential explanatory study, quantitative and qualitative results are integrated in the interpretation phase of the research. The qualitative results are used to explain the quantitative results, hence, in this section the results of the quantitative phase of the study are integrated with the qualitative results. The results of each of the six major concepts and skills in CRR are interpreted first. This will be followed by interpretation of the results on attitudes towards the lessons in CSBI.

In this study, it was found that CSBI was more effective in teaching CRR compared to traditional approach. After treatment, there was a statistically significant difference in academic achievement of the EG ($M=10.70$, $SD=4.06$) and CG ($M=7.85$, $SD=3.08$); $t(116)=4.34$, $p<.005$. Cohen's d, was determined to be 0.53 indicating a moderate effect size of treatment. Qualitative data analysis supported these findings as the participants from the CG were found either to have Lack of Knowledge (LK) (60.00%) of most of the concepts in CRR while the EG had Sound Understanding (SU) (74.17%) (Tables 5.21

& 5.22) of the same concepts. The interpretation is organized on the six major concepts and skills in CRR in the remainder of this section.

5.5.1 Reaction Rate and Calculation of Rate

On the concept of reaction rate and calculation of rate, learners were asked to define reaction rate, calculate average reaction rate showing all steps of the working and to explain what happens to reaction rate during a reaction. On defining reaction rate, 42% of the EG had CR compared to 14% in the CG in the post test. These results are in line with previous research where it was found that learners struggle with defining reaction rate where only 5% of learners understood the concept of reaction rate (Michalisková & Prokša, 2018:89). Kırık and Boz (2012:229) also, found that more than half of the learners in the CG, in their study, did not understand what reaction rate is. Although the CG struggled with defining reaction rate the EG had better understanding of the concept. This was confirmed by the interviews as 4 learners from the EG showed SU of the concept compared to only 2 learners in the CG.

On calculation of average reaction rate, 42% of the EG had Correct Responses (CR) compared to 25% of the CG. On use of stoichiometry in calculation of reaction rate, 21% of the EG had CR compared to 6% in the CG. These data are supported by the qualitative results which showed that CSBI was more effective in teaching the concept of reaction rate compared to traditional instruction. On calculation of average reaction rate, 5 of the EG had SU compared to 2 for the CG.

5.5.2 Factors Affecting Reaction Rate

Quantitative results showed that learners in the EG were scoring slightly better than those in the CG in the TCRRC. Analysis of the interview questions showed that the EG had better conceptual understanding than the CG. These results suggest that CSBI was a better teaching approach than the traditional approach for teaching factors affecting reaction rate. In CSBI, the learners performed virtual experiments to investigate the effect of temperature, surface area and concentration on reaction rate using the Predict-Observe-Explain approach. The justification for the use of this POE approach with the Experimental Group only and not the Control Group, is provided in Chapter 2 and Chapter

3. In addition, learners observed simulations of the effect of these factors on reaction rate. All these activities may have contributed to a better conceptual understanding as compared to the CG. Consistent with the Cognitive Theory for Computer Simulation-based Instruction (Chapter 2), the POE strategy and the simulations are scaffolding tools which when used within the learners' ZPD, leads to better understanding of concepts. The results obtained are in line with this theory.

In the TCRRC, Q1 examined the learners' understanding of concentration as a factor that affect reaction rate - 38% of the learners in the EG gave the correct response as compared to 6% for the CG in the post-test. This question was a higher order question in that it involved a comparison of reaction rate of a weak and a strong acid, therefore, learners had to rely on their Grade 11 knowledge of weak and strong acids. This partly explains why the scores of both the EG and CG were low. In the interview, learners were asked to state and explain what happens to most reactions when concentration is increased. The responses showed that learners in the CG understood that if concentration is increased, reaction rate increases but they do not understand why this happens. This empirical finding in this research agrees with previous researchers' results - Kurt & Ayas, (2012:986); Sari *et al.,* (2019:4). The interviews showed that the EG had 2 learners with Sound Understanding (SU) and 3 learners had Partial Understanding (PU) while the CG had no learner with SU, 2 learners with PU and 3 learners with Lack of Knowledge (LK). The learners who had experienced CSBI, understood the effect of concentration better than those who did not. For example, the learner coded EGF04 explained the effect of concentration as follows:

> *"If concentration is increased the reaction rate will increase … because there are more reactant molecules per unit volume, which means that more molecules with higher kinetic energy per unit volume … more effective collisions occur per unit time,"* participant EGF04.

Question 3 (Q3) in the TCRRC asked learners to identify a factor that would increase the rate of decomposition of $CaCO_{3(s)}$. Temperature was the factor that could affect that reaction rate, since concentration affects reactions in aqueous state, pressure affects reactions in gaseous state and mass had no effect. In the revised taxonomy of educational objectives, this question was at the *remembering* level. The proportion of learners who gave the CR were the same in both the EG and the CG (49% in each group). The interview questions revealed that the level of understanding of temperature as a factor affecting reaction rate was not the same in both the EG and the CG, as suggested by the quantitative data. In the interview, 3 learners from the EG could identify temperature with a correct reason, 2 could identify temperature but could not give a reason; in the CG, 1 learner could identify temperature with a reason, 1 could not give a reason and 3 could not identify temperature as a factor affecting rate of reaction between $Mg_{(s)}$ and $HCl_{(aq)}$. The EG had better conceptual understanding of effect of temperature on reaction rate. In addition, 4 learners in the EG could explain why increasing temperature increase reaction rate in the interview compared to only 1 learner in the CG. One learner in the EG explained effect of increasing temperature as follows:

> *"Rate of reaction is increased … the kinetic energy of the particles inside the reaction increases thus resulting in more effective collisions,"* participant EGM03.

Previous studies have shown that learners understand that when temperature is increased the rates of most reactions increases but the learners do not know why the rate increases even after teaching them (Michalisková & Prokša, 2018:90, Sari *et al.,* 2019:4). In line with these researches, the learners in the CG also could not explain why increasing temperature increases reaction rate. The finding of this study is that CSBI improves learners' conceptual understanding of factors affecting reaction rates such as temperature. One reason why CSBI improves learners' conceptual understanding is that simulations assist learners to visualize chemical phenomena at the sub-microscopic level as noted by one learner:

> *"… I remember when doing a simulation … when the temperature was increased the speed of the particles increased. So more effective collisions were going on. So, the rate of reaction was actually faster,"* participant EGM01.

Question 21 (Q21) in the TCRRC was on effect of surface area on reaction rate. The EG had a better understanding of the concept that when particles of a solid reactant are big, then reaction rate is slow (49% compared to 46% in CG). The analysis of interviews, however, revealed that the EG had a much better understanding of effect of surface area on reaction rate than what the quantitative data in Q21 suggest. *Sari et al.,* (2019:4) found that learners understand that if particles are small, then the reaction rate is fast and if particles are big, then reaction rate is slow but they could not explain why. This finding was observed in the response of the learners on the interview questions on what happens to reaction rate when big particles of a solid reactant are used. Learners in the CG, unlike those in the EG, could not give reasons for their correct answers. This may suggest that they were learning by rote or memorization. For example, one learner in the CG, when asked whether it is correct to say '*reaction rate is fast'* when big particles are used in a reaction said:

> *"No. Because when the substance is bigger, it will take too much time to react," participant CGM06.*

The participant lacked conceptual understanding of the fact that big particles have a smaller surface area, which means there are fewer collisions with the other reactant, leading to fewer effective collisions per unit time. In summary, the learners taught using simulation had better conceptual understanding of factors affecting reaction rate than those taught by the traditional approach. The collision theory was used to explain how these factors affects reaction rate. The interpretation of the results of the collision theory follow.

5.5.3 Collision Theory

One of the three questions that assessed learners' knowledge of the collision theory was Q22 in the TCRRC. They needed to recognize from the given options that a successful collision occurs if particles collide with the correct orientation and if they have a certain minimum energy. The proportion of the learners' correct answers in the EG and the CG were almost similar (55% for the EG to 49% of the CG) in the post-test, however, the interview questions revealed that the CG had little understanding of the concept. All 5 learners in the EG could explain the collision theory as compared to 2 learners in the CG during the interviews. In addition, learners were asked during the interview to explain the reaction between carbon and oxygen in terms of the collision theory to test whether transfer of learning had occurred. Three learners in the EG could use the collision theory to explain, in simple terms that the carbon atom and the oxygen molecule must collide with the correct orientation and as they collide they must have a certain minimum energy so that the collision can be effective. None of the learners in the CG could explain this reaction in terms of the collision theory.

CSBI was more effective than the traditional instruction in making learners understand the collision theory. The reason for this may be that simulations enable visualization of chemical phenomena at the particulate level. Difficulties in Chemistry has been attributed to the three levels of thinking in the subject - the macroscopic, the sub-microscopic and the symbolic level (Johnstone, 2000:11). The learners also confirmed that the simulations helped them to understand chemical processes at the sub-micro level of thinking during the interviews. One learner said:

> *"… usually in Physical Sciences we are talking about things like particles and atoms, molecules and such things are not things one can actually see it becomes a little bit difficult for a person to understand those things until they actually see them through the computer simulations,"* Participant EGM02.

It can, hence, be deduced that simulations helped in conceptual understanding of CRR as learners could observe processes at the sub-micro level.

5.5.4 Heat of Reaction and Activation Energy

Questions on Heat of Reaction and Activation Energy proved to be very challenging both for the EG and the CG. These challenges are due to lack of understanding of thermodynamic principles. The findings in this study agree with Cakmakci (2010:453) who observed that learners do not understand how activation energy relates to enthalpy change and consequently do not comprehend energy profile diagrams. He also noted that although activation energy is central to the understanding of reaction rates, secondary school learners do not understand this concept.

In the TCRRC, Q5 asked learners how best to describe activation energy. Of the choices, available, the best was that it is the minimum energy required by reactant molecules for effective collisions. Only 26% learners in the EG and 25% learners in the CG gave the correct response in the post-test. During teaching, activation energy was defined as the minimum amount of energy needed for a reaction to occur. When asked during the interviews, 4 of the learners in the EG defined E_A in this way and only 2 learners in the CG could define E_A. Q6 asked learners to describe the effects of a positive catalyst on E_A and ΔH. Only 13% of the EG could give the correct response as compared to 12% in the CG in the post test. Since the interviews showed that the learners in the EG understood that a catalyst lowers the E_A, their poor scores could be attributed to failure to understand that the catalyst has no effect on ΔH.

In Q8 learners were required to identify enthalpy change of reaction as the difference between the potential energy of the products and the potential energy of the reactants. Only 25% of the EG compared to14% of the CG could identify the answer in the post test. Further confirmation that learners did not understand this concept was provided by the poor performance on Q9 which asked what the energy change in a chemical reaction is known as; EG 26% and CG 17% had CR. The interview also confirmed the learners' failure to understand the concept of Heat of Reaction. When asked to define heat of reaction only 3 learners from the EG compared to 1 learner from the CG could define heat of reaction. In the interviews, learners in the EG could draw energy profile diagrams correctly. It could not, however, be ascertained whether they understood the diagrams. Further difficulties where noted when in Q11 learners were provided with an energy profile diagram and asked to calculate ΔH and E_A - 13% of EG and 15% of CG had CR. This study also showed that learners have serious misconceptions related to the relationship between temperature and E_A. This was revealed by their responses to Q17 which showed that 66% of the EG compared to 52% in the CG had misconceptions about this concept. They could not understand that an increase in temperature does not change the activation energy of a reaction. In summary, CSBI had little effect on the learners' understanding of concepts related to thermodynamics. In the next section the data on catalysis is interpreted.

5.5.5 Catalysis

The understanding of the learners on the concept of catalysis was generally low. This agrees with previous studies, as Supasorn and Promarak (2015:6) for example, found that there was low gain on conceptual understanding of effect of catalysts on reaction rate. They observed that learners have misconceptions on catalysts. Some learners in their study wrongly believed that catalysts increase the rate of a reaction by increasing the kinetic energy of the reactants.

In the TCRRC, Q13 tested learners to find out their understanding of how a catalyst work. They were provided with a labelled energy profile diagram and were then asked which quantity would change, if a catalyst is added. The proportion of learners with the CR was the same for both the EG and CG (57% for each group), however, when the learners were asked this same question in the interview, only 2 learners in the CG could provide a correct reason for their answers as compared to 4 learners from the EG. It was clear that the EG had better conceptual understanding of how a catalyst work.

Question 18 (Q18) tested the same concept, but in addition, the question sought to find out if learners were aware that a catalyst does not change the ΔH of the reaction. The proportion of Correct Responses (CR) were almost similar in both groups (42% EG to 46% CG). In the interviews, 3 learners in the EG could give reasons for their answers to the same question, compared to only one learner in the CG. This confirms that the EG had better conceptual understanding of the effect of a catalyst on reaction rate. In Q19 the learners were directly asked why a catalyst causes a reaction to proceed faster. The required answer was that it lowers the E_A; the performance was again very similar - 32% EG to 31% CG had CR. In Q27 the learners were again asked how a catalyst increases the reaction rate and from the available options, the required answer was that the catalyst provide an alternative reaction mechanism. The EG was better than the CG as 26% of the EG was aware that a catalyst provides an alternative reaction mechanism compared to 6% for the CG in the post-test. These results are in tandem with previous empirical findings that while learners know that catalysts increase reaction rate, they do not understand why and how (Kurt & Ayas, 2012b:987). In the qualitative part of the study, learners were asked to explain how a catalyst work. It was then clear that the EG had a better conceptual understanding of how a catalyst works to increase the reaction rate. Three learners of the EG had SU and two had PU. Only one learner from the CG had SU and the other four had LK. For example, one EG learner explained as follows:

> *"It makes the reaction faster by lowering the peak of the activated complex in a way of an alternative reaction mechanism. The activation energy will be lowered,"* participant EGM03.

The results of this study show that although CSBI was better than the traditional approach on the conceptual understanding of how catalysts work, generally, this concept was poorly understood. This finding is in line with previous research where it was discovered that many learners had limited understanding of how catalysts work (Cakmakci & Aydogdu, 2011:22).

To some extent, simulations improved the conceptual understanding of catalysts while traditional approach promote learning of this concept by rote/memorization as the learners in the CG could not give reasons for their answers in the TCRRC. The Maxwell-Boltzmann Distribution graph representing molecular energies against number of molecules are often used to explain the effect of temperature and catalysts on reaction rate. The learners' understanding of these graphs is considered next.

5.5.6 Distribution of Molecular Energies

The EG had a much better conceptual understanding of the concepts classified under, Distribution of Molecular Energies when compared to the CG. In the TCRRC (Appendix 7), Q7 required learners to recognize that temperature is a measure of the average kinetic energy of the molecules. In the EG, 57% of the learners could give the correct answer compared to only 17% of the CG in the post-test. In question 12, the learners were given graphs representing the molecular distribution of kinetic energies at different temperatures. They were then asked to identify the graph that represented the reaction at the highest temperature. The proportion of learners who could give the right answer was higher in the EG than in the CG - 57% in EG to 11% in CG. The same concept was assessed in Q14, except that in this question they were asked to identify the graph of the reaction occurring at the lowest temperature. Again, the proportion of learners with the correct answer was higher in the EG than the CG - 55% in EG to 9% in CG.

In the qualitative part of the study, learners were shown a graph of the distribution of the speed of molecules in a reaction mixture, at a certain temperature. They were then asked to draw another graph to show what happens to molecular speeds if temperature was increased. All the five learners in the EG could draw the correct graph compared to only 1 in the CG. They were then asked to use the graph to explain the effect of temperature on reaction rate. One learner in the EG showed SU and two showed PU while all the learners in the CG had LK. The learner from the EG explained as follows:

> *"So, temperature actually increases the rate of the reaction. If temperature is increased it will increase the kinetic energy making the kinetic energy greater or equal to the activation energy,"* participant EGF005.

It can be deduced, therefore, that CSBI improved the learners' conceptual understanding of the concept of distribution of molecular energies and how to apply this concept to explain the effect of temperature.

In the interview, the learners were also asked to use the graph to explain the effect of a catalyst on reaction rate. Two learners from the EG had SU and two had PU, while all learners from the CG had LK. One of the learners in the EG explained as follows:

> *"There is fewer (less) energy needed for the reaction to start; lower energy needed for the reaction to start. … the number of particles with more average kinetic energy (than E_A) increase right that's meaning the effective collision will occur more,"* participant EGM02.

This indicates that the learner had a comprehensive conceptual understanding of why reaction rate increases in the presence of a catalyst.

This study has shown that for most of the major concepts and skills in CRR taught at Grade 12 in Physical Sciences, CSBI was more effective and lead to a greater conceptual understanding as compared to traditional instruction. CSBI was more effective and led to greater conceptual understanding of - Reaction Rate and Calculation of Rate, Factors

Affecting Reaction Rate, Collision Theory, Catalysis and Distribution of Molecular Energies. The approach was less effective in the teaching of Heat of Reaction and Activation Energy. The results are in line with the Cognitive Theory for Computer Simulation-based Instruction (Chapter 2). During teaching of the EG, extraneous load was reduced by cueing, direct guidance, schema automation, segmentation, pre-training and avoiding split attention. Germane load was increased by the POE strategy and adaptive scaffolding. The cognitive tools used for scaffolding instruction in CSBI are simulations, virtual experiments, animations and the POE strategy. When these strategies are used, the Cognitive Theory for Computer Simulation-based Instruction predicts that teaching would be more effective, leading to greater conceptual understanding.

5.5.7 Interpretation of Results of Attitudes Toward the Chemistry Lessons Scale

The independent sample Mann-Whitney U test performed after treatment indicated that there was a statistically significant difference in the attitudes of learners in the CG (Mean Rank = 45.68, N = 65) and EG (Mean Rank = 76.45, N = 53), U = 824, z = -4.867, $p < .05$, two tailed with $\eta^2=0.20$). The Mean Rank of the EG was higher than that of the CG implying that the Attitudes of the EG improved compared to the CG. The value of η^2 (0.20) means that CSBI had a large effect size in improving the learners' attitudes towards the lessons on CRR.

These findings provide empirical support to previous studies. For example, in a study to determine the effects of an inquiry-based laboratory approach in teaching electrochemistry on learners' attitudes, Sesen and Tarhan (2013:423), found that there was a significant difference in the attitudes of learners in the EG and the CG after treatment in favour of the EG, however, they did not calculate the effect size.

The results from the qualitative part of this study also supported the findings that CSBI was effective in improving the learners' attitudes towards the chemistry lessons on CRR. In the interview, one learner said the following about simulations:

> *"I enjoyed them because firstly we don't do much of computer simulations so it was a new thing for me, a new experience, it was a good experience I enjoyed it because I did it with my class, I*

learned something new and understand chemistry more," participant EGM01.

Since this learner enjoyed CSBI it can be inferred that the learner's liking of chemistry lesson theory had increased after exposure to CSBI. The qualitative data supports the findings that there were big increases in the percentage of learners with more positive attitudes in the dimension of *liking of chemistry theory lessons* and *liking of virtual chemistry laboratory work.* On the dimension of *liking of virtual chemistry laboratory work,* one learner said:

> *"… I did enjoy the experiments like when doing experiments over computer simulations it is much better than being taught by a teacher without doing the simulations like, like doing the experiments in class, things like the reaction rate how the decrease with time. Changing variables was helpful as I could see that as temperature increases it also changed the kinetic energy of the reactant particles,"* participant EGM02.

This implies that the learner liked to do virtual chemistry experiments, felt that it was something important and that doing them in school was fun.

Analysis of the data from the ATCLS also revealed that the EG made huge gains in percentage of learners with more positive attitudes on evaluative beliefs about school chemistry and behavioural tendency towards learning chemistry. The attitudes of the CG, either, remained unchanged, improved marginally and in a few cases, became worse after exposure to traditional instruction. These findings are important as attitudes are considered crucial in curriculum planning and in the evaluation of effectiveness of teaching approaches (Cheung, 2011:117). Demircioglu (2016:2) believes that attitudes play a role in learning and negative attitudes are likely to develop because of the difficulties that learners encounter while trying to understand abstract concepts in Chemistry. The positive attitudes that these learners developed may be due to easier ways in which they conceptualized abstract concepts in CRR, when taught through CSBI. This is consistent with the Cognitive Theory for Computer Simulation-based Instruction in which the Attitude Construal Model (ACM) which predicts that if an attitude object (CSBI) is more accessible, it results in assimilation effects, hence, in an attitude change. The CG did not have access to CSBI, the attitude object, hence, their attitudes were unlikely to change.

5.6 Conclusion

In this Chapter the analyses of qualitative data and quantitative data were presented. Quantitative data from the TCRRC were analysed using the independent samples *t*- test, which showed that there was a statistically significant difference in the post-test scores of the EG and the CG in favour of the EG, with a medium effect size in the post-test. Quantitative data from the ATCLS were analysed using the Mann Whitney U test. There was a statistically significant difference in the attitudes of the EG and CG, post-treatment, in favour of the EG with a large effect size. Qualitative data on conceptual understanding of learners of CRR were analysed using Qualitative Content Analysis (QCA). The results were that the EG had better conceptual understanding of CRR when compared to the CG. The views of the learners and the teacher showed that the EG had better conceptual understanding, since simulations enabled the EG to learn through dynamic visualizations of chemical phenomena at the sub-microscopic level. In the interpretation of the results, quantitative and qualitative data were integrated.

Chapter 6 Findings, Recommendations and Conclusions

6.1 Introduction

In this Chapter the findings of the study, recommendations and conclusions are presented. The findings address the research question in the study. The recommendations consider future research, potential benefits for policy makers, continuous teacher professional development, pre-service teacher preparation and learners. The Chapter ends with the conclusions.

6.2 Findings of the study

The purpose of this study was to examine the effects of Computer Simulation-Based Instruction (CSBI) on the academic achievement of learners in the topic, CRR in Chemistry. The research question was: *What are the effects of using CSBI on the academic achievement of Grade 12 learners in CRR?*

The following subsidiary questions were raised:

1. How effective is the use of CSBI compared to the traditional approach on the academic achievement of learners in CRR concepts?
2. What are the effects of CSBI and the traditional approach on learners' attitudes towards the chemistry lessons in CRR?
3. Does Computer Simulation-Based Instruction improve learners' conceptual understanding of Chemical Reaction Rate as compared to traditional instruction?

To answer the research question, I developed a teaching approach, CSBI which was carefully planned, based on the Cognitive Theory for Computer Simulation-Based Instruction. This theory was developed from the literature of cognitive theories to guide the research in all its aspects. This was a mixed-method research in which the quantitative phase was a quasi-experimental study with NCGD, which was followed by the qualitative phase. In the quantitative phase, I planned and carried out a quasi-experiment which involved administering a pre-test to two different Grade 12 classes at two different schools in Mopani District, teaching the EG using CSBI and the CG using the traditional approach. After treatment, a post-test was administered to the two groups. Qualitative data was collected through semi-structured interviews with a small sample of learners and one teacher. In the sections below, the findings of the quantitative phase of the research are presented first, followed by the findings of the qualitative phase.

6.2.1 Findings on the effectiveness of the use of CSBI as compared to the traditional approach, on the academic achievement of learners in CRR concepts

Data on academic achievement of learners were collected using the TCRRC, an instrument I designed. The TCRRC was administered two weeks before treatment and two weeks after treatment to both the EG and CG. The independent sample *t*-test was used to find out if there was a statistically significant difference in the academic achievement of learners before and after the treatment. The results of the *t*-test indicated that the scores of the EG (N = 53, M = 3.92, *SD* = 2.344) and the CG (N = 65, M = 4.74, *SD* = 2.62) were not statistically different in the pre-test, $t(116) = -1.758$, p = .081, hence, the academic achievement of learners before treatment was the same for both the EG and CG.

After treatment, the results of the independent *t*-test showed that there was a statistically significant difference in the academic achievement of the EG and the CG. The EG (N = 53) had a mean post-test score of M = 10.70 (*SD* = 4.06), and the CG (N = 65) had mean score, M = 7.85 (*SD* = 3.08); $t(116) = 4.34$, $p < .005$. The independent *t*-test suggests that the differences in the academic achievement of the EG and CG were not due to chance but were due to treatment effects. The mean score for learners taught CRR by CSBI, M=10.70, was greater than for the learners taught through the traditional approach, M=7.85; d=0.53. The value of Cohen's *d* implies that the effect size of CSBI was moderate. The findings of this study, therefore, are that CSBI is more effective than the traditional approach in teaching CRR, with a moderate effect size. The results have practical significance in improving the academic achievement of learners since Cohen's *d* is greater than 0.5 (Mayer, 2010).

6.2.2 Findings on effects of Computer Simulation-Based Instruction and the traditional approach on learners' attitudes towards the chemistry lessons in Chemical Reaction Rates

There was a statistically significant difference, in the attitudes of learners, between the CG (Mean Rank = 45.68, N = 65) and EG (Mean Rank = 76.45, N = 53), U = 824, z = -

4.867, $p < .05$, two tailed as determined using Mann-Whitney U test after treatment. The Mean Rank of the EG was higher than that of the CG implying that the Attitudes of the EG improved when compared to the CG. This means that the difference in attitudes were not due to chance but were due to exposure of the EG to CSBI.

The effect size was large as determined by eta squared. The value of eta squared was 0.20 - a very large effect size. This effect size means that 20% of the variance in Attitudes between the CG and EG can be explained by exposure to treatment. In other words, 20% of variance in Attitudes was due to CSBI.

6.2.3 Findings on Learners' Conceptual understanding of Chemical Reaction Rates

The results of QCA showed that learners taught through CSBI had a greater conceptual understanding of CRR as compared to those taught through the traditional instruction. The learners who were taught using CSBI had 74.17% SU compared to 25.83% SU for those taught through the traditional approach. The views of the learners were that simulations enabled them to observe chemical processes at the sub-microscopic level and this is what helped them to have conceptual understanding of CRR.

In summary, CSBI was more effective than the traditional approach - in improving the learners' academic achievement as measured by the TCRRC; improved learners' attitudes towards the lessons presented through CSBI and led to better conceptual understanding of CRR concepts.

6.3 Contribution of the research to the body of knowledge

The review of literature in Chapter 3 showed that there is a paucity of research that attempts to improve learners' conceptual understanding of Chemical Reaction Rate although researchers have observed that the topic is very challenging for both learners and teachers. Some researches that have attempted to improve the learners' conceptual understanding have focussed on the use of the laboratory methods. Of the studies that were reviewed, very few focussed on the use of simulations to address these challenges. None of these had exclusively focussed on cognitive theories as a way of ensuring the effectiveness of their instruction approaches. This study, guided by the Cognitive Theory for Computer Simulation-based Instruction, has shed light on how to effectively incorporate simulations in instruction. In Chapter 2, it was argued that it is not just exposing learners to simulations *per se* that lead to conceptual understanding, but it is the cognitive processes learners engage in as they use the simulations. The findings in this study support the Cognitive Theory for Computer Simulation-based Instruction, as this theory had predicted that the use of the various psychological tools such as simulations, animations, virtual experiments and the Predict-Observe-Explain (POE) strategy would lead to better academic outcomes. Although the Predict-Observe-Explain (POE) strategy has been previously used together with simulations to engage learners in cognitive processes in teaching other topics (Kotoka & Kriek, 2014), it has, however, not been used in the teaching of CRR. This was the gap that was noted in the review of the literature. The findings of the study have shown that the use of POE, with simulations, improves academic achievement and attitudes of learners towards Chemistry lessons and conceptual understanding of CRR. This is the contribution of this study to the body of knowledge.

6.4 Limitations of the study

Green (2018) opines that limitations must be reported to show rigour and provide focus for future research. While the findings of the study have shown that CSBI is effective in the learning of CRR concepts, the study was limited to only two schools in Mopani District. The study was quasi-experimental as I could not carry out random sampling of the participants due to practical constraints. Efforts, however, were made to ensure that the sample was as comparable to the population as possible, nonetheless, any generalization of the findings should be done with caution. The research was also limited in terms of time. If more time was available, then a large sample could have been used. This limitation, particularly, affected the sample size for the qualitative phase of the study; more participants would have been interviewed if sufficient time was available.

6.5 Recommendations

These recommendations are aimed at future research, policy making, teacher professional development, pre-service teacher preparation and learners.

6.5.1 Recommendations for further research

It is recommended that a replication of the study should be done in South Africa and other countries with a large sample sizes. The study was based on the topic CRR at Grade 12 level. CSBI, however, can apply equally well to other topics in Physical Sciences and future research should also focus on such challenging topics in the curriculum.

6.5.2 Recommendations for Policy Makers

The study was conducted in a rural area in South Africa where CSBI was implemented in a large class. This has immediate potential benefits to the DBE in South Africa as the study has provided empirical evidence of the effectiveness of the approach. The teaching strategy was developed because of the observation that the academic achievement of learners in the topic CRR was very low. It is recommended that DBE could conduct workshops for the implementation of CSBI to improve the academic achievement of learners. The current teaching methods seem to be complicit in the low academic achievement of learners for several reasons. The CAPS document clearly states the practical experiments that learners are expected to do in the topic CRR. For such reasons as lack of equipment and chemicals it is unlikely that these experiments are being conducted. CSBI has the capacity to fill this gap and save time and financial resources unlike actual laboratory work. The CAPS document also recommends the use of simulations and recognizes that this topic is foundational and the knowledge gained is a prerequisite to an understanding of other topics. That CSBI was implemented in a large class in a rural area means that it is possible to implement CSBI even in places where it can be considered difficult to do so.

6.5.3 Recommendations for in-service teacher professional development

It is recommended that the curriculum advisors in the DBE should familiarize themselves with CSBI and carry out in-service teacher professional development to educate practicing teachers about the potential benefits of the approach. This would also help in the issues of lack of implementation of CAPS Physical Sciences curriculum, as currently it is possible that some learners write the final examinations without having covered some aspects of CRR, such as experiments. Virtual experiments in CSBI can be used to cover this gap.

6.5.4 Recommendations for pre-service teacher preparations

It is recommended that higher education institutions responsible for pre-service teacher preparation consider inclusion of CSBI in their courses on teaching methods. This would ensure that the teachers would then be prepared to implement this teaching strategy during teaching practice and after graduation.

6.5.5 Recommendations for learners

In the development of CSBI, the learner was the target beneficiary of the teaching approach. Given that information and communication technology is now ubiquitous and is the bedrock of CSBI, it is recommended that learners take advantage of technology and include simulations as part of their studies on concepts they may have difficulties in understanding. The websites that offer free access to the simulations, such as PHET should be utilized by the learners, even at home.

6.6 Conclusion

This study was carried out after the realization that the academic achievement of learners was consistently low in Chemical Reaction Rates. Guided by the Cognitive Theory for Computer Simulation-based Instruction, an intervention was designed which made use of animations, simulations and virtual experiments aided with the Predict-Observe-Explain strategy to teach the topic Chemical Reaction Rates. The study is unique in that no previous studies had used simulations underpinned by cognitive theories and used the POE strategy. The intervention was implemented to influence the academic achievement, attitudes and conceptual understanding of learners. The research was a mixed methodology study that employed a quasi-experiment which used a Non-equivalent Control Group Design (NCGD) to collect quantitative data followed by structured interviews to collect qualitative data.

The results of the study were that the intervention (CSBI) was a more effective teaching strategy than the traditional approach used mostly in schools in South Africa. There was a statistically significant difference in the academic achievement of the EG ($M = 10.70$, SD = 4.06) and CG (M = 7.85, SD = 3.08); $t(116) = 4.34$, $p < .005$) in favour of the EG. The effect size was moderate, d=0.53. This effect size implies that the result has practical significance as CSBI can improve the academic achievement of learners. In addition, the intervention improved the attitudes of the learners with an effect size of 0.20 which is a large effect size. In summary, CSBI improved the learners' academic achievements, attitudes and conceptual understanding of CRR.

Based on these results, it is recommended that the DBE should embrace CSBI and consider it as one of the strategies that it can use to improve the academic achievement of learners. This is particularly essential as the schools that participated in the study were situated in rural areas which also applies to most schools in Mopani District. Furthermore, future research should look at replication of the study in various settings, such as urban areas. Computer Simulation-Based Instruction holds promise for the idea of utilising technology in improving the academic achievement of learners, in challenging topics like Chemical Reaction Rates. Various stakeholders are encouraged to consider the potential benefits of implementing CSBI as an alternative to conventional or traditional approaches in the teaching of CRR and other challenging topics.

References

Abd-el-Khalick, F. 2012. Nature of science in science education: Toward a coherent framework for synergistic research and development *Second International Handbook of Science Education.* Springer, Dordrecht.

Alberta Education. 2006. Cyber-Science. Available: http://www.learnalberta.ca [Accessed 9 June 2020].

Abungu, H. E., Okere, M. I. & Wachanga, S. W. 2014. The effect of science process skills teaching approach on secondary school students' achievement in chemistry in Nyando district, Kenya. *Journal of Educational and Social Research,* 4(6), 359-371.

Adams, W. K. & Wieman, C. E. 2011. Development and validation of instruments to measure learning of expert-like thinking. *International Journal of Science Education,* 33, 1289-1312. DOI: 10.1080/09500693.2010.512369

Ahiakwo, M. J. & Isiguzo, C. Q. 2015. Students' conceptions and misconceptions in chemical kinetics in Port Harcourt metropolis of Nigeria. *African Journal of Chemical Education,* 5(2), 112-130.

Ainsworth, S. 2008. The educational value of multiple-representations when learning complex scientific concepts. *Visualization: Theory and practice in science education (pp. 191-208).* Springer, Dordrecht.

Akpınar, E. 2014. The use of interactive computer animations based on POE as a presentation tool in primary science teaching. *Journal of Science Education and Technology,* 23(4), 527-537.

Aktamis, H. and Ergin, Ö., 2008, June. The effect of scientific process skills education on students' scientific creativity, science attitudes and academic achievements. In *Asia-Pacific forum on science learning and teaching* (Vol. 9, No. 1, pp. 1-21). The Education University of Hong Kong, Department of Science and Environmental Studies.

Al-Mashaqbeh, I. 2014. Computer Simulation Instruction: Carrying out chemical experiments. *International Journal of Modern Education and Computer Science,* 6(5), 1-7. DOI: 10.5815/ijmecs.2014.05.01.

Anney, V.N., 2014. Ensuring the quality of the findings of qualitative research: Looking at trustworthiness criteria. *Journal of Emerging Trends in Educational Research and Policy Studies*, *5*(2), 272-281.

Atabek-Yigit, E., 2018. Can cognitive structure outcomes reveal cognitive styles? A study on the relationship between cognitive styles and cognitive structure outcomes on the subject of chemical kinetics. *Chemistry Education Research and Practice*, *19*(3), 746-754. DOI: 10.1039/c8rp00018b.

Aydoğdu, B., Erkol, M. and Erten, N., 2014, June. The investigation of science process skills of elementary school teachers in terms of some variables: Perspectives from Turkey. In *Asia-Pacific Forum on Science Learning & Teaching* (Vol. 15, No. 1).

Ayres, P. & Paas, F. 2012. Cognitive load theory: New directions and challenges. *Applied Cognitive Psychology*, *26*(6), 827-832. DOI: 10.1002/acp.2882.

Bain, K. & Towns, M., H. 2016. A review of research on the teaching and learning of chemical kinetics. *Chemistry Education Research and Practice*, *17*(2), 246-262.

Bajar-Sales, P., A., Avilla, R., A. & Camacho, V., M., I. 2015. Predict-explain-observe-explain (PEOE) approach: tool in relating metacognition to achievement in chemistry. *The Electronic Journal for Research in Science & Mathematics Education*, *19*(7), 1-21.

Barassi, R. 2007. *Reaction Rate* [Online]. Pearson Education. [Accessed 21 October 2018].

Barke, H. D. 2015. Learners Ideas, Misconceptions, and Challenge. *In:* Garc´Ia-Mart´Inez, J., Serrano-Torregrosa, E. (ed.) *Chemistry Education Best Practices, Opportunities and Trends.* Weiheim: Wiley-VCH Verlag GmbH & Co.

Beitin, B. T. 2012. Interview and Sampling: How many and Whom. *In:* Gubrium, J., F., Holstein, J., A., Marvasti, A., B. & Mckinney, K., D. (ed.) *The SAGE Handbook of Interview Research: The Complexity of the Craft.* London: SAGE Publications.

Bhattacherjee, A. 2012. *Social science research: Principles, methods, and practices.* Florida, Anol Bhattacherjee.

Brush, T., A. & Saye, J., W., 2002. A summary of research exploring hard and soft scaffolding for teachers and students using a multimedia supported learning environment. *The Journal of Interactive Online Learning*, *1*(2), 1-12.

Burkett, V., C. and Smith, C. 2016. Simulated vs. hands-on laboratory position paper. *The Electronic Journal for Research in Science & Mathematics Education*, *20*(9), 8-20. Available at ejse.southwestern.edu. [Date Accessed 27 June 2020]

Carter, N., Bryant-Lukosius, D., Dicenso, A., Blythe, J. & Neville, A. J. 2014. The use of triangulation in qualitative research. In *Oncology Nursing Forum,* 41(5)**,** 545-547.

Cakmakci, G. 2009. Emerging issues from textbook analysis in the area of chemical kinetics. *Australian Journal of Education in Chemistry,* 70**,** 31-38.

Cakmakci, G. 2010. Identifying alternative conceptions of chemical kinetics among secondary school and undergraduate students in Turkey. *Journal of Chemical Education*, *87*(4), 449-455.

Cakmakci, G. & Aydogdu, C. 2011. Designing and evaluating an evidence-informed instruction in chemical kinetics. *Chemistry Education Research and Practice*, *12*(1), 15-28.

Centre for Distance Learning and Innovation. 2007. *Chemistry3202* [Online]. Available: https://www.cdli.ca/subjects/chemistry/ [Accessed April 26 2020].

Chairam, S., Klahan, N. & Coll, R. 2015. Exploring secondary students' understanding of chemical kinetics through inquiry-based learning activities. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(5), 937-956. Available: https://www.ejmste.com/download/exploring-secondary-students-understanding-of-chemical-kinetics-through-inquiry-based-learning-4432.pdf [Accessed 20 April 2020].

Chandrasegaran, A., L., Treagust, D., F. & Mocerino, M. 2007. The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice*, *8*(3), 293-307.

Cheung, D. 2007, July. Confirmatory factor analysis of the attitude toward chemistry lessons scale. In *Proceeding of the 2nd NICE Symposium, Taipei, Taiwan*.

Cheung, D. 2011. Evaluating student attitudes toward chemistry lessons to enhance teaching in the secondary school. *Educación Química*, *22*(2), 117-122.

Christie, M., Christie, J. R. 2000. Laws and theories in chemistry do not obey the rules. *In:* Bhushan, N., Rosenfeld, S., Rosenfeld, S. M. (ed.) *Of minds and molecules New Philosophical Perspectives in Chemistry.* London: Oxford University Press.

Chung, M. & Kim, J. 2016. The Internet Information and Technology Research Directions based on the Fourth Industrial Revolution. *KSII Transactions on Internet & Information Systems*, *10*(3).

Clark, J. 2002. *Effect of Temperature on Reaction Rate* [Online]. Available: https://www.chemguide.co.uk/physical/basicrates/temperature.html [Accessed April 26 2020].

Cohen, J. 1992. A power primer. *Psychological bulletin,* 112(1)**,** 155-159. Available: https://www.ime.usp.br/~abe/lista/pdfn45sGokvRe.pdf [Accessed 5 May 2020]

Cohen, J. B. & Reed, A. 2006. A multiple pathway anchoring and adjustment (MPAA) model of attitude generation and recruitment. *Journal of Consumer Research,* 33(1)**,** 1-15.

Cohen, L., Manion, L. & Morrison, K. 2007. *Research Methods in Education,* London, Routledge.

Connors, K. A. 1990. *Chemical Kinetics: The Study of Reaction Rates in Solution,* New York, John Wiley & Sons.

Corbetta, C. 2011. Sampling *Social Research: Theory, Methods and Techniques* London: SAGE Publications, Ltd

Creamer, E. G. 2019. Recognizing Paradigmatic Assumptions *An Introduction to Fully Integrated Mixed Methods Research* Thousand Oaks SAGE Publications, Inc.

Creswell, J., W., Plano Clark, V. L., Gutmann, M., L., Hansen, W., E. 2003. *Advanced mixed methods research designs. Handbook of mixed methods in social and behavioral research,* London, Sage.

Creswell, J., W. 1999. Mixed-method research: Introduction and application. *Handbook of educational policy.* Elsevier.

Creswell, J., W. 2009. *Research Design: Quantitative, Qualitaitive and Mixed method approach,* London, Sage.

Creswell, J., W. 2014. *A concise introduction to mixed methods research,* Los Angeles, Sage Publications.

Creswell, J., W. 2017. *Designing and Conducting Mixed Methods Research,* Los Angeles SAGE Publications.

Cronbach, L., J. 1951. Coefficient alpha and the internal structure of tests. *Psychometrika,* 16(3)**,** 297-334.

Daineko, Y., Dmitriyev, V. & Ipalakova, M., 2017. Using virtual laboratories in teaching natural sciences: An example of physics courses in university. *Computer Applications in Engineering Education*, *25*(1), 39-47.

De Jong, T. 2012. Physical and Virtual Laboratories in Science and Engineering. *Journal of Learning Disabilities,* 45**,** 538.

de Jong, T. & Njoo, M., 1992. Learning and instruction with computer simulations: Learning processes involved. In *Computer-based Learning Environments and Problem Solving* (pp. 411-427). Springer, Berlin, Heidelberg.

De Jong, T., Linn, M., C. & Zacharia, Z., C. 2013. Physical and virtual laboratories in science and engineering education. *Science*, *340*(6130), 305-308.

De Jong, T. & Van Joolingen, W., R., 1998. Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research*, *68*(2), 179-201.

De la Sablonnière, R., Taylor, D., M. & Sadykova, N. 2009. Challenges of applying a student-centered approach to learning in the context of education in Kyrgyzstan. *International Journal of Educational Development*, *29*(6), 2-7. doi:10.1016/j.ijedudev.2009.01.001.

de Winter, J., F., C. & Dodou, D. 2010. Five-Point Likert Items: t test versus Mann-Whitney-Wilcoxon (Addendum added October 2012). *Practical Assessment, Research, and Evaluation*, 15(11), 1-16. DOI: https://doi.org/10.7275/bj1p-ts64 Available at: https://scholarworks.umass.edu/pare/vol15/iss1/11. [Accessed 5 May 2020].

De Winter, J.C., 2013. Using the Student's t-test with extremely small sample sizes. *Practical Assessment, Research, and Evaluation*, *18*(1), 1-12. DOI: https://doi.org/10.7275/e4r6-dj05. Available at: https://scholarworks.umass.edu/pare/vol18/iss1/10 [Accessed 5 May 2020].

Demircioglu, G. 2016. Developing an Interactive Non-Formal Chemistry Setting and Investigating Its Effectiveness on High School Students' Attitudes towards Chemistry. *Journal of Education and Training Studies*, *4*(12), 1-13.

Demircioğlu, G. & Yadigaroğlu, M. 2011. The Effect of Laboratory Method on High School Students' Understanding of the Reaction Rate. *Western Anatolia Journal of Educational Sciences***,** 509-516.

Denzin, N., K., L. 2008. *Collecting and Interpreting Qualitative Materials* London, Sage Publications.

Department of Basic Education 2011. Curriculum and Assessment Policy Statement Grades 10-12 Physical Sciences. Pretoria.

Department of Basic Education 2015. National Senior Certificate 2015 Diagnostic Report. Pretoria.

Department of Basic Education 2016. National Senior Certificate Diagnostic Report. Pretoria.

Department of Basic Education 2017. National Senior Certificate Diagnostic Report Part 1. Pretoria.

Dills, C. R. & Romiszowski, A. J. 1997. *Instructional development paradigms,* Englewood Cliffs, N.J., Educational Technology Publications.

Doane, D. P. & Seward, L. E. 2011. Measuring skewness: a forgotten statistic? *Journal of Statistics Education,* 19(2), 1-18.

Domagk, S., Schwartz, R. N. & Plass, J. L. 2010. Interactivity in multimedia learning: An integrated model. *Computers in Human Behavior,* 26(5)**,** 1024-1033.

Driscoll, M. 2005. Psychology of learning for instruction: Pearson new international edition. *Harlow, Združeno kraljestvo: Pearson Education*.

Driver, R., Asoko, H., Leach, J., Mortimer, E. & Scott, P. 1994. Constructing Scientific Knowledge in the Classroom. *Educational Researcher,* 23(7)**,** 5-12.

Duruk, U., Akgün, A., Dogan, C. & Gülsuyu, F. 2017. Examining the Learning Outcomes Included in the Turkish Science Curriculum in Terms of Science Process Skills: A Document Analysis with Standards-Based Assessment. *International Journal of Environmental and Science Education*, *12*(2), 117-142.

Eagly, A. H. & Chaiken, S. 1993. *The psychology of attitudes*, Harcourt, Brace Jovanovich College Publishers.

Ergul, R., Simsekli, Y., Calis, S., Ozdilek, Z., Docmencelebi, S. & Sanli, M. 2011. The effects of inquiry-based science teaching on elementary school students'science process skills and science attitudes. *Bulgarian Journal of Science & Education Policy,* 5(1) 48-68.

Etikan, I., Musa, S., A. & Alkassim, R., S. 2016. Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics,* 5(1)**,** 1-4.

Fiorella, L. & Mayer, R. E. 2014. Role of expectations and explanations in learning by teaching. *Contemporary Educational Psychology,* 39(2)**,** 75-85.

Fraser, K. L., Ayres, P. & Sweller, J. 2015. Cognitive load theory for the design of medical simulations. *Simulation in Healthcare,* 10(5)**,** 295-307.

Gallardo-Echenique, E. E., Marqués-Molías, L., Bullen, M. & Strijbos, J.-W. 2015. Let's talk about digital learners in the digital era. *International Review of Research in Open and Distributed Learning,* 16(3)**,** 156-187.

Gastwirth, J. L., Gel, Y. R. & Miao, W. 2009. The impact of Levene's test of equality of variances on statistical theory and practice. *Statistical Science 24(3)***,** 343-360. DOI: 10.1214/09-STS301.

Gegios, T., Salta, K. & Koinis, S. 2017. Investigating high-school chemical kinetics: the Greek chemistry textbook and students' difficulties. *Chemistry Education Research and Practice,* 18(1)**,** 151-168.

Goedhart, M. J. 2015. Changing perspectives on the undergraduate chemistry curriculum. *In:* GARCIA-MARTINEZ, J. & SERRANO-TORREGROSA, E. (eds.) *Chemistry Education: Best Practices, Opportunities and Trends.* Weinheim Germany: Wiley-VCH.

Gray, D. E. 2013. *Doing Research in the Real World*. Thousand Oaks, CA: Sage Publications.

Guba, E. 1990. *The paradigm dialog. Newbury,* Newbury Park, CA: Sage.

Guba, E. G. & Lincoln, Y. S. 1994. Competing paradigms in qualitative research. *In:* Denzin, N. K. & Lincoln, Y. S. (eds.) *Handbook of qualitative research.* Thousand Oarks: CA:Sage.

Gurel, D. K., Eryılmaz, A. & Mcdermott, L. C. 2015. A Review and Comparison of Diagnostic Instruments to Identify Students' Misconceptions in Science. *Eurasia Journal of Mathematics, Science & Technology Education,* 11(5), 989-1008.

Hall, A., 2007. Vygotsky goes online: Learning design from a socio-cultural perspective. In *Learning and socio-cultural Theory: Exploring modern Vygotskian perspectives international workshop 2007* (Vol. 1, No. 1, 94-107).

Hasler, B., S., Kersten, B. & Sweller, J. 2007. Learner control, cognitive load and instructional animation. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *21*(6), 713-729.

Hmelo-Silver, C. E. 2006. Design principles for scaffolding technology-based inquiry. *Collaborative Learning, Reasoning, and Technology***,** 147-170.

Hofstein, A. & Mamlok-Naaman, R. 2011. High-school students' attitudes toward and interest in learning chemistry. *Educación Química,* 22(2)**,** 90-102.

Hsieh, H., F. & Shannon, S. E. 2005. Three approaches to qualitative content analysis. *Qualitative Health Research,* 15(9)**,** 1277-1288.

Huskinson, T., L. & Haddock, G. 2006. Individual differences in attitude structure and the accessibility of the affective and cognitive components of attitude. *Social Cognition,* 24(4)**,** 453-468.

Ismail, H., N., Kuldas, S. & Hamzah, A. 2013. Do students need more motivational resources or more cognitive resources for better learning? *Procedia-Social and Behavioral Sciences,* 97**,** 325-332.

Johnson, R., B. & Onwuegbuzie, A., J. 2004. Mixed methods research: A research paradigm whose time has come. *Educational Researcher,* 33(7)**,** 14-26.

Johnstone, A.H., 2006. Chemical education research in Glasgow in perspective. *Chemistry Education Research and Practice*, *7*(2), 49-63.

Johnstone, A., H. 2000. Teaching of chemistry-logical or psychological? *Chemistry Education Research and Practice,* 1(1)**,** 9-15.

Jony, S. 2016. Student centered instruction for interactive and effective teaching learning: Perceptions of teachers in Bangladesh. *International Journal of Advanced Research in Education & Technology (IJARET),* 3(3)**,** 172-178.

Justi, R. 2003. Teaching and learning Chemical Kinetics. *In:* GILBERT, J. K., DE JONG, O., JUSTI, R., TREAGUST, D. F. & VAN DRIEL, J. H. (ed.) *Chemical education: Towards research-based practice.* New York: V. Kluwer Academic Publishers.

Kaheru, S., J. & Kriek, J. 2016. The effect of computer simulations on acquisition of knowledge and cognitive load: a gender perspective. *African Journal of Research in Mathematics, Science and Technology Education,* 20(1)**,** 67-79.

Kamtor, E. 2016. The Impact of Virtual Laboratories on Academic Achievement and Learning Motivation in the Students of Sudanese Secondary School. *International Journal of English Language, Literature and Humanities,* 4(9)**,** 464-483.

Karamustafaoğlu, S. & Mamlok-Naaman, R. 2015. Understanding Electrochemistry Concepts Using the Predict-Observe-Explain Strategy. *Eurasia Journal of Mathematics, Science and Technology Education,* 11(5)**,** 923-936.

Kaya, E. & Geban, Ö. 2012. Facilitating Conceptual Change in Rate of Reaction Concepts Using Conceptual Change-Oriented Instruction. *Education and Science,* 37(163)**,** 216-225.

Kearney, M., Treagust, D. F., Yeo, S. & Zadnik, M., G. 2001. Student and teacher perceptions of the use of multimedia supported predict–observe–explain tasks to probe understanding. *Research in Science Education,* 31(4)**,** 589-615.

Kırık, Ö., T. & BOZ, Y. 2012. Cooperative learning instruction for conceptual change in the concepts of chemical kinetics. *Chemistry Education Research and Practice,* 13(3)**,** 221-236.

Kirschner, P., A., Sweller, J. & Clark, R., E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational psychologist,* 41(2)**,** 75-86.

Kline, P. 2013. *Handbook of Psychological Testing,* London, Routledge.

Koopman, O. 2013. *Teachers' Experiences of Implementing the Further Education and Training (FET) Science Curriculum.* Doctor of Philosophy, Stellenbosch University.

Kotoka, J. and Kriek, J., 2014. The impact of computer simulations as interactive demonstration tools on the performance of Grade 11 learners in electromagnetism. *African Journal of Research in Mathematics, Science and Technology Education*, *18*(1),100-110.

Kozulin, A. 2003. *Vygotsky's educational theory in cultural context*, Cambridge University Press.

Krathwohl, D., R. 2002. A revision of Bloom's taxonomy: An overview. *Theory into Practice,* 41(4)**,** 212-218.

Kulik, J., A., Kulik, C., C. & Cohen, P. A. 1980. Effectiveness of Computer-based College Teaching: A Meta-analysis of Findings. *Review of Educational Research,* 50(4)**,** 525-544.

Kurt, S. & Ayas, A. 2012. Improving students' understanding and explaining real life problems on concepts of reaction rate by using a four step constructivist approach. *Social and Educational Studies,* 4(2)**,** 979-992.

Lajoie, S., P. 2005. Extending the scaffolding metaphor. *Instructional Science,* 33(5-6)**,** 541-557.

Lakens, D. 2013. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in psychology,* 4**,** 1-12. https://doi.org/10.3389/fpsyg.2013.00863.

Lederman, N., G., Abd-El-Khalick, F., Bell, R. & Schwartz, R., S. 2002. Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching,* 39(6)**,** 497-521.

Lederman, N., G. 2013. Nature of science: Past, present, and future. *Handbook of research on science education.* Routledge.

Levy, Y. & Ellis, T., J. 2011. A guide for novice researchers on experimental and quasiexperimental studies in information systems research. *Interdisciplinary Journal of information, knowledge, and management,* 6(1)**,** 151-161.

Lodico, M., G. 2006. Methods in Educational Research: From Theory to Practice. *Jossey-Bass, An Imprint of Wiley*.

Lodico, M., G., Spaulding, D. T. & Voegtle, K. H. 2006. *Methods in educational research: From theory to practice,* San Francisco, John Wiley & Sons.

Magno, C. 2010. The role of metacognitive skills in developing critical thinking. *Metacognition and learning,* 5(2)**,** 137-156.

Main, O. 2018. *Local Government Handbook: South Africa 2018 A complete guide tomanicipalities in South Africa,* Mowbray Yes Media Publishers.

Malan, S., B. & Ndlovu, M. 2014. Introducing problem-based learning (PBL) into a foundation programme to develop self-directed learning skills. *South African Journal of Education,* 34(1), 1-16.

Margaryan, A., Littlejohn, A. & Vojt, G. 2011. Are digital natives a myth or reality? University students' use of digital technologies. *Computers & education,* 56(2)**,** 429-440.

Mayer, R., E. 2002. Multimedia learning. *Psychology of Learning and Motivation.* Academic Press.

Mayer, R., E. 2003. The Promise of Multimedia Learning: Using the same instructional design methods across different media. *Learning and Instruction,* 13(2)**,** 125-139.

Mayer, R., E. 2008. Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American psychologist,* 63(8)**,** 760-769.

Mayer, R., E. 2010. Applying the science of learning to medical education. *Medical Education,* 44(6)**,** 543-549.

Mayring, P. 2014. Qualitative content analysis: theoretical foundation, basic procedures and software solution. Klagenfurt. Available: https://nbn-resolving.org/urn:nbn:de:0168-ssoar-395173 [Accessed 5 May 2020].

McComas, W.F. and Olson, J.K., 1998. The nature of science in international science education standards documents. In *The nature of science in science education* (pp. 41-52). Springer, Dordrecht.

McHugh, M., L. 2012. Interrater reliability: the kappa statistic. *Biochemia medica: Biochemia medica,* 22(3)**,** 276-282.

McKee, C. & Mortimer, M. 2007. Chemical Kinetics. *In:* Mortimer, M., Taylor, P. (ed.) *Chemical Kinetics and Mechanism: The Molecular World.* Royal Society of Chemistry.

Mertens, D., M. 2014. *Research and Evaluation in Education and Psychology: Integrating Diversity With Quantitative, Qualitative, and Mixed Methods*, SAGE Publications.

Michalisková, R. & Prokša, M. 2018. The level of mastery of the concept of chemical reaction rate by 9th grade students. *Chemistry-Didactics-Ecology-Metrology,* 23(1-2), 81-95. DOI: 10.1515/cdem-2018-0005

Miller, G., A. 1956. The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological review,* 63(2)**,** 81-97.

Minner, D., D., Levy, A., J. & Century, J. 2010. Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching,* 47(4)**,** 474-496.

Moore, E., B., Herzog, T., A. & Perkins, K., K. 2013. Interactive simulations as implicit support for guided-inquiry. *Chemistry Education Research and Practice,* 14(3)**,** 257-268.

Moreno, R. & Valdez, A. 2005. Cognitive load and learning effects of having students organize pictures and words in multimedia environments: The role of student interactivity and feedback. *Educational Technology Research and Development,* 53(3)**,** 35-45.

Morse, J., M. 2012. The Implications of Interview Type and Structure in Mixed Method Design. *In:* Gubrium, J. F., Holstein, J. A., Marvasti, A., B. & Mckinney, K., D. (ed.) *The SAGE Handbook of Interview Research: The Complexity of the Craft.* London: SAGE Publications.

Mortimer, M. & Taylor, P. 2002. *The Molecular World: Chemical Kinetics and Mechanism,,* London, Cambridge, Royal Society of Chemistry.

Mubeen, S. & Reid, N. 2014. The Measurement of Motivation with Science Student. *European Journal of Educational Research,* 3(3)**,** 129-144.

Mutlu, A. & Sesen, B., A. 2015. Development of a two-tier diagnostic test to assess undergraduates' understanding of some chemistry concepts. *Procedia-Social and Behavioral Sciences,* 174**,** 629-635. doi: 10.1016/j.sbspro.2015.01.593

Nachar, N. 2008. The Mann-Whitney U: A test for assessing whether two independent samples come from the same distribution. *Tutorials in quantitative Methods for Psychology,* 4(1)**,** 13-20.

O'neill, G. & Mcmahon, T. 2005. Student–centred learning: what does it mean for students and lecturers? *In:* O'neill, G., Moore, S. & Mcmullin, B. (eds.) *Emerging Issues in the Practice of University Learning and Teaching.* Dublin: AISHE.

Odongo, M. 2013. *Development, Implementation and Evaluation of a computer plus-talk teaching sequence to improve students' understanding of chemical rate of reaction: A Ugandan Case Study.* Doctor of Philosophy, University of Leeds.

Olakanmi, E., E., 2015. The effects of a web-based computer simulation on students' conceptual understanding of rate of reaction and attitude towards chemistry. *Journal of Baltic Science Education*, *14*(5), p.627.

Omilani, N., A., Ochanya, N., M., R. & Aminu, S., A. 2016. The Effect of Combined Virtual and Real Laboratories on Students' Achievement in Practical Chemistry. *International Journal of Secondary Education,* 4(3)**,** 27-31. doi: 10.11648/j.ijsedu.20160403.11

Onwuegbuzie, A., J. 2000. *Positivists, Post-Positivists, Post-Structuralists, and Post-Modernists: Why Can't We All Get Along? Towards a Framework for Unifying Research Paradigms*. Annual meeting of the Association for the Advancement of Educational Research (AAER), Ponte Vedra, Florida, November, 18, 2000.

Oppong, S., H. 2013. The problem of sampling in qualitative research. *Asian Journal of Management Sciences and Education,* 2(2)**,** 202-210.

Osborne, J. 2014. Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education,* 25(2)**,** 177-196.

Osborne, J., Collins, S., Ratcliffe, ., Millar, R. & Duschl, R. 2003. What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching,* 40(7)**,** 692-720.

Oxtoby, D., W., Freeman, W., A. & Block, T., F 2003. *Chemistry:Science of Change,* Belmont, Brooks/Cole-Thomson.

Ozmen, H. 2008. The influence of computer-assisted instruction on students' conceptual understanding of chemical bonding and attitude toward chemistry: A case for Turkey. *Computers & Education,* 51(1)**,** 423-438.

Paas, F., Renkl, A. & Sweller, J. 2004. Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional science,* 32(1-2)**,** 1-8.

Pallant, J. 2005. *SPSS Survival Manual A step by step guide to data analysis using SPSS for Windows (Version 12)*. Sydney Allen & Unwin.

Petty, N., J., Thomson, O., P. & Stew, G. 2012. Ready for a paradigm shift? Part 2: Introducing qualitative research methodologies and methods. *Manual Therapy,* 17(5)**,** 378-384.

Polit, D., F., & Beck, C., T. 2006. The content validity index: are you sure you know what's being reported? Critique and recommendations. *Research in nursing & health*, *29*(5), 489-497.

Prensky, M. 2007. How to teach with technology: Keeping both teachers and students comfortable in an era of exponential change. *Emerging Technologies for Learning,* 2(4)**,** 40-46.

Prince, M., J. & Felder, R., M. 2006. Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of engineering education,* 95(2)**,** 123-138.

Puntambekar, S. & Hubscher, R. 2005. Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist,* 40(1)**,** 1-12.

Pyatt, K. & Sims, R. 2012. Virtual and physical experimentation in inquiry-based science labs: Attitudes, performance and access. *Journal of Science Education and Technology,* 21(1)**,** 133-147.

Razali, N., M. & Wah, Y., B. 2011. Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. *Journal of statistical modeling and analytics,* 2(1)**,** 21-33.

Renkl, A. & Atkinson, R., K. 2007. Interactive learning environments: Contemporary issues and trends. An introduction to the special issue. *Educational Psychology Review,* 19, 235-237. DOI 10.1007/s10648-007-9052-5

Reyes, P., B., España, R., C., N. & Belecina, R., R. 2014. Towards developing a proposed model of teaching-learning process based on the best practices in chemistry laboratory instruction. *International Journal of Learning, Teaching and Educational Research,* 4(1) 83-166.

Robinson, W., R., Odom, J., D. & Holtzclaw Jr, H., F. 1997. *General Chemistry,* New York, Houghton Mifflin.

Rutten, N., Van Joolingen, W. & Veen, J. 2012. The learning effects of computer simulations in science education. *Computers & Education,* 58(1)**,** 136-153.

Samaras, A., P. & Gismondi, S. 1998. Scaffolds in the field: Vygotskian interpretation in a teacher education program. *Teaching and Teacher Education,* 14(7)**,** 715-733.

Sari, W., Supriatna, A. & Hendayana, S. 2019. Analysis of students difficulties based on respondents ability test on the topic of factors affecting reaction rate. *Journal of Physics: Conference Series.* IOP Publishing, 042032.

Schreier, M. 2019. Content Analysis, Qualitative. London: Sage Publications Ltd.

Schunk, D. H. 2012. *Learning theories an educational perspective sixth edition*, Pearson.

Schwarz, N. 2006. Attitude research: Between Ockham's razor and the fundamental attribution error. *Journal of Consumer Research,* 33(1)**,** 19-21.

Schwarz, N. 2007. Attitude construction: Evaluation in context. *Social Cognition,* 25(5)**,** 638-656.

Scotland, J. 2012. Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching,* 5(9)**,** 9-16.

Sesen, B., A. & Tarhan, L. 2013. Inquiry-based laboratory activities in electrochemistry: High school students' achievements and attitudes. *Research in Science Education,* 43(1)**,** 413-435.

Sharma, P. & Hannafin, M. J. 2007. Scaffolding in technology-enhanced learning environments. *Interactive Learning Environments,* 15(1)**,** 27-46.

Shenton, A., K. 2004. Strategies for ensuring trustworthiness in qualitative research projects. *Education for information,* 22(2)**,** 63-75.

Shiffrin, R., M. & Schneider, W. 1977. Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological review,* 84(2)**,** 1-66.

Shutterstock. 2020. *Burning Wood Images* [Online]. Available: https://www.shutterstock.com/search/burning+wood [Accessed April 26 2020].

Simonson, M., R. & Maushak, N. 1996. *Instructional technology and attitude change.* Fischler College of Education: Faculty Books and Book Chapters. Book 12.

Singer, S., R., Hilton, M., L., Schweingruber, H., A. & National research council. 2006. Committee on high school laboratories: Role and vision, America's lab report: Investigations in high school science.

Singh, A., S. & Masuku, M., B. 2014. Sampling techniques & determination of sample size in applied statistics research: An overview. *International Journal of Economics, Commerce and Management,* 2(2)**,** 1-22.

Sirhan, G. 2007. Learning Difficulties in Chemistry: An Overview. *Journal of Turkish Science Education,* 4(2)**,** 2-20.

Sorden, S., D. 2005. A cognitive approach to instructional design for multimedia learning. *Informing Science Journal,* 8**,** 263-279.

Stat SA 2015. Media Release: Education Series 1-Focus on Schooling in Limpopo. Pretoria.

Suits, J., P. 2015. Twenty-First Century Skills: Using the Web in Chemistry Education. *In:* Garcio-Martinez, J. & Serrano-Torregrosa, E. (eds.) *Chemistry Education: Best Practices, Opportunities and Trends.* Weinhein: Wiley VCH.

Supasorn, S. & Promarak, V. 2015. Implementation of 5E inquiry incorporated with analogy learning approach to enhance conceptual understanding of chemical reaction rate for grade 11 students. *Chemistry Education Research and Practice,* 16(1)**,** 121-132.

Suter, W., N. 2014a. Sampling in Research *Introduction to Educational Research: A Critical Thinking Approach* Thousand Oaks Sage Publications, Inc.

Suter, W., N. 2014b. Statistical Data Analysis *Introduction to Educational Research: A Critical Thinking Approach* Thousand Oaks Sage Publications, Inc.

Sweller, J. 1988. Cognitive load during problem solving: Effects on learning. *Cognitive Science,* 12(2)**,** 257-285.

Sweller, J. 1994. Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction,* 4(4)**,** 295-312.

Sweller, J., Van Merrienboer, J., J. & Paas, F., G. 1998. Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251-296.

Taber, K., S. 2017. *Educational Research Methods Methodology* [Online]. Available: http://people.ds.cam.ac.uk/kst24/EdResMethod/Methodology.html [Accessed August 19 2019].

Taber, K., S. 2013. Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice,* 14(2)**,** 156-168.

Tashakkori, A., Teddlie, C. & Teddlie, C., B. 1998. *Mixed methodology: Combining qualitative and quantitative approaches*, Sage.

Tatli, Z. & Ayas, A. 2013. Effect of a virtual chemistry laboratory on students' achievement. *Journal of Educational Technology & Society,* 16(1)**,** 159-170.

Tavakol, M. & Dennick, R. 2011. Making sense of Cronbach's alpha. *International Journal of Medical Education,* 2**,** 53-55.

Teddlie, C. & Yu, F. 2007. Mixed methods sampling: A typology with examples. *Journal of Mixed Methods Research,* 1(1)**,** 77-100.

Tosun, C. & Senocak, E. 2013. The effects of problem-based learning on metacognitive awareness and attitudes toward chemistry of prospective teachers with different academic backgrounds. *Australian Journal of Teacher Education,* 38(3)**,** 61-73.

Treagust, D., F. 2013. General instructional methods and strategies. *In:* Abell, S., K., Appleton, K. & Hanuscin, D., L. (ed.) *Handbook of research on science education.* Routledge.

Troudi, S. 2014. Paradigmatic nature and theoretical framework in educational research. In *English in Learning: Learning in English*, M. Al-Hamly (ed) Dubai: TESOL Arabia Pub. Available: https://education.exeter.ac.uk/ojs/index.php/inspire/article/viewFile/25/16 [Accessed June 15, 2020]

Tsaparlis, G. 2009. Learning at the macro level: The role of practical work. *Multiple Representations in Chemical Education.* Springer.

Turányi, T. & Tóth, Z. 2013. Hungarian university students' misunderstandings in thermodynamics and chemical kinetics. *Chemistry Education Research and Practice,* 14(1)**,** 105-116.

Tüysüz, C. 2010. The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry. *International Online Journal of Educational Sciences,* 2(1), 37-53. http://www.iojes.net/ [Accessed June 15 2020].

Van Driel, J., Gilbert, J., Jong, O. D., Justi, R. & Treagust, D. 2002. *Chemical Education: Towards Research-Based Practice*, Springer.

Vaske, J., J., Beaman, J. & Sponarski, C., C. 2017. Rethinking internal consistency in Cronbach's Alpha. *Leisure Sciences,* 39(2)**,** 163-173.

Vogel, J., J., Vogel, D., S., Cannon-Bowers, J., Bowers, C., A., Muse, K. & Wright, M. 2006. Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research,* 34(3)**,** 229-243.

Vygotsky, L., S. 1978. Mind in society: The development of higher mental process. Cambridge, MA: Harvard University Press.

Wagner, W., E. & Gillespie, B., J. 2019. Effect Size *Using and Interpreting Statistics in the Social, Behavioral, and Health Sciences* Thousand Oaks SAGE Publications, Inc.

Westen, D. & Rosenthal, R. 2003. Quantifying construct validity: Two simple measures. *Journal of Personality and Social Psychology,* 84(3)**,** 608-618.

Willig, C., 2013. *Introducing Qualitative Research in Psychology*. McGraw-hill education (UK).

Wright, M., R. 2005. *Introduction to Chemical Kinetics*, John Wiley & Sons.

Yan, Y., K. & Subramaniam, R. 2016. Diagnostic appraisal of grade 12 students' understanding of reaction kinetics. *Chemistry Education Research and Practice,* 17(4)**,** 1114-1126.

Yilmaz, K. 2013. Comparison of quantitative and qualitative research traditions: Epistemological, theoretical, and methodological differences. *European Journal of Education,* 48(2)**,** 311-325.

Zephrinus, C. & Phoebe, M., I. 2015. Resolving Nigerian secondary school students' learning difficulties in nuclear chemistry using computer animation solutions. *Procedia-Social and Behavioral Sciences,* 176, 1034-1040.

Zhang, Z., H. & Linn, M. C. 2011. Can generating representations enhance learning with dynamic visualizations? *Journal of Research in Science Teaching,* 48(10)**,** 1177-1198.

Zhang, Z., H. & Linn, M., C. 2013. Learning from chemical visualizations: Comparing generation and selection. *International Journal of Science Education,* 35(13)**,** 2174-2197.

Appendices

Appendix 1: Ethical Clearance from the Research Ethics Committee: University of Venda

RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:
Mr S Jere

Student No:
18006077

PROJECT TITLE: **The effects of Computer-Based Instruction on Chemical Reaction Rate on the academic achievement of Grade 12 learners in Mopani District.**

PROJECT NO: **SEDU/19/CSEM/06/0110**

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Dr M Mpeta	University of Venda	Promoter
Dr S Kaheru	University of Venda	Co- Promoter
Mr S Jere	University of Venda	Investigator – Student

ISSUED BY:
UNIVERSITY OF VENDA, RESEARCH ETHICS COMMITTEE

Date Considered: October 2019
Decision by Ethical Clearance Committee Granted
Signature of Chairperson of the Committee: ....
Name of the Chairperson of the Committee: Senior Prof. G.E. Ekosse

UNIVERSITY OF VENDA
RESEARCH AND INNOVATION
2019 -10- 04

University of Venda
PRIVATE BAG X5050, THOHOYANDOU, 0950, LIMPOPO PROVINCE, SOUTH AFRICA
TELEPHONE (015) 962 8504/8313 FAX (015) 962 9060
"A quality driven financially sustainable, rural-based Comprehensive University"

Appendix 2: Supporting Letter for Application for Permission to the DBE

SCHOOL OF EDUCATION:
Professional Studies

MEMORANDUM

2019.10.28

TO WHOM IT MAY CONCERN
Mr Jere Samuel student no: 18006077

Mr Samuel Jere is a student a postgraduate student at the University of Venda, he is pursuing a Doctor of Education qualification. He is need of support to continue his research in the schools in Limpopo province.

Please accord him the necessary assistance to get permission to carry out the research.

Kind regards,

Dr Kaheru Sam James Murungi
Supervisor
X 9095
Cell: 072 709 2626

University of Venda

A quality driven, financially sustainable, rural based comprehensive university
RIVATE BAG X5050, THOHOYANDOU, 0950 LIMPOPO PROVINCE SOUTH AFRICA
TELEPHONE (015) 962 9095 FAX (015) 962 8050
E-MAIL: sam.kaheru@univen.ac.za

Appendix 3: Application to the DBE for Permission to Conduct Study

University of Venda Creating Future Leaders	**UNIVERSITY OF VENDA** **SCHOOL OF EDUCATION** **DEPARTMENT OF CURRICULUM STUDIES** **DOCTOR OF EDUCATION DEGREE**

Enq: Jere S. Tel/Cell: 0798822784/0787219939 Date: 28/10/2019

To: The Head of Department
Department of Education
Private Bag 9489
Polokwane
0700

From: Jere S.
P.O. Box 337
Soekmekaar
0810

Sir/Madam

RE: REQUEST TO CONDUCT RESEARCH IN MOPANI EAST DISTRICT

1. I am hereby making a request to conduct research in schools in the Mopani East District of the Limpopo Province.

2. The **research outline** is as follows:

2.1. Area

The research is focused on the Physical Sciences Education field as the area that is still less researched on. I am investigating the effectiveness of the use of Computer Simulation-Based Instruction on learners' academic achievement in the Chemistry Section of Physical Sciences. The study involves teaching learners in one school, the Experimental Group, using simulations on the topic Chemical Reaction Rates. The other class at a different school (Control Group) will initially be taught in the usual way. The topic is one of the challenging topics in Physical Sciences.

2.2. Topic

The title of the topic is the following: The effect of Computer Simulation-Based Instruction in Chemical Reaction Rate on the academic achievement of Grade 12 learners in Mopani East District.

2.3. Methodology

The research method that will be used in the study is the mixed method approach. The first part of the research is a quasi-experimental (Pre/Post Test) study in which one Physical Sciences class at one school will be taught the topic Chemical Reaction Rates using Computer Simulation-Based Instruction. The other class at a different school will be taught by the researcher the same topic using the usual method of teaching this topic which does not involve simulations. The schools are sampled based on the number of learners doing Physical Sciences at these schools. The minimum number of learners in a class is about 50 to enable statistical analysis. The second part of the research is a qualitative study in which purposive sampling of a few learners and teachers who participated in the first part of the study will be interviewed. Data will be collected through pre/post-test in which the same test will be administered at the beginning of the study and at the end. The questions are thirty multiple choice items from previous NSC Physical Science Paper 2 and from research. Qualitative data will be collected through semi-structured interviews.

2.4. Registration

I am a registered Doctor of Education (Curriculum Studies) student with the University of Venda, my student number is **18006077**. Currently I am in second year. The Ethics Committee of the university has approved the study. Attached is a copy of their approval.

3. The value of the study

The aim of the study is to investigate the effectiveness of using Computer Simulations to improve learners' academic achievement in Chemical Reaction Rate. The topic has been identified as one where learners performs poorly in the final Grade 12 exams. It is hoped that if the method is found to be effective, then practicing teachers can adopt this method. The participating learners are expected to gain a greater understanding of the topic after learning through research-based teaching approach. If the approach proves to be effective, the control group in the other class would also be taught using the same method.

4. Period of the research

The research will be conducted between January and April 2020. The study starts with validation of research instruments and carrying out reliability study of the instruments. This is then followed by pilot study and finally main study.

5. Approval

Approval is hereby requested to be allowed to conduct such a study in the Mopani East District.

Regards

Jere S.

Educator: Lephai Secondary School. Mopani East District.

6. Recommendation by the Director: Planning and Research

____________________ __________________

Director Date

7. Approval by the HOD

APPROVED	NOT APPROVED

____________________ __________________

Signature Date

Appendix 4: Approval Letter from the DBE for Permission to Conduct Study

LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF
EDUCATION

Ref: 2/2/2 Enq: Mabogo MG Tel No: 015 290 9365 E-mail: MabogoMG@edu.limpopo.gov.za

Jere S
Box 337
Soekmekaar
0810

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH

1. The above bears reference.
2. The Department wishes to inform you that your request to conduct research has been approved. Topic of the research proposal: **"THE EFFECT OF COMPUTER SIMULATION-BASED INSTRUCTION IN CHEMICAL REACTION RATE ON THE ACADEMIC ACHIEVEMENT OF GRADE 12 LEARNERS IN MOPANI DISTRICT."**
3. The following conditions should be considered:

3.1 The research should not have any financial implications for Limpopo Department of Education.

3.2 Arrangements should be made with the Circuit Office and the School concerned.

3.3 The conduct of research should not in anyhow disrupt the academic programs at the schools.

3.4 The research should not be conducted during the time of Examinations especially the fourth term.

3.5 During the study, applicable research ethics should be adhered to; in particular the principle of voluntary participation (the people involved should be respected).

3.6 Upon completion of research study, the researcher shall share the final product of the research with the Department.

REQUEST FOR PERMISSION TO CONDUCT RESEARCH: JERE S

CONFIDENTIAL

Cnr. 113 Biccard & 24 Excelsior Street, POLOKWANE, 0700, Private Bag X9489, POLOKWANE, 0700
Tel: 015 290 7600, Fax: 015 297 6920/4220/4494

The heartland of southern Africa - development is about people!

4 Furthermore, you are expected to produce this letter at Schools/ Offices where you intend conducting your research as an evidence that you are permitted to conduct the research.

5 The department appreciates the contribution that you wish to make and wishes you success in your investigation.

Best wishes.

Ms NB Mutheiwana
Head of Department

31/10/19
Date

REQUEST FOR PERMISSION TO CONDUCT RESEARCH: JERE S

CONFIDENTIAL

Appendix 5: Informed Consent Letter for Participants

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Samuel Jere, about the nature, conduct, benefits and risks of this study –
  Research Ethics Clearance Number: SEDU/19/CSEM/06/0110
- I have also received, read and understood the above written information regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerized system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Full Name of Participant: …………………….... Date: …………… Time: ……
Signature: ……………………….

I, Samuel Jere …………………..
herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Full Name of Researcher

Samuel Jere Date: ………………… Signature**…………………**

Full Name of Witness (If applicable)

……………………. Date **……………….** Signature**…………………..**

Full Name of Legal Guardian (If applicable)

…………………….. Date**………………** Signature**…………………….**

Appendix 6: Content Validation Form

CONTENT VALIDATION FORM USED FOR TCRRC, ATCLS & INTERVIEW SCHEDULES

Thank you for accepting to participate in content validation of the Test on Chemical Reaction Rate Concepts (TCRRC). Please rate each test item on a four-point ordinal rating scale where 1=not relevant; 2=somewhat relevant; 3=quite relevant; 4=highly relevant. Use the grid below to indicate your ratings.

Question	1 Not Relevant	2 Somewhat Relevant	3 Quite Relevant	4 Highly Relevant
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
33				

Appendix 7:Test of Chemical Reaction Rate Concepts

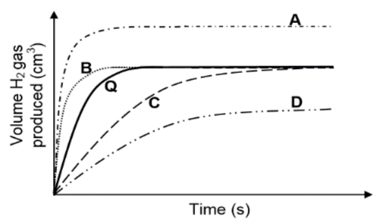
Instructions

1. This question paper consists of thirty multiple choice questions. Answer ALL questions on the separate answer sheet provided by putting a circle on the letter *A, B, C* or *D* that corresponds to the correct answer.
2. For each question indicate how confident you are of your answer by putting a circle on 1,2,3 or 4 to show whether you are *very unconfident*, *unconfident*, *confident* or *very confident*.
3. Do not write or draw anything on this question paper.
4. Do not write your name on the answer sheet.
5. Your answers will be used for research purposes only.

Time: 1 Hour

1. Graph Q (the solid line) below was obtained for the reaction of $100cm^3$ of a 0.1 $mol.dm^{-3}$ HCl solution with excess magnesium powder.

Which graph (A, B, C or D) most probably represents the reaction of $100cm^3$ of a 0.1 $mol.dm^{-3}$ CH_3COOH solution with excess magnesium powder?



2. The rate of a chemical reaction can be expressed as …
   A. grams of a reactant per mole.
   B. energy consumed per mole.
   C. volume of gas formed per unit time.
   D. moles of product per litre of solution.

3. The equation below represents the decomposition of calcium carbonate.

$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$

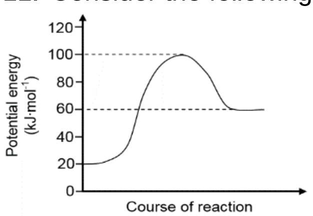
Which <u>*ONE*</u> of the following factors will increase the initial rate of decomposition of calcium carbonate?
   A. Pressure
   B. Temperature
   C. Concentration
   D. Mass of $CaCO_{3(s)}$

4. The rate of a chemical reaction is most correctly defined as …
   A. time taken for a reaction to take place.
   B. speed at which a reaction takes place.
   C. change in the amount of reactants or products.
   D. change in the amount of reactants per second.
5. Activation energy can best be described as the minimum energy required …
   A. by reactant molecules for effective collision.
   B. to make reactant molecules collide more often.
   C. to increase the kinetic energy of reactant molecules.
   D. to change the orientation of reactant molecules.
6. Which one of the following describes the effect of a positive catalyst on the net activation energy and the heat of reaction (ΔH) of a specific reaction?

	NET ACTIVATION ENERGY	ΔH
A	Increases	No effect
B	Decreases	Increases
C	No effect	Decreases
D	Decreases	No effect

7. The temperature of a substance is a measure of the … of the particles.
   A. average potential energy
   B. average kinetic energy
   C. total kinetic energy
   D. total potential energy
8. In a chemical reaction, the difference between the potential energy of the products and the potential energy of the reactants is equal to the…
   A. enthalpy of the chemical reaction.
   B. Rate at which the reaction occurs.
   C. enthalpy change of the reaction.
   D. total potential energy of the particles.
9. The energy change during a chemical reaction is known as …
   A. bond energy.
   B. heat of reaction.
   C. activation energy.
   D. activated complex.
10. The balanced equation below represents a hypothetical reaction
    $2P(g)+3Q(g) \rightarrow 4R(g)+2S(g)$
    The rate of the reaction in terms of the number of moles of substance P used up is $1X10^{-3}mol.dm^{3}.s^{-1}$. What is the rate (in $mol.dm^{-3}.s^{-1}$) at which product R is formed?
    A. $1X10^{-3}$
    B. $4(1X10^{-3})$
    C. $(1X10^{-3})\div 2$
    D. $2(1X10^{-3})$

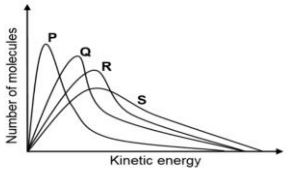
11. Consider the following potential energy diagram for a chemical reaction:



Which *ONE* of the following shows the values of the total energy change and the activation energy for this reaction?

	Energy change ($kJ \cdot mol^{-1}$)	**Activation energy ($kJ \cdot mol^{-1}$)**
A	80	40
B	60	100
C	40	80
D	– 40	80

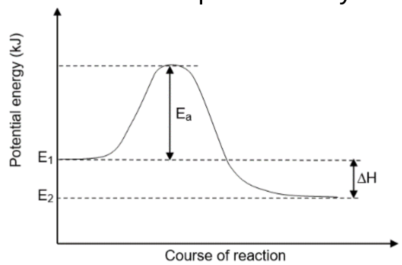
12. The graphs below represent the molecular distribution for a reaction at different temperatures.



Which *ONE* of the graphs above represents the reaction at the highest temperature?

A. P
B. Q
C. R
D. S

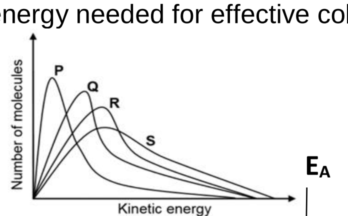
13. A certain reaction is represented by the potential energy diagram below.



Which *One* of the following quantities will change when a catalyst is added?

A. E_2
B. E_1
C. E_a
D. ΔH

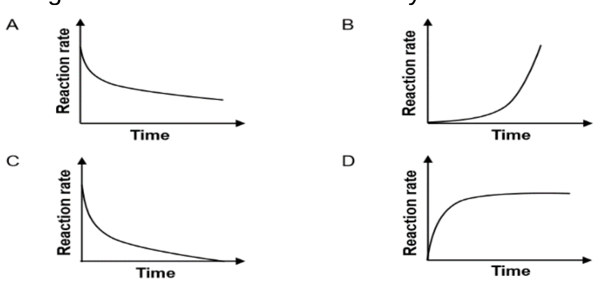
14. The Maxwell-Boltzmann energy distribution curves below show the number of particles as a function of their kinetic energy for a reaction at four different temperatures. The minimum kinetic energy needed for effective collisions to take place is represented by E_A.



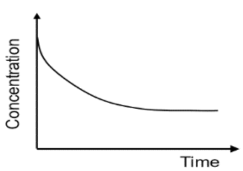
Which *ONE* of these curves represents the reaction with the lowest rate?

A. P
B. Q
C. R
D. S

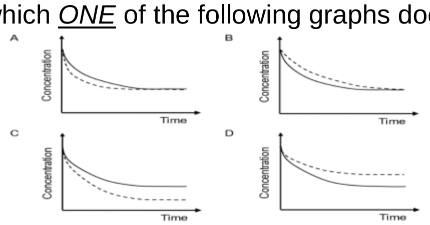
15. Which *ONE* of the reaction rate versus time graphs below best represents the reaction between magnesium and EXCESS dilute hydrochloric acid?



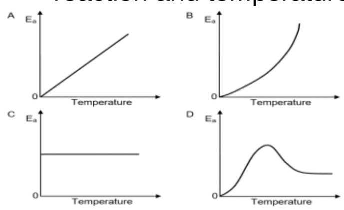
16. The graphs below represent the change in concentration of a reactant against time for a chemical reaction.



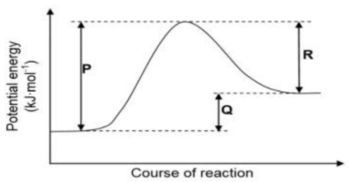
In which *ONE* of the following graphs does the dotted line show the effect of a catalyst on this reaction?



17. Which ONE of the following graphs show the relationship between the activation energy (E_a) of a reaction and temperature?



18. The energy changes represented by P, Q and R on the potential energy graph below take place during a reversible chemical reaction.



Which *ONE* of the following changes will decrease both P and R but leave Q unchanged?

A. A decrease in volume.
B. The addition of a catalyst.
C. A decrease in temperature.
D. A decrease in concentration.

19. Why does a catalyst cause a reaction to proceed faster?

A. They are more collisions of reactants per second.
B. The collisions of reactants occur with greater energy.
C. The activation energy of the reaction is lowered.
D. There are more collisions per time of greater energy.

20. Reactions are generally faster at high temperature because the …

A. activation energy increases.
B. energy of the product is lowered.
C. energy of the reactant decreases.
D. number of effective collision increases.

21. Which of the following statements about reaction rate is *NOT* correct?

A. The bigger the particle size of a solid reactant, the faster the reaction
B. The lower the activation, the faster the reaction
C. The higher the temperature, the faster the reaction
D. The higher the pressure of gaseous reactants the faster the reaction.

22. According to the collision theory, a successful collision will occur if:

I	Particles collide with correct orientation.
II	Particles collide more frequently.
III	Colliding particles have energy greater than a certain minimum amount.

Which of the above statement(s) is/are correct?

A. I and II only
B. III only
C. I and III only
D. I, II and III

23. Consider the following reaction which reached equilibrium in a closed vessel at a certain temperature.

$2NO_{(g)} + Cl_{2(g)} \leftrightarrow 2NOCl_{(g)}$ $\Delta H < 0$ (Exothermic)

If the temperature of the system is now *INCREASED*, it will …

A. increase only the rate of the forward reaction.
B. increase only the rate of the reverse reaction.
C. increase the rate of the forward and reverse reaction.
D. decrease only the rate of the forward reaction.

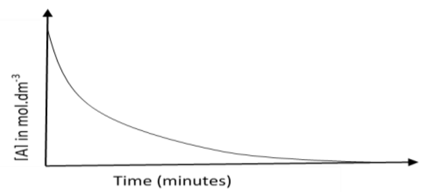
24. When the temperature of an elementary reaction increases …

A. The rate of the reaction increases if the reaction is exothermic.
B. The rate of the reaction increases if the reaction is endothermic.
C. The reaction rate increases for both exothermic and endothermic reactions.
D. The rate of the reaction does not change if the reaction is exothermic.

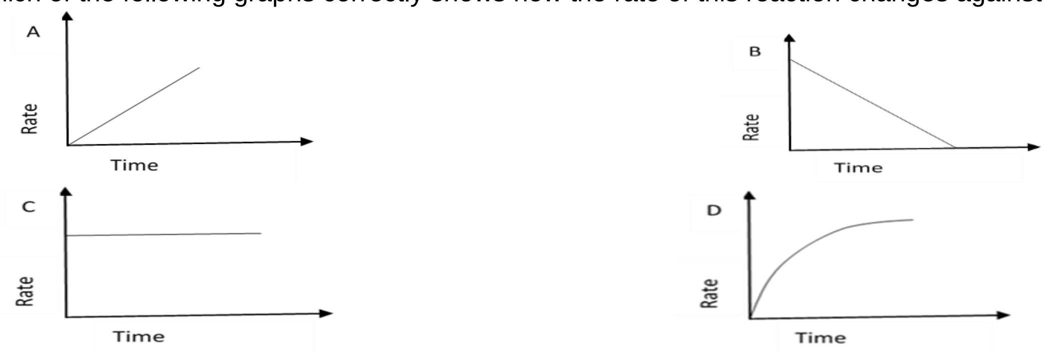
25. Two chemicals A and B react to form C as shown in the equation below.

$A_{(aq)} + B_{(aq)} \rightarrow C_{(aq)}$

The graph below shows how the concentration of A changes with time



Which of the following graphs correctly shows how the rate of this reaction changes against time?



26. The gases A and B react according to the elementary reaction:

$A_{(g)} + B_{(g)} \rightarrow AB_{(g)}$

What is the effect of increasing the reaction temperature on the following?

I. Rate of collisions between reactants A and B
II. Rate of effective collisions between reactants A and B

A. Only I increase
B. Only II increases
C. Both I and II increases
D. Both I and II decreases

27. A catalyst increases the rate of a reaction by …
A. decreasing the change in enthalpy of the reaction.
B. providing an alternative reaction mechanism.
C. increasing the average kinetic energy of the reactants.
D. increasing the activation energy of the reaction.

28. The gases A and B react according to the elementary reaction:

A (g)+ B(g)→AB(g).

The reaction proceeds in the presence of a catalyst. During the reaction …
A. the rate of the reaction remains constant.
B. the rate of the reaction decreases.
C. the rate of the reaction increases.
D. it is not clear how the reaction rate changes.

29. During the course of the reaction

$2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$

At time *t,* the instantaneous rate of formation of O_2 was found to be 3 mol.dm^{-3}.min^{-1}.
The instantaneous rate of consumption of N_2O_5 at time *t*, is equal to…
A. 1.5 mol.dm^{-3}min^{-1}

B. 3 $mol.dm^{-3}.min^{-1}$
C. 6 $mol.dm^{-3}.min^{-1}$
D. 9 $mol.dm^{-3}.min^{-1}$

30. During the study of rate of the reaction:
$2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained

Time (s)	0	20	40	60	80	100
[A]/$mol.dm^{-3}$	5.6	4.6	3.7	3.0	2.4	2.0

The average consumption rate of A, in $mol.dm^{3}.s^{-1}$ during the time interval between 20 s and 40 s is ….

A. -0.045
B. 0.045
C. 0.036
D. -0.036

Appendix 8: Attitudes Towards Chemistry Lessons Scale (ATCLS)

Adapted from Cheung (2011:119)

Subscale	Items	Strongly disagree	Disagree	Agree	Strongly agree
		1	2	3	4
Liking chemistry theory lessons	Q1. I like chemistry more than any other school subject.				
	Q5. Chemistry lessons are interesting.				
	Q9. Chemistry is one of my favourite subjects.				
Liking virtual chemistry laboratory work	Q2. I like to do virtual chemistry experiments.				
	Q6. When I am working on the virtual chemistry lab, I feel I am doing something important				
	Q10. Doing virtual chemistry experiments in school is fun.				
Evaluative beliefs about school chemistry	Q3. Chemistry is useful for solving everyday problems.				
	Q7. People must understand chemistry because it affects their lives				
	Q11. Chemistry is one of the most important subjects for people to study.				
Behavioural tendencies towards learning chemistry	Q4. I am willing to spend more time reading chemistry books.				
	Q8. I like trying to solve new problems in chemistry.				
	Q12. If I had a chance, I would do a project in chemistry.				

Appendix 9: Interview Schedule for teacher

Personal Details

Age:

Sex:

Highest Qualifications:

Questions

1. In your opinion, do simulations help learners to understand chemical reaction rate concepts? If yes, why? If no, why not?
2. In the lessons taught using Simulations learners performed virtual experiments. In your opinion, how effective were these virtual experiments in assisting learners in the understanding of chemical reaction rates? Please explain.
3. Do simulations assist learners in conceptual understanding of the collision theory? If yes, what are the features of these simulations which assist them. If no, give reasons.
4. Do simulations play a role in assisting learners in understanding science process skills? If yes, why? If no, why not?
5. Do virtual experiments play any role in helping learners in understanding of factors affecting reaction rates? Please explain.
6. Do animations help learners in the understanding of effect of various factors on the rate of reactions? If yes, how do they assist. If no, why?
7. Are simulations of any help in the understanding of the Maxwell Boltzmann Distribution curve of molecular speeds and reaction mechanisms. Please explain.
8. Do simulations play any role in the learners' attitudes towards the topic? Do they in any way improve learners' interest in the lessons taught? Please explain.

We have come to the end of the interview. Is there anything that was not discussed that you think is important? Thank you for attending this interview.

Appendix 10: Interview Schedule for Learners

Interview Schedule for Learners

DATE: ………………. DURATION: 45 MINUTES TIME: FROM ……... TO…………

Firstly, I would like to thank you for accepting to participate in the interview phase of my study. The purpose of my study is to find out how Computer Simulation Based Instruction affects learners' achievement in the topic Chemical Reaction Rates. The study also investigates the attitudes and views of learners about learning CRR using CSBI and using traditional approach. Our interview will last about 45 minutes. I will ask you about the experiences you had when you were learning CRR using computer simulations to find out your views on learning using this method.

At the beginning of the study you signed a form in which you gave me permission to audio record our conversation. Are you still willing to let me record the interview today?

If Yes. *Thank you! Please let me know if you change your mind at any point during the interview.*

If No. *Thank you! I will only take notes of the interview*.

Do you have any questions or comments before we begin? Also, feel free to ask any questions at any point during the conversation.

Background Information

To begin this interview, I'd like to ask you some questions about yourself and your general knowledge and understanding of Computer Simulation-Based Instruction.

1.1 How old are you?
1.2 Before participating in this study, were you ever taught any topic in Physical Science using computer simulations? If Yes. Please tell me what topic(s). Briefly describe how the teacher taught you using the simulations
1.3 Do you have a computer, tablet or cell phone on which you can access the internet? If Yes. Have you ever used computer simulations on the internet to learn some scientific concepts? Please explain.

Learners' conceptual understanding of CRR and their views of CSBI

Thank you for your responses. Now, I'd like to ask you questions regarding your experiences of learning Chemical Reaction Rates using Computer Simulation-Based Instruction.

2. Look at these pictures which shows a slow and a fast reaction.

Iron rusting - a CHEMICAL REACTION with a *slow* reaction rate.

Wood burning - a **CHEMICAL REACTION** with a ***fast*** **reaction rate**.

2.1 Tell me what you understand by the term "rate of a chemical reaction".
2.2 During the study of rate of the reaction:
$2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained

Time (s)	0	20	40	60	80	100
[A]/mol.dm^{-3}	5.6	4.6	3.7	3.0	2.4	2.0

The average consumption rate of A, in $mol.dm^3.s^{-1}$ during the time interval between 20 s and 40 s is ….

2.3 During the course of the reaction

$$2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$$

At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$.

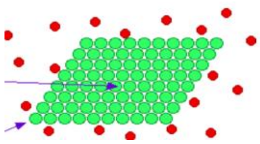
The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

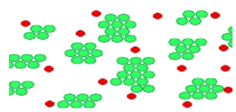
2.4 Did CSBI help you to understand how to solve these problems? Please explain.

3.The reaction of magnesium and hydrochloric acid can be represented by the following equation

$$Mg(s) + 2H^+ \rightarrow Mg^{2+}(aq) + H_2(g)$$

Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions.


A


B

3.1 Which of these two reactions will be faster? Explain why.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

3.3.1 Factor 1:

3.3.2 Factor 2:

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

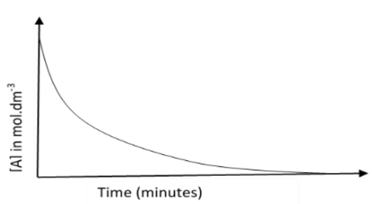
3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

3.6 Were computer simulations of any help in understanding of the rate of this reaction? Please tell me more about that.

4 Two chemicals A and B react to form C as shown in the equation below

$$A(aq) + B(aq) \rightarrow C(aq)$$

The graph below shows how the concentration of A changes with time



4.1 Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

4.2 The reaction for burning of wood may be represented by this equation.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

4.2.1 What do you understand by the term "Collision Theory"?

4.2.2 Explain how this reaction occurs in terms of the collision theory.

4.3 Were computer simulations helpful in making you understand the reaction in the picture? Please tell me more.

5 Look at this picture

[redacted]

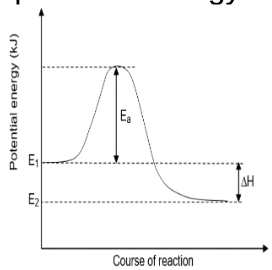
5.1 Why do you think the person need to use the match stick to start the fire? Please explain.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

5.3 What do you understand by the term Heat of reaction?

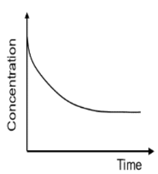
5.4 What do you understand by the term activation energy? Can you tell me more?

6 Look at the potential energy diagram below



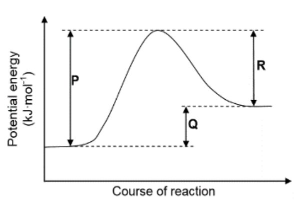
6.1 Which quantity E_1, E_2, E_a or ΔH will change when a catalyst is added. Please explain.

6.2 Look at the graph of concentration against time below



On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

6.3 Look at the potential energy diagram below



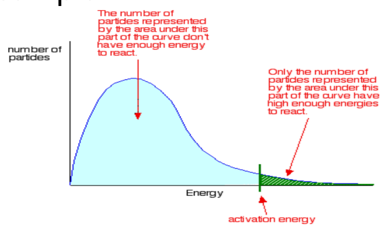
What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

6.4 Explain how a catalyst work to make a reaction faster.

6.5 The elementary reaction

A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

7 The diagram shows the distribution of speed of molecules in a reaction mixture sample.



Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

7.1 Use the graph to explain the effect of temperature on reaction rate.
7.2 Use the graph to explain the effect of a catalyst on the rate of reaction.
7.3 Were computer simulations of any use in helping you understand the effect of temperature on reaction rate? Please explain.
8 When you compare learning CRR using computer simulations or learning through the usual way the teacher normally use, which method do you think leads to a better understanding of this topic. Please elaborate your answer.
9 In performing virtual experiments in CSBI, you were given a worksheet that asked you to go through the process of Predict, Observe and Explain. Was the POE experience helpful in your understanding of the virtual experiments and reaction rate? Please elaborate.

Learner's attitude towards CSBI

Thank you. Now I'd like to ask you a few questions specifically about your preferred method of learning CRR.

10 You performed some experiments using computer simulations when you were learning CRR. Did you enjoy doing those experiments. Please explain.
11 Which of the following methods do you prefer in learning CRR?
   (a) Teacher reading from a textbook.
   (b) Teacher writing notes on the board.
   (c) Teacher talking and explaining.
   (d) Teacher explaining using computer simulations.
   Please explain why you prefer the method you choose.
12 Which method do you find more interesting, CSBI or the usual way that the teacher teaches you. Please tell me more about what you think.
13 Do you think Physical Science teachers should use computer simulations to teach? If Yes- Why; If No- Why not.

Conclusion

Before we conclude this interview, is there something about your experience in learning CRR using CSBI that we did not discuss?

Thank you very much for participating in this interview.

Appendix 11: Pre-Test/Post-Test Raw Scores for EG & CG

School	LearnerID	PreTestScore	PostTestScore
CG	1	0	5
CG	2	2	7
CG	3	4	7
CG	4	6	11
CG	5	7	10
CG	6	4	10
CG	7	5	8
CG	8	5	10
CG	9	9	9
CG	10	5	11
CG	11	4	6
CG	12	6	12
CG	13	9	6
CG	14	7	8
CG	15	6	10
CG	16	2	8
CG	17	6	8
CG	18	8	9
CG	19	2	4
CG	20	8	12
CG	21	1	5
CG	22	7	8
CG	23	3	5
CG	24	1	7
CG	25	4	6
CG	26	5	9
CG	27	4	4
CG	28	2	9
CG	29	4	8
CG	30	6	7
CG	31	4	8
CG	32	1	5
CG	33	10	12
CG	34	2	9
CG	35	9	15
CG	36	3	12
CG	37	10	9
CG	38	8	6
CG	39	5	7

CG	40	4	8
CG	41	8	11
CG	42	2	5
CG	43	4	12
CG	44	0	3
CG	45	0	2
CG	46	4	4
CG	47	10	13
CG	48	7	10
CG	49	5	8
CG	50	5	12
CG	51	6	5
CG	52	6	7
CG	53	3	4
CG	54	4	8
CG	55	5	5
CG	56	6	7
CG	57	2	6
CG	58	2	2
CG	59	4	8
CG	60	7	10
CG	61	8	16
CG	62	0	2
CG	63	3	3
CG	64	5	10
CG	65	4	7
EG	66	1	11
EG	67	7	15
EG	68	4	11
EG	69	5	16
EG	70	1	4
EG	71	4	10
EG	72	4	15
EG	73	1	12
EG	74	5	15
EG	75	7	10
EG	76	1	5
EG	77	3	12
EG	78	6	7
EG	79	6	18
EG	80	1	7
EG	81	4	8
EG	82	4	11

EG	LearnerID	PreTestScore	PostTestScore
EG	83	5	11
EG	84	2	6
EG	85	5	13
EG	86	6	13
EG	87	3	11
EG	88	3	15
EG	89	6	9
EG	90	3	6
EG	91	10	15
EG	92	9	22
EG	93	2	6
EG	94	4	8
EG	95	8	19
EG	96	3	9
EG	97	5	16
EG	98	0	13
EG	99	3	5
EG	100	6	7
EG	101	4	11
EG	102	8	11
EG	103	1	18
EG	104	2	10
EG	105	2	9
EG	106	2	10
EG	107	2	8
EG	108	7	14
EG	109	1	8
EG	110	5	8
EG	111	3	10
EG	112	6	2
EG	113	3	8
EG	114	0	9
EG	115	3	13
EG	116	2	9
EG	117	4	11
EG	118	6	7

Appendix 12: Interview Transcript: Participant EGM01

1.1 How old are you?

17 years

1.2 Before participating in this study, were you ever taught any topic in Physical Sciences using computer simulations? If Yes. Please tell me what topic(s). Briefly describe how the teacher taught you using the simulations

No

1.3 Do you have a computer, tablet or cell phone on which you can access the internet? If Yes. Have you ever used computer simulations on the internet to learn some scientific concepts? Please explain.

No

2.1 Tell me what you understand by the term rate of a chemical reaction?

Is the change in concentration of the reactant whereby it is divided by the time for the reaction.

2.1 What is the average consumption of A in $mol^{-1}dm^{-3}s^{-1}$ between 20s and 40s?

Calculating

Rate = $\Delta[A] = \frac{3,7-4,6}{20} = -0,045$ mol.dm^{-3}, s^{-1}

2.2 During the reaction 2A(g) → B(g) + C(g) the average rate of consumption of A from 20s to 40s is ….

Calculating

2 3 O_2 : H_2O_s
1 . 2
3 : 3x2 = 6 mol. dm^{-3} . s^{-1}

2.3 Did CSBI help you to understand how to solve this problem?

Yes. I had to do some virtual experiments in order for me to understand what to calculate and how

3.1 Reaction of Mg and HCl

B will be (more) faster. The surface area on this diagram it has been increased as the particles have a smaller size. The surface area that was increased was the Mg surface area.

3.2 Learner state that the bigger the particle size, the faster the reaction. Is the learner correct?

No. The bigger the particle size we are actually decreasing the surface area of the particles which means that the greater we decrease the surface area, the slower the reaction rate.

3.3 Which one if increased will make this reaction faster: Pressure, temperature, concentration or mass of Mg?

Temperature because as we increase temperature increases heat and has got greater effect and as we increase pressure does not have any effect on the diagram above and as for concentration, concentration according to my understanding it's for substances that are liquids like aqueous, mass of Mg does not have any effect; does not affect our rate of reaction. For now, I have observed temperature.

3.4 What is the effect of temperature on rates of most reactions?

Reaction rates increase as temperature is increased because temperature have got an effect of releasing heat meaning that it has got. The average kinetic energy of the molecules will also increase as the temperature is increased. For the reaction to occur the activation energy must either be equal or less than the kinetic energy.

3.5 State and explain what happens to most reactions rates if concentration is increased

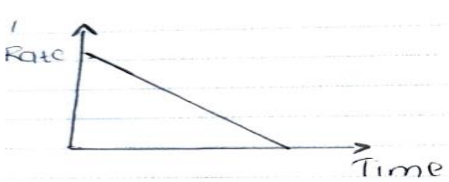
As concentration is increased the rate of reaction also increase. As we increase the volume of our molecules we are decreasing ….

3.6 Were simulations helpful in understanding the reaction of Mg with HCl?

Yes. There were very helpful because in most cases I had to do virtual experiments on my cellphone so that I could be able to see and understand what is happening actually. What I did in class is what I was doing using my cellphone

4.1 Draw a graph to show how the rate of this reaction changes against time. Explain the shape of your graph

The shape of the graph decreases in a linear format. Showing that rate of reaction decreases with time



4.3.1 Reaction of burning wood $C+O_2 \rightarrow CO_2$. What do you understand by the term collision theory?

According to my understanding the term collision theory refer to the effect that actually occur so that the colliding atoms should have the right orientation and also they must have the correct kinetic energy in order for them to move and collide.

4.3.2 Explain how this reaction occurs in terms of the collision theory

As they are colliding, the oxygen collides with the C atom as the collide they are in the right orientation because they are not the same atom …. The energy of the molecules is actually equal to or greater that the E_a of the molecules.

4.4 Were CSBI helpful in making you understand the reaction in the picture?

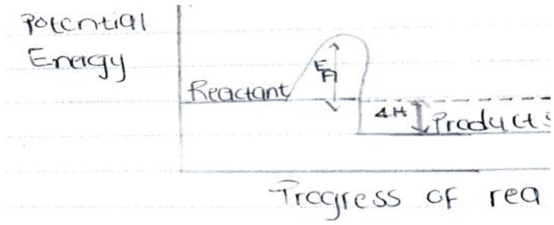
Yes they were helpful actually they also shown me which atoms actually collide in order for what happening in the picture to occur actually in reality.

5.1 Why do you think the person needs to use the match stick?

In order for the fire to start there must be the activation energy and this activation energy must be created by by the person holding the match stick towards the match box so that heat is released.

5.2 Is reaction an endothermic or exothermic reaction?

Exothermic reaction. participant drawing



5.3 What do you understand by “heat of reaction”?

It is the change between the heat of product and energy of reactants.

5.4 What do you understand by “activation energy”?

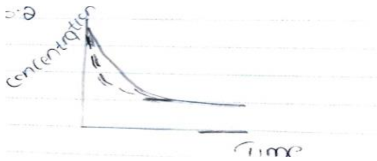
Activation energy is the minimum energy required to start a chemical reaction. What a I am trying to say is without the activation energy is the energy that is needed for a reaction to occur meaning that the reaction can not occur if there is no activation energy such as the minimum kinetic energy or potential energy for the reaction to occur.

6.1 Which quantity E_a, E1, E2 or ΔH will change when a catalyst is added?

The activation energy will change. The catalyst actually speed up the process and also it decreases the activation energy.

6.2 Graph of conc. against time. On the same axes add another graph to show how the graph appear if a catalyst is added

I understand how the catalyst actually work it makes the graph more steeper than it was before.



6.3 Potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged.

A catalyst can be used.

6.4 Explain how a catalyst work to make a reaction faster

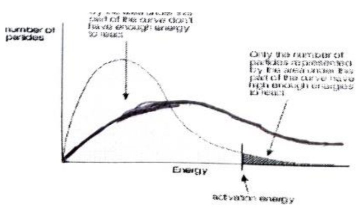
It decreases the activation energy.

6.5 Elementary reaction A+B→C occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes?

The rate of reaction actually decreases with time.

7.1Distribution of speed of molecules in a reaction mixture sample. Draw another graph for the same reaction at a higher temperature.

Participant drawing



7.2 Explain effect of temperature

If temperature increases rate of reaction increases, the kinetic energy of the molecules or particles increases. Molecules move and collide faster.

7.3 Use graph to explain the effect of a catalyst on reaction rate.

Catalyst decrease activation energy.

7.4 Were simulations helpful in understanding effect of temperature on reaction rate?

Yes there were of help in such a way that in class when the teacher is explaining and on other side I am seeing what actually he is referring to over the computer simulation it actually increases my knowledge in things such as this one.

8. When you compare learning CRR using computer simulations or learning through the usual way the teacher teaches which method do you think leads to a better understanding?

Computer simulations are better than what is taught in class because in computer simulations I can actually visually see the particles colliding and the rates of reaction increasing in the presence of a catalyst yeah things like that but when a teacher is teaching it becomes a little bit difficult for me to understand as I am unable to actually see so am forced to use my mind to do so in order for me to understand.

9. Predict-Observe-Explain

Yes it was a little bit of help because my predictions actually were correct or almost correct and the observations I made were recorded and marked. When explaining I was able to grasp the correct ideas

10. Did you enjoy the experiments?

Yes, I did enjoy the experiments like when doing experiments over computer simulations it is much better than being taught by a teacher without doing the simulations like, like doing the experiments in class, things like the reaction rate how the decrease with time. Changing variables was helpful as I could see that as temperature increases it also changed the kinetic energy of the reactant particles.

11. Which method of teaching CRR do you prefer?

Teacher explaining using computer simulations. Because in this format I will be able to understand what the teacher is actually referring to when he says the reaction rate decreases with time and the reason why for the reaction rate to increase it increases as temperature increases so that I can have an open mind.

12. Which teaching method is more interesting?

CSBI

13. Should teachers use simulations to teach?

Yes because usually in Physical Sciences we are talking about things like particles and atoms, molecules and such things are not things one can actually imagine it becomes a little bit difficult for a person to come up with the structure of those things until they actually see them through the computer simulations.

Appendix 13: Interview Transcript: Participant EGM02

1.1 How old are you?

18 years

1.2 Before participating in this study, were you ever taught any topic in Physical Sciences using computer simulations? If Yes. Please tell me what topic(s). Briefly describe how the teacher taught you using the simulations

No

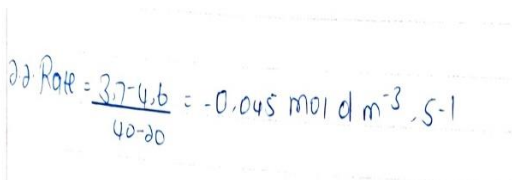
1.3 Do you have a computer, tablet or cell phone on which you can access the internet? If Yes. Have you ever used computer simulations on the internet to learn some scientific concepts? Please explain.

No

2.1 What do you understand by the term rate of a chemical reaction?

change in concentration of a reactant per unit time.

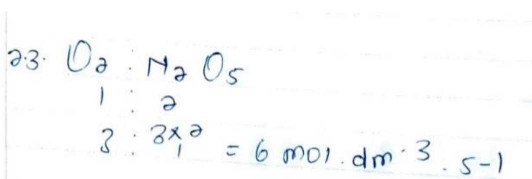
2.2 During the reaction 2A(g) → B(g) + C(g) the average rate of consumption of A from 20s to 40s is ….



Participant calculating

2.3 During the reaction $2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$ at time t the rate of formation of O2 was 3 mol.dm3.min-1. The rate of consumption of N_2O_5 at time t is ….

Participant calculating



2.4 Did CSBI help you to understand how to solve these problems

Yes. The simulation that showed the graph with concentrations of a reactant at two different times and how the average rate could be found. That was very helpful.

3.1 The reaction of magnesium and hydrochloric acid can be represented by the following equation

$$Mg(s) + 2H^{+} \rightarrow Mg^{2+}(aq) + H_2(g)$$

Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. Which of the two reactions will be faster

B. Smaller pieces of magnesium have a larger surface area so more of the magnesium atoms are exposed to the H+ ions. More effective collisions will occur per unit time.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No. Bigger particles have a smaller surface area which means fewer solid reactant atoms are exposed for the reaction. Fewer effective collision occur per unit time.

3.3 Which of the following when increased will make this reaction faster: pressure temperature, concentration, mass of magnesium?

Temperature because temperature effects all reactions and concentration of H^+ ions. Alright.

3.4 States and explain what happens reaction rates of most reactions if temperature has increased.

Rate of reaction is increased.

Please we can you explain why

…. the kinetic energy of the particles inside the reaction increases the thus resulting in more effective Collision.

Okay, in terms of activation energy. Can you clarify please?

Activation is lowered

3.5 Okay State and explain what happens to most reaction rates for most reactions if concentration is increased.

If it is increased rate of reaction increases,

Can you explain why increasing concentration increases the rate of reaction

Increasing concentration will increase the particles, number of particles that can collide and make the reaction; increase the number of particles that have a high kinetic energy.

All right. So in terms of number of effective collision

It will increase.

3.6 Okay, were computer simulations of any help in understanding of the rate of this reaction.

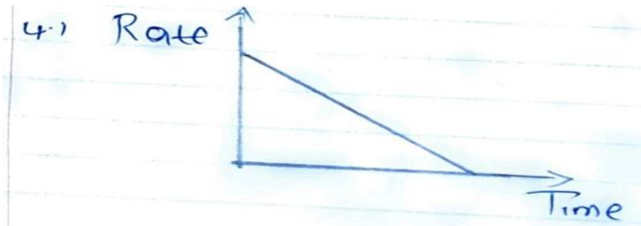
Yes,

Please. Can you elaborate

In the part where we were talking about the effective collisions and the right orientation, I had a problem when it was in theory, but when I saw it and how the particles had to collide with the right orientation, I could understand. It really helped me there.

4.1 Thank you very much. Two chemicals A and B react to form C as shown in the equation below. The graph shows the concentration of A changes with time. Draw a graph to show how the rate of this reaction changes with time next to the above graph.

Participant drawing. It decreases with time.



Okay, just label the exes. Okay. Explain what information the graph implies.

The rate of reaction decreases with time.

4.3.1 The reaction for the burning of wood may be represented by the equation: $C+O_2 \rightarrow CO_2$

What do you understand by the term Collision Theory?

The Collision theory states that for the rate of increase to increase the particles have to collide. With the right orientation.

All right, what else in terms of energy

It says that the activation energy must be overcome and the kinetic energy must be equal to the activation energy.

4.3.2 Okay, explain how this reaction occurs in terms of the collisions theory.

The reaction is carbon reacting with oxygen and carbon dioxide or the carbon atoms must collide with oxygen with a right with the right orientation.

And in terms of energy

Activation energy must be overcome or the kinetic energy (of the reactants) must be equal to the activation energy.

4.4 Okay. Were computer simulations helpful in making you understand this reaction?

Yes.

Okay, please. Can you tell me a little bit more?

Like I said about the orientation and the computer simulations also showed that the activation energy is lowered and activation energy is lowered more energy is more kinetic energy is given off that increasing the number of effective collisions.

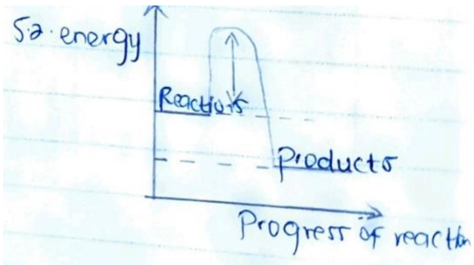
5.1 Okay. Okay this picture what do I think the person need to use? Why do you think the person need to use the match stick to start the fire.

To give the minimum amount of energy required for the reaction to start.

5.2 Okay, and is the reaction on this picture endothermic or exothermic reaction?

Exothermic

Okay, can we draw in an energy profile diagram for this reaction next to the picture and label the activation energy, heat of reaction and reactants and products.



Participant drawing. Okay.

These are the reactants. This is the activation energy. This is the change enthalpy. This is the product.

5.3 What do you understand by the term heat of reaction?

The heat of reaction is the change in enthalpy it is difference between the energy of products and the energy of reactants.

5.4 Okay. What do you understand by the term activation energy?

Activation energy is the minimum amount of energy required for a reaction to occur.

6.1 All right, look at the potential energy diagram below. Which quantity E1, E2, E_A or ΔH will change when a catalyst is added? Can you explain.

E_A When a catalyst is added, you see the purpose of a catalyst it lowers the activation energy.

Ok. What is the purpose of the catalyst.

It lowers the activation energy.

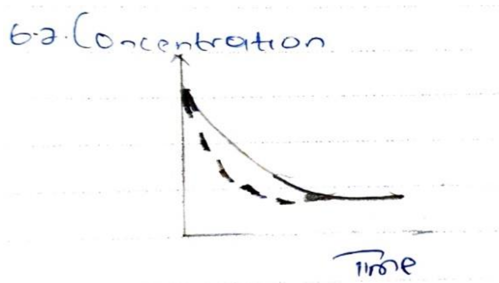
Okay, do you have any idea how a catalyst lowers the activation energy?

It increases the kinetic energy the kinetic energy will have more energy than the activation energy.

6.2 Okay, look at the graph of concentration against time. On the same set of axes draw another graph to show how the graph would appear if a catalyst is added. Okay, so can you explain how that answer was arrived at?

What does such a graph look like? What does it mean?

Participant drawing.



Well the rate of reaction increases with time. Okay, it decreases the time taken for the reaction to come to an end.

6.2 What else does it tell us about the rate of that reaction?

The rate of reaction increases.

6.3 Look at the potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged?

Addition of a catalyst

Okay, please can you explain.

A catalyst lowers the activation energy. So, it would probably lower P and R.

6.4 Explain how I got a catalyst work to make a reaction faster.

It lowers the activation energy.

Any idea about how it lowers the activation energy.

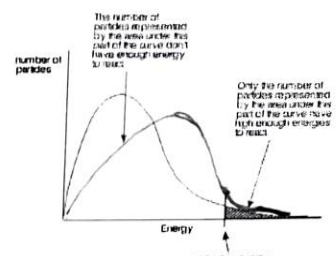
Well, the number of effective of collisions are increased when the activation energy is lowered.

6.5 Okay for the elementary reaction A plus B to form C occurs in the presence of a catalyst. What happens the rate of reaction as time passes?

It decreases with time.

7.1 Okay, the diagram shows the distribution of speed of molecules in a reaction mixture sample draw a graph on me some set of axes to show what happens molecular speeds of reaction mixture of temperature is increased.

Participant drawing graph



7.2 All right. Use the graph to expain the effect of temperature on reaction rate. What is the effect of temperature on reaction rate.

It increases the rate of reaction.

Can use the graph to explain how that happens?

Well, the number of particles are a lot. There will be fewer number of particles because the reaction occurs faster the particles change into reactants faster so particles will be lower. The activation energy.

So we are talking about we increase temperature what happens reaction rate?

The reaction rate increases.

Okay, before we get reaction rate what happens to the average kinetic energy of the molecules?

It increases

What does that mean?

The number of effective collisions increases.

7.3 Okay. All right. Use the graph to explain the effect of the catalyst on the rate of a reaction

A catalyst lowers the activation energy.

Okay. So how does that how does that help to increase the rate of reaction?

There is fewer (less) energy needed for the reaction to start; lower energy needed for the reaction to start.

Ok in terms of number of molecules with sufficient kinetic energy?

There will increase.

That's what I want you to explain. Can you explain everything?

Okay. Yes, yes. Oh the number of molecules. The number of particles with more average kinetic energy increase right that's meaning the effective collision will occur more.

7.4 Were computer simulations of any help in understanding the effect of temperature on reaction rate?

Yes.

Can you please explain a little bit more?

So when the on the okay when temperature I remember when you in doing a simulation increased temperature when the temperature was increased the speed of the particles increased. So more effective collisions were going on. So the rate of reaction was actually faster.

8. I thank you very much. When you compare learning chemical reaction rates using computer simulations or learning through the usual way, which method do you think leads to a better understanding of this topic.

The computer simulations.

Please can you elaborate on

When a teacher just talks, it is very hard to imagine something you've never seen and when you see the reactions and the particles on a simulation you actually get a good idea and I understand what is going on when they say temperature is increased the average kinetic energy increases surface, you know, those kind things. We'll have more understanding.

9.In performing virtual experiments in computer simulation based instructions, you were given a worksheet that asked you to go through the process of predict-observe-explain. Was the predict-observe-explain experience helpful in your understanding of each of the experiments and reaction rate?

Yes.

Can you please elaborate:

When we predict write things that we expect to happen and then we observed on the simulations what was going on and then we got our answers and it was really helpful to see what was going on other than to see it in a textbook or just thinking yourself, to see on the screen.

10. Thank you very much. Now we are going ask you a few questions based on your preferred method of learning chemical reaction rate. You performed some experiments using computer simulations when you were learning chemical reaction rates, did you enjoy those experiments?

Yes,

Please can you explain

I enjoyed them because firstly we don't do much of computer simulations so it was a new thing for me, a new experience, it was a good experience I enjoyed it because I did it with my class, I learned something new and understand chemistry more.

11. Ok, which of the following methods do you prefer in learning CRR? Teacher reading from a textbook, teacher writing notes on the board, teacher talking and explaining, teacher explaining using a computer simulation?

Teacher explaining using a computer simulation.

Please can you explain a little bit.

As I explained before, when you see something on the screen rather than reading in a book its easy, when you see the particles move *and everything that goes on in action its more understandable than when written down you get a sense of what is going on*.

12. Which method do you find more interesting: CSBI or the usual way the teacher teaches?

CSBI

13. Do you think Physical Sciences teachers should use computer simulations to teach. Yes. Please explain.

It is more understandable and its better to learn that way I think for me it's better it's like performing an experiment you always gain some more knowledge.

Appendix 14: Interview Transcript: Participant EGM03

1.1 How old are you?

> *I am 16*

1.2 Were you ever taught physical Sciences using computer simulations?

> *Yeah. I no longer remember the topic but what I can say is that it was all about those Laws on how electrons exchange*

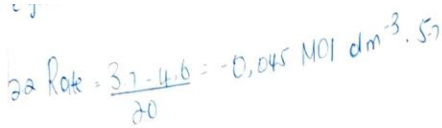
1.3 Do you have a computer or tablet or cell phone on which you can access the internet?

> *Yes. I do, Yeah, Ok mostly I use a computer I buy data and search some topics I use it …. Like i use it for information like YouTube*

2.1 Tell me what you understand by the term rate of a chemical reaction

> *According to my understanding it talks about how the reaction happen per unit time … how fast a reaction is to make product*

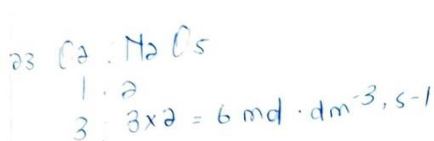
2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained … The average consumption rate of A, in $mol.dm^3.s^{-1}$ during the time interval between 20 s and 40 s is ….



Participant calculating

2.3 During the course of the reaction $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$. At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

> *Participant Calculating*



2.4 Did CSBI help you to understand how to solve these problems? Please explain.

> *Yes I will say I prefer it because it is much practical because I can visualize and see how those particles behave on one another forming product.*

3.1 The reaction of magnesium and hydrochloric acid can be represented by the equation. Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. Which reaction A or B will be faster?

Reaction B will be faster. I will say it have a larger surface area in a way that particles are freely moving so effective collisions will be happening.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No, particle they will be congested I guess when you are in a congested area it's not easy to take any action I can say a learner is incorrect like particles won't be moving freely they wouldn't be colliding to one another.

4.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

4.3.1 Factor 1
4.3.2 Factor 2

I will say both concentration and temperature. Firstly I will talk about temperature. Temperature increases the rate of particles in a way that the kinetic energy is equal or greater than the activation energy which will make the effective collisions per unit time. Secondly I am going to talk about the concentration. Concentration …. I am not adequate on that.

4.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

When temperature is increased there will be much effective collisions the reaction will be faster in a way that particles will be colliding faster.

3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

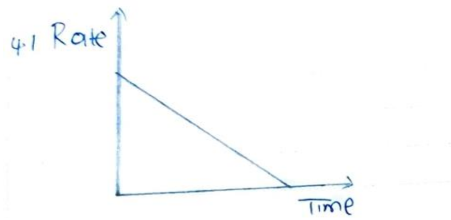
Concentration I don't know about concentration.

4.5 Were computer simulations of any help in understanding of the rate of this reaction? Please tell me more about that.

Yes ok firstly I will say that I have seen particles reacting but they were not just reacting but for particles to form products they should first be in a right orientation and secondly I have observed that when particles are moving slowly products will not be available in a way that particles will be weak but when we are having fast particles the reaction will be fast, what I am saying exactly is that particles need a minimum energy for reactants to collide and make products.

4.1 Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies

Participant drawing graph.



My graph says that the concentration will be decreasing with time the gradient will be less steeper

4.2 The reaction for burning of wood may be represented by this equation. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

4.2.1 What do you understand by the term “Collision Theory”?

Collision theory is when a reaction happens due the collision of particles colliding in a way that they might have a minimum energy and also they should be in the right orientation.

4.2.2 Explain how this reaction occurs in terms of the collision theory.

Firstly, they will be a carbon atom and two oxygen atoms Firstly the carbon atoms will bond with the O atom to form carbon oxide there will be one oxygen, carbon oxide will bond with the other oxygen to form carbon dioxide.

4.3 Were computer simulations helpful in making you understand the reaction in the picture? Please tell me more.

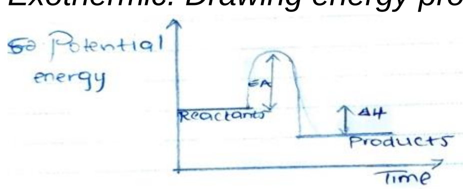
Yes I can just say it was observable.

5.1 Why do you think the person need to use the match stick to start the fire? Please explain.

Because generally it is stated that for a reaction to occur the minimum energy is required so he was giving the reaction the activation energy.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

Exothermic. Drawing energy profile diagram.



5.3 What do you understand by the term Heat of reaction?

Products are lower than the reacts and heat is released

5.4 What do you understand by the term activation energy? Can you tell me more?

I have forgotten

6.1 Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added. Please explain.

E_A

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing graph. When the catalyst was added its main function was to come up with an alternative reaction with a lower activation energy. The reaction went faster

6.3 What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

A catalyst. It brings an alternative reaction mechanism with a lower activation energy.

6.4 Explain how a catalyst work to make a reaction faster.

It makes the reaction faster by lowering the peak of the activated complex in a way of an alternative reaction mechanism. (Activation energy) will be lowered.

6.5 The elementary reaction A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

Rate of reaction decreases as time passes

7.1 Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

Participant drawing graph

7.2 Use the graph to explain the effect of temperature on reaction rate.

When the temperature is high graph shift to the right and also have a lower peak. When the graph is lowered I will say the peak is inversely proportional to temperature

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

Effect of catalyst is it lowers the activation energy.

7.4 Were computer simulations of any use in helping you understand the effect of temperature on reaction rate? Please explain.

Yes. Because using the computer we were able to make some experiments and see the effect of those things on one another like what happens to the reaction when temperature is increased things like that it was observable by doing an experiment.

8.When you compare learning CRR using computer simulations or learning through the usual way the teacher normally use, which method do you think leads to a better understanding of this topic. Please elaborate your answer

Using the computer, because normally those things let me say the science that talks about the particles and all those things for learners to understand its better they visualize it in a way that we see on how particles behave on one another like a when a teacher teaches talking about particles, particles but we as learners not seeing those particles so it's better we use the computer.

9. In performing virtual experiments in CSBI, you were given a worksheet that asked you to go through the process of Predict, Observe and Explain. Was the POE experience helpful in your understanding of the virtual experiments and reaction rate? Please elaborate.

Yes it was but what I can say is that with the experiment that we had our experiment was not our experiment was not clearly with the prediction because we didn't use what adequate values like ….

10. You performed some experiments using computer simulations when you were learning CRR. Did you enjoy doing those experiments. Please explain.

Yes. For my case I enjoyed it because I saw those things like those particles reacting and also for the beside of understanding it was funny because when you increased the temperature those particles were going very fast like colliding effectively so I guess it was a better way

11. Which of the following methods do you prefer in learning CRR?
    (e) Teacher reading from a textbook.
    (f) Teacher writing notes on the board.
    (g) Teacher talking and explaining.
    (h) Teacher explaining using computer simulations.
    Please explain why you prefer the method you choose.

    I prefer the teacher writing notes on the board and secondly I prefer the teacher explaining using computer simulations, firstly for the teacher writing notes on the board, they will give me a way of studying don't wanna take a textbook I will use those notes because they will be straight forward and secondly for the teacher explaining using computer simulations it will help me on how to know the behaviour of those particles we had been talking about to have some additional ideas to know what the teacher is talking about exactly.

12 Which method do you find more interesting, CSBI or the usual way that the teacher teaches you. Please tell me more about what you think.

    CSBI

13. Do you think Physical Sciences teachers should use computer simulations to teach? If Yes- Why; If No- Why not.

    Yes because mostly of the physical science things we are talking about things that we don't see.

Appendix 15: Interview Transcripts: Participant EGF04

1.1 How old are you?

18 ears old

1.2 Before participating in this study, were you ever taught any topic in Physical Sciences using computer simulations? If Yes. Please tell me what topic(s). Briefly describe how the teacher taught you using the simulations

No

1.3 Do you have a computer, tablet or cell phone on which you can access the internet? If Yes. Have you ever used computer simulations on the internet to learn some scientific concepts? Please explain.

No

2.1 Tell me what you understand by the term “rate of a chemical reaction”.

Is the change in concentration of a reactant or product during a period of time.

2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained. The average consumption rate of A, in $mol.dm^{3}.s^{-1}$ during the time interval between 20 s and 40 s is ….

Participant Calculating

2.2 Rate = $\frac{3.7 - 4.6}{20}$

= $-0{,}045\ mol.dm^{-3}\ s^{-1}$

2.3 During the course of the reaction $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$ At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of $N_2O_{\underline{5}}$ at time t, is equal to…

Participant Calculating

2.3 $O_2 : N_2O_5$

1 : 2

3 : $3 \times 2 = 6\ mol.dm^{-3}.s^{-1}$

2.4 Did CSBI help you to understand how to solve these problems? Please explain.

Yes. They helped me to understand

3.1 Which of these two reactions will be faster? Explain why.

B. Because small particles have a larger surface area. More surface area exposes the concentration of a molecule. Reaction can be measured by measuring the amount of hydrogen gas.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No. Because the bigger the particles the reaction will be slow because bigger particles have small surface area.

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

Temperature and concentration will increase the rate of reaction. Temperature because will increase the rate of reaction because when we increase the temperature the rate of reaction will obviously, increase and concentration will increase the rate of reaction because when we increase the hydrochloric acid (concentration) the rate of reaction will increase.

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

If temperature is increased the reaction rate will increase. At higher temperature more molecules with higher kinetic energy, more effective collisions occur per unit time.

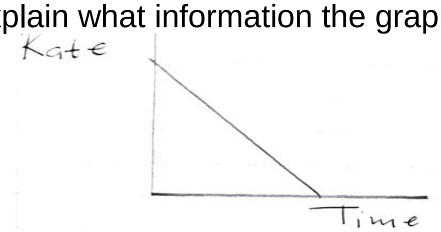
3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

If concentration is increased the reaction rate will increase. Firstly, because there are more reactant molecules per unit volume, which means that more molecules with higher kinetic energy per unit volume. Secondly, more effective collisions occur per unit time.

3.6 Were computer simulations of any help in understanding of the rate of this reaction? Please tell me more about that.

Yes. Because when we were using that computer simulation we performed a lot of reactions whereby we see that when we increase the temperature of the particles the graphs were increasing also and that's when we realized that when we increased the temperature the rate of reaction increase.

4.1 Two chemicals A and B react to form C as shown in the equation A(aq) + B(aq) → C(aq). The graph below shows how the concentration of A changes with time. Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.



Participant drawing graph.

This graph show that the rate of reaction decreases with time. Yes because when the reaction was taking place we saw that the graph was decreasing. At the point where it was on the lower level on the graph

4.2.1 What do you understand by the term "Collision Theory"?

Particles need to be in a correct orientation and have sufficient energy for the atoms or molecules to react sufficient energy is needed.

4.2.2 Explain how this reaction occurs in terms of the collision theory.

The minimum amount of carbon atoms would be needed to for the reaction to occur and there would be minimum ….

4.3 Were computer simulations helpful in making you understand the reaction in the picture? Please tell me more.

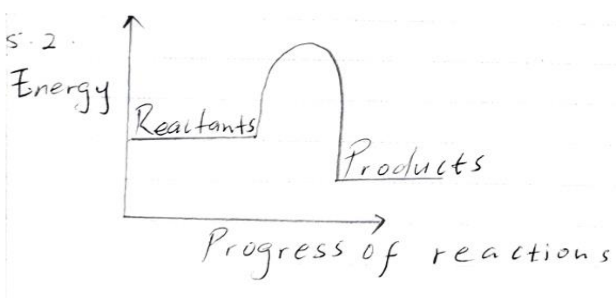
Yes because we were shown two ball a red one and a yellow one reacting and when there was more energy the reactants collided, the formed a yellow-red ball (product).

5.1 Look at this picture Why do you think the person need to use the match stick to start the fire? Please explain.

Because a match stick provides activation energy …. Activation energy is the minimum amount of energy needed for a reaction to occur.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

This reaction is an exothermic reaction. An exothermic reaction is a reaction whereby the heat is given out. Energy profile diagram.(participant drawing) Activation energy would change (if a catalyst is added).



5.3 What do you understand by the term Heat of reaction?

Heat of reaction. No idea.

5.4 What do you understand by the term activation energy? Can you tell me more?

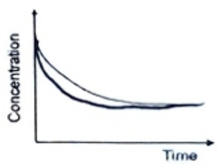
Activation energy is the minimum energy required for the reaction to occur. During the exothermic reaction we saw that saw that the *heat was given off and when we added the catalyst the activation energy was decreasing.*

6.1 Look at the potential energy diagram Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added. Please explain.

E_A Activation energy. Because when the catalyst is added the catalyst is to speed the reaction and when the catalyst is added it decreases the activation energy.

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing graph*. When a catalyst is added, the slope of this graph becomes steeper. That is why this graph is shifted to the left. The steeper slope shows that the …*



6.3 Look at the potential energy diagram below. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

Adding a catalyst.

6.4 Explain how a catalyst work to make a reaction faster.

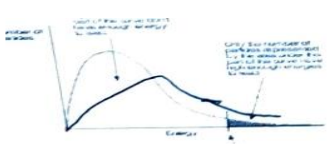
When we add the catalyst, the catalyst decreases the activation energy whereby the activation energy decreases.

6.5 The elementary reaction A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

When time passes the activation energy … the rate of reaction decreases

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

Drawing. If temperature is increased … the shape of the graph will shift to the right whereby the molecular speed is increased.



7.2 Use the graph to explain the effect of temperature on reaction rate.

The rate of reaction increases (if temperature is increased).

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

I don't know

7.4 Were computer simulations of any use in helping you understand the effect of temperature on reaction rate? Please explain.

Yes. When we were shown the graph that when the temperature increase we realized that the molecular speed of the reaction was increasing and also reaction rate. When there is sufficient energy the molecules will collide

8. When you compare learning CRR using computer simulations or learning through the usual way the teacher normally use, which method do you think leads to a better understanding of this topic. Please elaborate your answer.

I can say simulations, things become clearer. For example, when the teacher says surface area is increased we could see what it means. And that it increases reaction rate, when we increased the surface area by using smaller size of particles in the experiments. Without experiments, how can we understand?

9. In performing virtual experiments in CSBI, you were given a worksheet that asked you to go through the process of Predict, Observe and Explain. Was the POE experience helpful in your understanding of the virtual experiments and reaction rate? Please elaborate.

Yes. The observations from the simulation helped me to see if my prediction was correct, then when I was wrong I could understand why I was wrong, then I corrected myself.

10. You performed some experiments using computer simulations when you were learning CRR. Did you enjoy doing those experiments. Please explain.

Yeah because computer simulation was making more things clearer because when the teacher was explaining … collision theory some of us that thing we didn't understand it very well but when we saw it on the computer simulation we were shown that the molecules were colliding with sufficient energy those molecules will need to be in a correct orientation for them to collide … were shown for example a yellow ball and a red ball and form a product that ball was yellow and on the other side was red that's when we understand what was going on, on the collision theory

11. Which of the following methods do you prefer in learning CRR? Teacher reading from a textbook; teacher writing notes on the board; teacher talking and explaining; teacher explaining using computer simulations. Please explain why you prefer the method you choose.

Teacher teaching using computer simulation. Because everything the teacher is teaching we will be shown on the computer simulation and they won't be need for us to think what is going on with this …

the computer simulation will be showing us … when the reactant collide will be forming product … there won't be need for the teacher to draw and show us what this type of reactant will be colliding with what. Only the computer simulation will show a good example.

12 Which method do you find more interesting, CSBI or the usual way that the teacher teaches you. Please tell me more about what you think.

CSBI

13.Do you think Physical Science teachers should use computer simulations to teach? If Yes- Why; If No- Why not.

I prefer they use both methods. When we are doing this or when they want to show us the collision theory yeah but when coming to other modules … like when you need to explain what chemistry will need our teacher to explain in order to understand….

Appendix 16: Interview Transcript: Participant EGM05

1.1 How old are you?

18

1.2 Before participating in this study, were you ever taught any topic in Physical Sciences using computer simulations? If Yes. Please tell me what topic(s). Briefly describe how the teacher taught you using the simulations

No

1.3 Do you have a computer, tablet or cell phone on which you can access the internet? If Yes. Have you ever used computer simulations on the internet to learn some scientific concepts? Please explain.

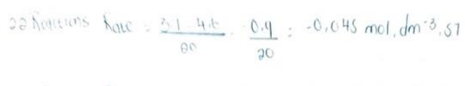
No

2.1 Tell me what you understand by the term "rate of a chemical reaction".

Is the change in amount of a product per unit time.05

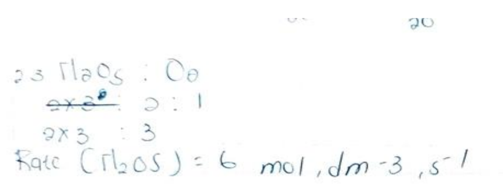
2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained. The average consumption rate of A, in $mol.dm^{3}.s^{-1}$ during the time interval between 20 s and 40 s is ….

Learner calculating



2.3 During the course of the reaction $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$. At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

Learner calculating



2.4 Did CSBI help you to understand how to solve these problems? Please explain.

Yeah yes it did help me to solve these problems at first I didn't understand such thing such as chemistry I went to internet and I searched this CSBI help me to solve these problems and understand chemistry better.

3.1 The reaction of magnesium and hydrochloric acid can be represented by the following equation Mg(s) + 2H+ → Mg2+(aq) + H2(g). Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. Which of these two reactions will be faster? Explain why.

It will be B. As you can see B has a large surface area than, I am referring to magnesium. Magnesium was cut into smaller pieces so it has a large surface area so they will be enough surface for effective collisions.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No the learner is not correct because the bigger the particles of the solid reactant the reaction is going to be slower .If the size of the solid is bigger so there won't be enough movement the rate of reaction will be slow.

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

It will be temperature. Pressure affect the substances or reactants in gaseous state and temperature affect all the reactions in every phase so concentration affect the reactions in aqueous and mass of magnesium does not have an effect at all.05

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

If temperature is increased it will increase the kinetic energy and that will increase the reaction rate.

3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

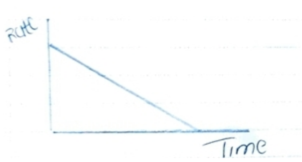
… if concentration is increased that will increase ….

3.6 Were computer simulations of any help in understanding of the rate of this reaction? Please tell me more about that.

Yes. So I understood temperature affect almost all reactions in any phase, pressure affect those in gas, concentration affect those in aqueous.

4.1 Two chemicals A and B react to form C as shown in the equation below. A(aq) + B(aq) → C(aq). The graph below shows how the concentration of A changes with time. Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

Our graph will be like this So this graph tells us that the rate of the reaction decreases with time.



4.2.1 The reaction for burning of wood may be represented by this equation. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ What do you understand by the term "Collision Theory"?

This term tells us that if particles are going to collide and there is going to be a reaction there must be a collision. The collision must be in the right orientation the energy of the particles must be greater or equal to the activation energy.

4.2.2 Explain how this reaction occurs in terms of the collision theory.

The carbon and oxygen must collide with the right orientation and the energy of particles must be greater or equal to the activation energy.

4.3 Were computer simulations helpful in making you understand the reaction in the picture? Please tell me more.

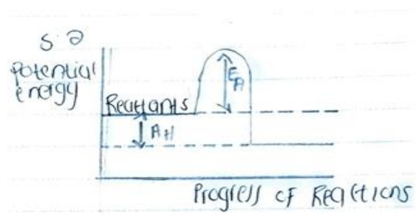
Yes it really showed me how thing go like an action movie such things how the particles are

5.1 Look at this picture. Why do you think the person need to use the match stick to start the fire? Please explain.

It provides us with the activation energy

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

Is an exothermic reaction. An exothermic reaction heat energy is released or given off. Energy profile Diagram (Drawing)



5.3 What do you understand by the term Heat of reaction?

So the heat of a reaction is the change in energy of the product minus the energy of the reactants

5.4 What do you understand by the term activation energy? Can you tell me more?

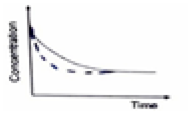
So the activation energy it is the minimum energy that is required to start a reaction. No it wont lead to a reaction

6.1 Look at the potential energy diagram. Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added. Please explain.

Obviously, it will be the activation energy E_A. When we add a catalyst, what it simply does it fast the reaction rate so it decreases the activation energy, the number of molecules that have sufficient energy will increase.

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

> *So, the graph will be like this, the catalyst will fast the reaction rate so it will decrease the time, so this one (gradient) will be much steeper.*



6.3 Look at the potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

> *Addition of catalyst. The catalyst actually … lowers the activation energy.*

6.4 Explain how a catalyst work to make a reaction faster.

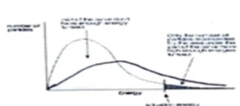
> *It actually … lowers the activation energy, so the energy of particles will be greater or equal to the activation energy. Number of effective collisions will increase.*

6.5 The elementary reaction. A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

> *The rate of reaction decreases with time, even though the catalyst is added.*

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

> *Drawing graph, so if temperature is increased the graph will shift this side*



7.2 Use the graph to explain the effect of temperature on reaction rate.

> *So, temperature actually … increases the rate of the reaction. If temperature is increased it will increase the kinetic energy making the kinetic energy greater or equal to the activation energy*

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

> *The catalyst decrease the activation energy thus making the energy of the reactants greater or equal to the energy greater or equal to the activation energy. The number of effective collisions will increase.*

7.4 Were computer simulations of any use in helping you understand the effect of temperature on reaction rate? Please explain.

Yes. Looking at those computer simulations, I could see that if temperature has been increased the particles moves faster so thus increasing the rate of reaction as the particles will collide but not just collide but collide in the right orientation.

8. When you compare learning CRR using computer simulations or learning through the usual way the teacher normally use, which method do you think leads to a better understanding of this topic. Please elaborate your answer.

Using computer leads to a better understanding because I could see pictures what is happening. When a teacher teaches he doesn't actually show the structures but just explaining so I could not just memorize those structures. Looking at the … like a movie it enables me to recognize those structure on how how do they work.

9. In performing virtual experiments in CSBI, you were given a worksheet that asked you to go through the process of Predict, Observe and Explain. Was the POE experience helpful in your understanding of the virtual experiments and reaction rate? Please elaborate.

Yes it was helpful because I could eventually see that how concentration, the increased surface area, increasing molecular mass of a substance affect the rate of a reaction and temperature also.

10. You performed some experiments using computer simulations when you were learning CRR. Did you enjoy doing those experiments. Please explain.

Yes, I really enjoyed that. Looking at those particles colliding and doing such things it was like that was for real it helped me a lot in improving my Chemistry. Yes it was helpful because I could see you teaching those things we I could see what happens when the temperature is changed or when the concentration is changed

11. Which of the following methods do you prefer in learning CRR? *(a)* Teacher reading from a textbook. *(b)* Teacher writing notes on the board. *(c)* Teacher talking and explaining. *(d)*Teacher explaining using computer simulations. Please explain why you prefer the method you choose.

Method number D, so this method actually makes us see some pictures of what is happening rather than listening to a teacher just explaining but not showing us pictures this method is great.

12. Which method do you find more interesting, CSBI or the usual way that the teacher teaches you. Please tell me more about what you think.

CSBI

13. Do you think Physical Science teachers should use computer simulations to teach? If Yes- Why; If No- Why not.

Yes so that learners could see what they are talking about.

Appendix 17: Interview Transcript: CGM06

1.1 How old are you?

I am 17 years old

2.1 Look at these pictures which shows a slow and a fast reaction. Tell me what you understand by the term "rate of a chemical reaction".

Rate of a reaction is the speed at which a reaction takes place

2.2 During the study of rate of the reaction. $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ this data were obtained. The average consumption rate of A, in $mol.dm^3.s^{-1}$ during the time interval between 20 s and 40 s is ….

Participant calculating.

$$\frac{4,6-3,7}{40} = 0,0225$$

2.3 During the course of the reaction. $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$. At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

I don't understand this question

3.1 The reaction of magnesium and hydrochloric acid can be represented by the following equation Mg(s) + 2H+ → Mg2+(aq) + H2(g). Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. In which diagram is the reaction faster.

According my perspective I think it is B. Because those molecules are not attached to each other so they just got less potential the reaction will be faster because the molecules are not attached to each other so they do not have too much potential. I am talking about … I can say let me say potential energy they don't have that energy to can overpower the reaction or to take time to react.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No. Because when the substance is bigger, it will too much time to react.

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

It will be temperature. Because if we increase the temperature then the reaction also increase. If the temperature is increased the rate of reaction will increase because the temperature is the controlling variable of this I can say this investigation. It means that the *temperature controls the reaction. The reaction rate is controlled by the temperature.*

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

I don't understand this question.

3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

I don't understand06

4.1 Two chemicals A and B react to form C as shown in the equation: A(aq) + B(aq) → C(aq). The graph shows how the concentration of A changes with time. Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

Participant drawing graph. How rate of reaction … I can say. This graph shows that if ehee … the reaction rate will be equalized to time and this is how I understand it. There I am confused. Rate of reaction y-axes.

4.2.1 What do you understand by the term "Collision Theory"?

I don't know it.

4.2.2 Explain how this reaction occurs in terms of the collision theory.

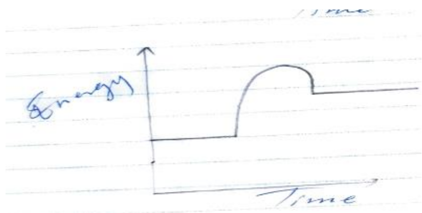
I don't understand even this one.

5.1 Look at this picture. Why do you think the person need to use the match stick to start the fire? Please explain.

Because between the match stick and that sketching area of the match box there is a collision … because a match stick is wooden hence it catches the fire so easily.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

Exothermic Drawing



5.3 What do you understand by the term Heat of reaction?

I forgot it

5.4 What do you understand by the term activation energy? Can you tell me more?

This one I also don't know it

6.1 Look at the potential energy diagram below. Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added. Please explain.

I can say delta H will change. Because delta H is the change of heat. (Delta H change) Because the catalyst is added to speed the reaction and then when a catalyst is added it started to speed the reaction and then when a catalyst is added on the reaction there will be too much heat; and the change in heat will then move from its originated place to another.

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing graph. Because when a catalyst is added there will be many molecules to react with the reactants and then there have to be more than the reactants, that's why the graph will be like this. The reactants will lose their potential and collided more.

6.3 Look at the potential energy diagram below. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

By adding a catalyst. Because when a catalyst is added the reaction will be more faster and then there will be a reduced of the reactant molecules that will decrease the reactant molecules that's why P and R will be decreased

6.4 Explain how a catalyst work to make a reaction faster.

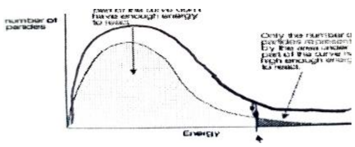
I don't understand

6.5 The elementary reaction A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

I don't know

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

Participant drawing



7.2 Use the graph to explain the effect of temperature on reaction rate.

Because the temperature was increased and then that increased the rate of reaction that's why the graph looks like that. The number of particles were added in the … to speed up the reaction and the temperature was also increased.

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

Is to speed up the reaction. I can say a catalyst was added in this reaction to increase the speed of the reaction and that was achieved by adding the number of particles so that they can increase the reactants That's why the graph increased from this level to another.

Appendix 18: Interview Transcript: Participant CGM07

1.1 How old are you?

I am 19 years old

2.1 Tell me what you understand by the term "rate of a chemical reaction".

Is the speed at which the reaction takes place.

2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained. The average consumption rate of A, in $mol.dm^3.s^{-1}$ during the time interval between 20 s and 40 s is ….

Calculation. We are going to take the average consumption rate. We are going to say in 40 sec we are going to say the average of 40 sec minus the average of consumption of 20 seconds we are going to say 3.7-4.6 it will give us 0.9 divide by 2. 0.45.

2.3 During the course of the reaction. $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$. At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

I gonna say. This question …

3.1 The reaction of magnesium and hydrochloric acid can be represented by the following equation Mg(s) + 2H+→ Mg2+(aq) + H2(g). Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. Which of these two reactions will be faster? Explain why.

Reaction A. Diagram A. Because the reaction is mostly taking place in a closed system.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No. in reaction A there are smaller particles of the reactant. But I don't think so in my knowledge I know that the particles in a closed system the reaction will occur faster than in an open system. Yeah A because particles are close to one another.

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

Concentration. It's difficult.

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

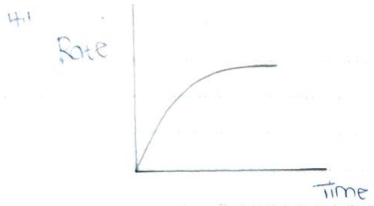
When the temperature increase also the reaction rate increase. Not sure

3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

When the concentration is increased, it will affect the size of the reaction rate, it will increase. It's difficult.

4.1Two chemicals A and B react to form C as shown in the equation below. A(aq) + B(aq) → C(aq). The graph below shows how the concentration of A changes with time. Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

Graph. As time goes when concentration increases the time increase. If time increases the volume of rate of reaction decreases. If time increases the rate of reaction drops. No



4.2.1 What do you understand by the term "Collision Theory"?

It's difficult to answer

4.2.2 Explain how this reaction occurs in terms of the collision theory.

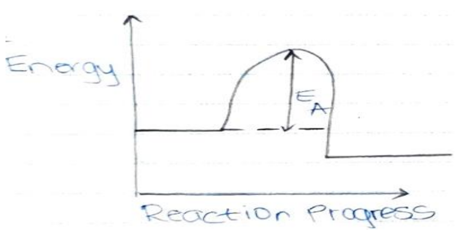
Not sure

5.1 Look at this picture. Why do you think the person need to use the match stick to start the fire? Please explain.

Not sure.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

Exothermic. Drawing



5.3 What do you understand by the term Heat of reaction? What do you understand by the term activation energy? Can you tell me more?

Not sure

5.4 What do you understand by the term activation energy? Can you tell me more?

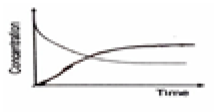
No idea

6.1 Look at the potential energy diagram below. Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added. Please explain.

Delta H. Because the shape changes.

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing. The shape of the graph, when a catalyst is added, the concentration will increase with time.



6.3 Look at the potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

When they can reduce the temperature.

6.4Explain how a catalyst work to make a reaction faster.

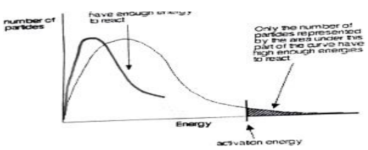
not sure

6.5 The elementary reaction A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

No idea

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

When the temperature is increased also the molecular speed of reactants increase.



7.2 Use the graph to explain the effect of temperature on reaction rate.

The effect of temperature is to make the reaction to occur faster. If temperature is increased …..

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

No idea.

Appendix 19: Interview Transcript: Participant EGM08

1.1 How old are you?

I am 19 years old

2.1 Look at these pictures which shows a slow and a fast reaction. Tell me what you understand by the term “rate of a chemical reaction”.

the reaction will be heated. I don’t know exactly what to say about this term.

2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained. The average consumption rate of A, in mol.dm^{3}.s^{-1} during the time interval between 20 s and 40 s is ….

Calculating. Between 20 and 40 seconds we can say … I will just take moles measured in dm3 from 40 s and subtract this one from 40. 3.7-4.6 this will be the rate

$$\frac{4.6-3.7}{2} = 0,45$$

2.3 During the course of the reaction: $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$. At time t, instantaneous rate of formation of O_2 was found to be 3 mol.dm^{-3}.min^{-1}. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

If I say 2X3 this represents the moles. It will be 6 moldm3min-1

3.1 The reaction of magnesium and hydrochloric acid can be represented by the equation Mg(s) + 2H+ → Mg2+(aq) + H2(g). Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions.

B will react faster than A. because the Mg ribbon has place that it can move around

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

Yes. When the particles are bigger there is going to experience much fizzes fizzing sound

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: Pressure; Temperature: Concentration; or mass of Mg? Please explain.

Pressure. No I am mistaken its temperature because when we increase the temperature the reaction will become faster will increase too. The reaction can be heated then high temperature will occur faster.

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

When temperature is increased the reaction also the reaction will increase because it will be heated with the catalyst.

3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

If concentration is increased reaction rate increase

4.1 Two chemicals A and B react to form C as shown in the equation A(aq) + B(aq) → C(aq). The graph below shows how the concentration of A changes with time. Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

Not sure

4.2.1 What do you understand by the term "Collision Theory"?

Atoms must collide, that's what it says

4.2.2 Explain how this reaction occurs in terms of the collision theory.

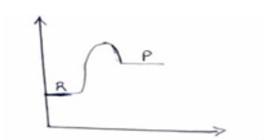
I don't know

5.1 Look at this picture Why do you think the person need to use the match stick to start the fire? Please explain.

Activation energy is needed to start the fire.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

Exothermic. Participant drawing.



5.3 What do you understand by the term Heat of reaction?

Is when a reaction is heated then it produces heat.

5.4 What do you understand by the term activation energy? Can you tell me more?

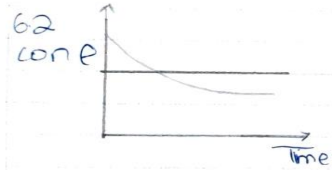
I don't know this one.

6.1 Look at the potential energy diagram below. Which quantity E_1, E_2, E_a or ΔH will change when a catalyst is added. Please explain.

Activation energy I don't know

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing graph



6.3 Look at the potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

I don't know

6.4 Explain how a catalyst work to make a reaction faster.

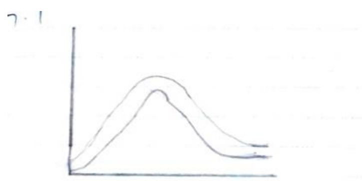
The catalyst heats the reaction so that the reaction can occur faster.

6.5 The elementary reaction. A (g)+ B(g)→AB(g) occurs in the presence of a catalyst. What happens to the rate of the reaction as time passes? Please explain.

Reaction rate decreases as time passes. From the beginning of a reaction the temperature is low when time goes on it increases and reaches a maximum temperature and reaction decrease.

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

Participant drawing.



7.2 Use the graph to explain the effect of temperature on reaction rate.

When the temperature is increased to increase the speed of the reaction the speed also increases.

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

I don't know that one.

Appendix 20: Interview Transcript: Participant CGF09

1.1 How old are you?

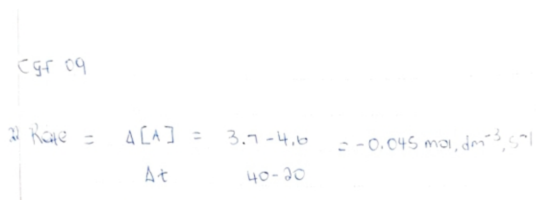
I am 18 years old

2.1 Look at these pictures which shows a slow and a fast reaction. Tell me what you understand by the term “rate of a chemical reaction”.

Chemical reaction rate is a change in concentration of a product amount per unit time09

2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained. The average consumption rate of A, in $mol.dm^{3}.s^{-1}$ during the time interval between 20 s and 40 s is ….

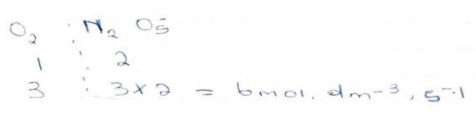
Participant Calculating. Firstly, we write the formula for rate of the chemical reaction. Rate of a chemical reaction is equal to the change in concentration divided by time. The we say 3.7 is the concentration minus 4.6 over 40-20 the answer is -0.045.



2.3 During the course of the reaction: $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$

At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

I used the geometric formula and I say N2O5=Ratio is a I named O2 b Concentration …. ½



3.1 The reaction of magnesium and hydrochloric acid can be represented by the following equation Mg(s) + 2H+ → Mg2+(aq) + H2(g). Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. Which of these two reactions will be faster? Explain why.

B. Since Magnesium is cut into smaller pieces in a large surface area, the effective collision will happen faster since we increase the surface area and cut the magnesium into smaller pieces.

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

No Since now we increase the … since now they is the smaller surface area then the bigger particles the reaction will not happen *faster because those particles they are in a small surface area the effective collision will not happen faster.*

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

Temperature and concentration. When we are having magnesium and H+ ions the more effective collisions will happen. Temperature affect the all reactions.

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

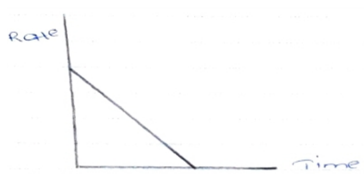
Increase the temperature they increase the kinetic, the kinetic energy and more effective happen faster per unit time.

3.5 State and explain what happens to reaction rates for most reactions if concentration is increased.

It increases. More reactants per unit volume, the more the effective collisions per unit volume. Because if we add a minimum required energy … I don't know how ….

4.1 Two chemicals A and B react to form C as shown in the equation: A(aq) + B(aq) → C(aq). The graph below shows how the concentration of A changes with time Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

Time on a x-axis rate on a y-axis. The rate will decrease against time.



4.2.1 The reaction for burning of wood may be represented by this equation. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ What do you understand by the term "Collision Theory"?

The term Collision Theory … the particles of the reaction collide require the minimum energy for the reaction to form a product and the reactants to form a product they must collide with the right orientation.

4.2.2 Explain how this reaction occurs in terms of the collision theory.

Carbon … I don't know.

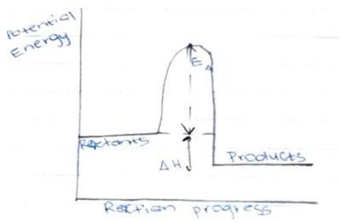
5.1 Look at this picture. Why do you think the person need to use the match stick to start the fire? Please explain.

It required the activation energy for this to occur.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture.

On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

Exothermic since the heat is released Participant drawing. Y-axis I write potential energy on the x-axis The reactant are higher than the product and my graph is like this. Delta H is less than zero



5.3 What do you understand by the term Heat of reaction?

Heat of reaction is the difference between the potential energy of the product and reactant

5.4 What do you understand by the term activation energy? Can you tell me more?

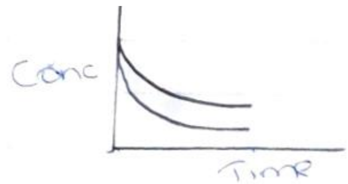
Activation energy is the minimum energy that is required to start a reaction

6.1 Look at the potential energy diagram below. Which quantity E_1, E_2, E_a or ΔH will change when a catalyst is added. Please explain.

E_A. Since the catalyst lowers the activation energy.

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing. Shifted below



6.3 Look at the potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer.

Catalyst. Catalyst increases the rate of reaction and it become steeper. P

6.4 Explain how a catalyst work to make a reaction faster.

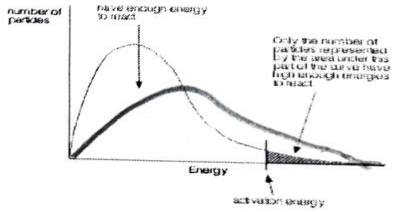
It lowers the activation energy by increasing the number of particles.

6.5 What happens to rate of reaction as time passes in the presence of a catalyst

Not sure

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

Participant drawing



7.2 Use the graph to explain the effect of temperature on reaction rate.

Not sure

7.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

Not sure

Appendix 21: Interview Responses: Participant CGM10

1.1 How old are you?

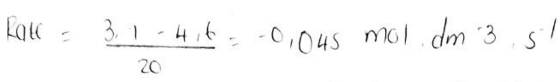
18 years' old

2.1 Look at these pictures which shows a slow and a fast reaction. Tell me what you understand by the term "rate of a chemical reaction".

It is the change in concentration of product or reactant per unit time.

2.2 During the study of rate of the reaction: $2A_{(g)} \rightarrow B_{(g)} + C_{(g)}$ the following data were obtained. The average consumption rate of A, in $mol.dm^{3}.s^{-1}$ during the time interval between 20 s and 40 s is ….

Learner calculation



2.3 During the course of the reaction: $2N_2O_{5(g)} \rightarrow 4NO_{2(g)} + O_{2(g)}$

At time t, instantaneous rate of formation of O_2 was found to be 3 $mol.dm^{-3}.min^{-1}$. The instantaneous rate of consumption of N_2O_5 at time t, is equal to…

Not sure

3.1 The reaction of magnesium and hydrochloric acid can be represented by the following equation Mg(s) + 2H+ → Mg2+(aq) + H2(g). Diagram A shows magnesium ribbon reacting (green) reacting with H^+ ions (red). Diagram B shows the same magnesium ribbon cut into smaller pieces reacting with H^+ ions. Which of these two reactions will be faster? Explain why.

B, the molecular size in B is smaller therefore has a higher surface area

3.2 A learner states that the bigger the particle size of a solid reactant, the faster the reaction. Is the learner correct. Please explain.

Yes bigger particles have react faster …….

3.3 Two of the following factors, when increased, will make the reaction above faster. Identify the two factors: **Pressure**; **Temperature**: **Concentration**; or **mass of Mg**? Please explain.

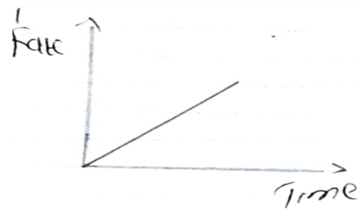
I don't know.

3.4 State and explain what happens to reaction rates of most reactions if temperature is increased.

Temperature will make the reaction faster.

4.1 Two chemicals A and B react to form C as shown in the equation: A(aq) + B(aq) → C(aq). The graph below shows how the concentration of A changes with time Draw a graph to show how the rate of this reaction changes against time next to the above graph. Explain what information the graph implies.

Drawing. I don't understand



4.2.1 The reaction for burning of wood may be represented by this equation. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ What do you understand by the term "Collision Theory"?

The rate of this reaction decreases against time.

4.2.2 Explain how this reaction occurs in terms of the collision theory.

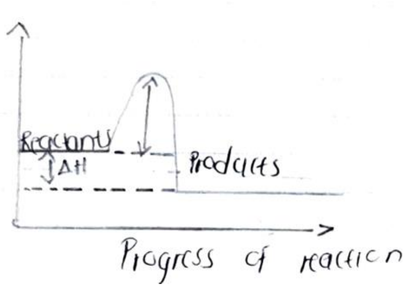
A carbon atom needs to react with oxygen to form carbon dioxide.

5.1 Look at this picture. Why do you think the person need to use the match stick to start the fire? Please explain.

For activation energy for the minimum amount of energy needed for starting the fire.

5.2 Is the reaction occurring in this picture an endothermic or an exothermic reaction? Draw an energy profile diagram for this reaction next to the picture. On your diagram label the activation energy E_A, Heat of reaction ΔH, Reactants and Products.

It is an exothermic reaction. Drawing energy profile diagram



5.3 What do you understand by the term Heat of reaction?

Heat produced during a reaction

5.4 What do you understand by the term activation energy? Can you tell me more?

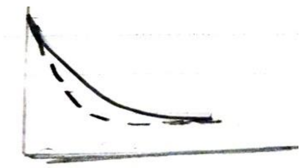
It is the minimum amount of energy needed for the reaction to occur.

6.1 Look at the potential energy diagram below. Which quantity E_1, E_2, E_A or ΔH will change when a catalyst is added. Please explain.

Activation energy will change The activation energy when a catalyst is added the activation energy decreases for effective collisions to occur.

6.2 Look at the graph of concentration against time. On the same set of axes, add another graph to show how the graph will appear if a catalyst is added. Explain how you arrived at your answer.

Drawing graph*. The slope of graph is steeper and it means rate of reaction increased.*



6.3 Look at the potential energy diagram. What change can be used to decrease both P and R but leave Q unchanged. Please explain your answer

Addition of a catalyst

6.4Explain how a catalyst work to make a reaction faster.

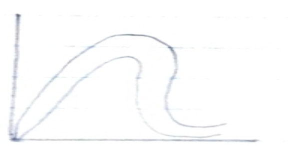
It increases the rate of effective collisions in the reaction.

6.5 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

It increases. Rate of reaction increases as time passes, there will be effective collisions as time passes.

7.1 The diagram shows the distribution of speed of molecules in a reaction mixture sample. Draw another graph on the same axes to show what happens to molecular speeds of reaction mixture if temperature is increased.

The graph move to the left, number of effective collisions increases



7.2 Use the graph to explain the effect of temperature on reaction rate.

Temperature is increased therefore causing the rate of reaction also to increase and effective collisions to occur.

7.37.3 Use the graph to explain the effect of a catalyst on the rate of reaction.

I don't know

Appendix 22: Coding of Learners' Interview Responses into SU, PU and LK

IQ	SU	PU	LK
2.1	*Is the change in concentration of the reactant … divided by the time for the reaction.01*	*… how the reaction happen per unit time … how fast a reaction is to make product03*	*the reaction will be heated. I don't know exactly what to say about this term. 08*
	change in concentration of a reactant per unit time02	*Rate of a reaction is the speed at which a reaction takes place06*	
	Is the change in concentration of a reactant or product during a period of time 04	*Is the speed at which the reaction takes place.07*	
	Is the change in amount of a product per unit time.05		
	Chemical reaction rate is a change in concentration of a product … per unit time09		
	It is the change in concentration of product or reactant per unit time. 10		
3.1	*B. … effective collision … increase the surface area 09*		*B. Because those molecules are not attached to each other so they just got less potential 06*
	B will be (more) faster. The surface area … increased ...01		*No. … a closed system the reaction will occur faster than in an open system. 07*
	B. Smaller pieces of magnesium have a larger surface area 02		*B will react faster than A. because the Mg ribbon has place that it can move around 08*
	Reaction B will be faster. … have a larger surface area 03		*B, the molecular size in B is smaller therefore has a higher surface area 10*
	B. Because small particles have a larger surface area.4		
	It will be B. … B has a large surface area than, I am referring to magnesium. 05		
3.2	*bigger particles … small surface area the effective collision will not happen faster.09*	*No. Because when the substance is bigger, it will too much time to react.06*	Yeah A … particles are close to one another 07
	No. The bigger the particle size we are actually decreasing the surface area 01	*No, particle they will be congested 03*	*Yes. When the particles are bigger there is going to experience much fizzes fizzing sound08*
	No Bigger particles … smaller surface area 02	*No … the solid is bigger so there won't be enough movement … 05*	Yes bigger particles react faster 10
	No. Because the … small surface area.04		
3.3.1	*Temperature because temperature effects all reactions 02*	*Temperature because as we increase temperature increases heat 01*	*I don't know. 10*
	Temperature increases the rate of particles in a way that the kinetic energy is equal or greater than the activation energy 03	*Temperature because will increase the rate of reaction because when we increase the temperature the rate of reaction will obviously, increase 04*	
		temperature is the controlling variable 06	
	temperature affect all the reactions in every phase 05	*temperature because when we increase the temperature the reaction will become faster will increase 08*	
	Temperature affect the all reactions.09		
3.3.2	*concentration … it's for substances that are liquids like aqueous 01*	*concentration of H^+ ions.02*	*I don't know. 10*
	concentration affect the reactions in aqueous 05	*Concentration …. I am not adequate on that.03*	
		concentration … increase the hydrochloric acid (concentration) the rate of reaction will increase.04	
		Concentration. It's difficult.07	
		Concentration ... H+ ions the more effective collisions will happen 09	
3.4	*Increase the temperature they increase … the kinetic energy and more effective happen faster per unit time.09*	*When the temperature increase also the reaction rate increase. Not sure 07*	*I don't understand this question. 06*
	When temperature is increased there will be much effective collisions … 03	*When temperature is increased the reaction also the reaction will increase because it will be heated with the caytalst 08*	
	Rate of reaction is increased … and the kinetic energy of the particles … increases the thus resulting in more effective Collision. 02	*Temperature will make the reaction faster.10*	
	Reaction rates increase …average kinetic energy of the molecules will also increase … .. activation energy must either be equal or less than the kinetic energy.01	*If temperature is increased it will increase the kinetic energy and that will increase the reaction rate 05*	
	If temperature is increased the reaction rate will increase … more effective collisions occur per unit time.04		

3.5	If it is increased rate of reaction increases, Increasing concentration will increase the particles, number of particles that can collide and make the reaction; increase the number of particles that have a high kinetic energy. 02	As concentration is increased the rate of reaction also increase. As we increase the volume of our molecules we are decreasing ….01	Concentration I don't know about concentration.03
	If concentration is increased the reaction rate will increase. Firstly, because there are more reactant molecules per unit volume, which means that more molecules with higher kinetic energy per unit volume. Secondly, more effective collisions occur per unit time.04	When the concentration is increased, it will affect the size of the reaction rate, it will increase. It's difficult.07	… if concentration is increased that will increase …. 05
	It increases. More reactants per unit volume, the more the effective collisions per unit volume. Because if we add a minimum required energy….09	If concentration is increased reaction rate increase08	I don't understand06
4.1	So this graph tells us that the rate of the reaction decreases with time.05	My graph says that the concentration will be decreasing with time the gradient will be less steeper 03	Participant drawing graph. How rate of reaction … I can say. This graph shows that if ehee … the reaction rate will be equalized to time and this is how I understand it. 06
	Participant drawing graph. This graph show that the rate of reaction decreases with time 04		Graph. As time goes when concentration increases the time increase. 07
	Participant drawing. It decreases with time.02		Participant drawing graph. Not sure 08
	The shape of the graph decreases in a linear format. Showing that rate of reaction decreases with time01		Drawing. I don't understand 10
	Time on a x-axis rate on a y-axis. The rate will decrease against time. 09		
4.2.1	The collision must be in the right orientation the energy of the particles must be greater or equal to the activation energy.05	Atoms must collide, that's what it says 08	I don't know it 06
	Particles need to be in a correct orientation and have sufficient energy 04		It's difficult to answer 07
	Collision theory is when a reaction happens due the collision of particles colliding in a way that they might have a minimum energy and also they should be in the right orientation.03		The rate of this reaction decreases against time.10
	particles have to collide. With the right orientation … and the kinetic energy must be equal to the activation energy.02		
	colliding atoms should have the right orientation and also they must have the correct kinetic energy in order for them to move and collide.01		
	the particles of the reaction collide require the minimum energy for the reaction to form a product and the reactants to form a product they must collide with the right orientation.09		
4.2.2	As they are colliding, the oxygen collides with the C atom as the collide they are in the right orientation because they are not the same atom …. The energy of the molecules is actually equal to or greater that the E_a of the molecules.01		Firstly, they will be a carbon atom and two oxygen atoms Firstly the carbon atoms will bond with the O atom 03
	carbon atoms must collide with oxygen with a right with the right orientation … Activation energy must be overcome02		I don't understand even this one.06
	The carbon and oxygen must collide with the right orientation and the energy of particles must be greater or equal to the activation energy.05		Not sure07
	Particles need to be in a correct orientation and have sufficient energy 04		I don't know08
			Carbon … I don't know.09
			A carbon atom needs to react with oxygen to form carbon dioxide. 10
5.1	It provides us with the activation energy05		Not sure. 07
	Because a match stick provide activation energy 04		Because between the match stick and that sketching area of the match box there is a collision …06
	for a reaction to occur the minimum energy is required so he was giving the reaction the activation energy.03		
	To give the minimum amount of energy required for the reaction to start. 02		
	for the fire to start there must be the activation energy 01		
	For activation energy for the minimum amount of energy needed for starting the fire.10		
	It required the activation energy for this to occur. 09		
	Activation energy is needed to start the fire.08		
5.2	It is an exothermic reaction. Drawing energy profile diagram 10	Exothermic. Drawing 07	
	Exothermic since the heat is released Participant drawing.09	Exothermic Drawing06	
	Exothermic. Participant drawing.		
	Is an exothermic reaction. An exothermic reaction heat energy is released or given off. Energy profile Diagram (Drawing) 05		
	This reaction is an exothermic reaction. An exothermic reaction is a reaction whereby the heat is given out. Energy profile diagram.(participant drawing) 04		
	Exothermic. Drawing energy profile diagram. 03		

	Exothermic. Participant drawing. These are the reactants. This is the activation energy. This is the change enthalpy. This is the product. 02		
	Exothermic reaction. participant drawing01		
5.3	The heat of reaction is the change in enthalpy it is difference between the energy products and the energy of reactants. 02	It is the change between the heat of product and energy of reactants01	Products are lower than the reacts and heat is released 03
	So the heat of a reaction is the change in energy of the product minus the energy of the reactants 05		Heat of reaction. No idea 04
	Heat of reaction is the difference between the potential energy of the product and reactant 09		I forgot it 06
			Not sure 07
			Is when a reaction is heated then it produces heat.08
			Heat produced during a reaction 10
5.4	Activation energy is the minimum energy required to start a chemical reaction. 01		I have forgotten 03
	Activation energy is the minimum amount of energy required for a reaction to occur.02		This one I also don't know it 06
	Activation energy is the minimum energy required for the reaction to occur 04.		No idea 07
	So the activation energy it is the minimum energy that is required to start a reaction.05		I don't know this one.08
	Activation energy is the minimum energy that is required to start a reaction 09		
	Is the minimum amount of energy needed for the reaction to occur. 10		
6.1	The activation energy will change. The catalyst actually speed up the process and also it decreases the activation energy.01	E_A 03	I can say delta H will change. Because delta H is the change of heat. 06
	E_A When a catalyst is added, you see the purpose of a catalyst it lowers the activation energy.02	Activation energy I don't know 08	Delta H. Because the shape changes. 07
	EA Activation energy. Because when the catalyst is added the catalyst is to speed the reaction and when the catalyst is added it decreases the activation energy.04		
	Obviously, it will be the activation energy E_A. When we add a catalyst, what it simply does it fast the reaction rate so it decreases the activation energy, the number of molecules that have sufficient energy will increase. 05		
	E_A. Since the catalyst lowers the activation energy. 09		
	Activation energy will change The activation energy when a catalyst is added the activation energy decreases for effective collisions to occur. 10		
6.2	I understand how the catalyst actually work it makes the graph more steeper than it was before.01	Drawing. Shifted below 09	Drawing graph. Because when a catalyst is added there will be many molecules to react with the reactants 06
	Participant drawing. Well the rate of reaction increases with time. Okay, it decreases the time taken for the reaction to come to an end. 02		Drawing. The shape of the graph, when a catalyst is added, the concentration will increase with time. 07
	Drawing graph. When the catalyst was added its main function was to come up with an alternative reaction with a lower activation energy. The reaction went faster 03		Drawing graph No reason 08
	Drawing graph. When a catalyst is added, the slope of this graph becomes steeper. That is why this graph is shifted to the left. 04		
	So, the graph will be like this, the catalyst will fast the reaction rate so it will decrease the time, so this one (gradient) will be much steeper. 05		
	Drawing graph. 2 The slope of graph is steeper and it means rate of reaction increased. 10		
6.3	A catalyst lowers the activation energy. So, it would probably lower P and R. 02	A catalyst can be used01	When they can reduce the temperature. 07
	A catalyst. It brings an alternative reaction mechanism with a lower activation energy. 03	Adding a catalyst. 04	I don't know 08
	Addition of catalyst. The catalyst actually … lowers the activation energy. 05	By adding a catalyst. Because when a catalyst is added the reaction will be more faster 06	
		Catalyst. Catalyst increases the rate of reaction … P 09	
		Addition of a catalyst 10	
6.4	It lowers the activation energy. Well, the number of effective of collisions are increased when the activation energy is lowered. 02	It decreases the activation energy.01	I don't understand 06
	It makes the reaction faster by lowering the peak of the activated complex in a way of an alternative reaction mechanism. (Activation energy) will be lowered. 03	catalyst decreases the activation energy 04	not sure 07
	It actually … lowers the activation energy, so the energy of particles will be greater or equal to the activation energy. Number of effective collisions will increase. 05	It lowers the activation energy by increasing the number of particles. 09	The catalyst heats the reaction so that the reaction can occur faster. 08
		It increases the rate of effective collisions in the reaction. 10	
6.5	The rate of reaction actually decreases with time.01		I don't know 06

	It decreases with time. 02		*No idea 07*
	Rate of reaction decreases as time passes 03		*Not sure 09*
	… the rate of reaction decreases 04		*It increases. Rate of reaction increases as time passes, there will be effective collisions as time passes. 10*
	The rate of reaction decreases with time, even though the catalyst is added. 05		
	Reaction rate decreases as time passes.08		
7.1	*Participant drawing 01*		*Participant drawing 06*
	Participant drawing graph 02		*Participant drawing 08*
	Participant drawing graph 03		*Participant drawing 09*
	Drawing. If temperature is increased … the shape of the graph will shift to the right whereby the molecular speed is increased. 04		*The graph move to the left, number of effective collisions increases 10*
	Drawing graph, so if temperature is increased the graph will shift this side 05		
	When the temperature is increased also the molecular speed of reactants increase. 07		*The rate of reaction increases 04*
7.2	*So, temperature actually … increases the rate of the reaction. If temperature is increased it will increase the kinetic energy making the kinetic energy greater or equal to the activation energy 05*	*If temperature increases rate of reaction increases, the kinetic energy of the molecules or particles increases. Molecules move and collide faster.01*	*The number of particles were added in the … to speed up the reaction and the temperature was also increased.06*
		Temperature is increased therefore causing the rate of reaction also to increase and effective collisions to occur. 10	*When the temperature is high graph shift to the right and also have a lower peak. 03*
			It increases the rate of reaction. 02
			The effect of temperature is to make the reaction to occur faster. If temperature is increased …..07
			When the temperature is increased to increase the speed of the reaction the speed also increases. 08
			not sure 09
7.3	*A catalyst lowers the activation energy. There is fewer (less) energy needed for the reaction to start; lower energy needed for the reaction to start. The number of particles with more average kinetic energy increase right that's meaning the effective collision will occur more. 02*	*Catalyst decrease E_A 01*	*I don't know 04*
	The catalyst decrease the activation energy thus making the energy of the reactants greater or equal to the energy greater or equal to the activation energy. The number of effective collisions will increase. 05	*Effect of catalyst is it lowers the activation energy. 03*	*Is to speed up the reaction. I can say a catalyst was added in this reaction to increase the speed of the reaction 06*
			No idea. 07
			I don't know that one. 08
			No idea 09
			I don't know 10

Appendix 23: Transcribed Interview for the Teacher: Participant ED11

So, we are now going to have a conversation about chemical reaction rates and computer simulations, and I would like to ask for your permission to audio record this interview?

Its fine. No problem.

Thank you. In your opinion, do computer simulations help to understand chemical reaction rate concepts.

Oops. Yes, I say yes. Yeah. they do help.

Okay. May you explain please

It's like in simulations we are having one text formats. We are also using video format. So, we are trying to assist the learner to create a picture in the mind through seeing and through reading. In a way, we assist them to understand better than using text only.

In *the lessons taught using simulations learners performed virtual experiments. In your opinion, how effective were with these virtual experiments in assisting Learners to understand of chemical reaction rates.*

Yeah, since we also involving video as I said before, a video is showing you the movement of picture that picture movement will create also a picture in the mind of the learner which assist the learner to remember whatever he/she was observing in the video. Yes.

In those virtual experiments, we used the Predict, Observe and Explain approach to teach. The Predict-Observe-Explain, was a cognitive tool. Do you think these cognitive tools was helpful in in assisting Learners to understand Reaction Rate Concepts?

POE, Yes the tool itself was allowing the learner to engage, to interact, to ask, or to be asked and that communication part of it was somehow assisting the learner to comprehend better, so that the learner will be involved.

Okay, the first step is Predict. How do you see this Predict helping learners?

POE That's the initial knowledge in learner's mind. The learner will have what we call prior knowledge. Using that prior knowledge, the learner can predict what is expected basing on what the learner is the mind. That's the be prediction. Normally when you predict you are using what you have in your mind. Your previous experiences. So that previous experience tell you because of what I saw last time, I think it will be like this. Then after the experiment you say okay, what I saw is different from what I am seeing now, that means you're correcting your prediction basing on what you have wanted from the experiment.

Thank you very much.

That's the ahaa effect, the ahaa experience.

Thank you very much. Do simulations assist learners in conceptual understanding of collision theory?

Yes, I can say yes. Simulation is involving movement involving a picture. It's also involving a text and also involving sound. We are having these three modes of communication. We are trying to impart whatever we are teaching to the learners understanding and using modes I think is better than using text to only so simulation is a better way of also assisting designer to understand.

Yes, which features of these simulations assisted learners to understand the Collision Theory?

Yah the features; since it's a picture which is in motion that motion part of it where you see in an atom moving and colliding with another atom, you cannot explain it in words perfectly but in with a picture or video rather which is the moving picture it's better for the learner to see what is happening in motion.

Thank you, though. Do simulations play a role in assisting learners in understanding of science processes skills such as being able to state the hypothesis, state investigative questions, identify variables, planning an investigation, carry out the investigation and write table of results, or results in another form and then we also in drawing conclusions? Do simulations assist learners in understanding of science process skills?

Yeah they do assist very much you know a learner can repeat and repeat, the assimilation until he (she) can understand what he's missing there. Initially, you know, a learner may start blank, but when he see something he is trying to create in understanding they is interaction, if you fail to understand it you repeat the simulation again. It's different from an experiment where you know, you may just exhaust the chemicals. But in a simulation, you do it several times, that way you are giving room to the learner to correct mistakes or learn as much as possible depending on how many times the learner can repeat.

Ok, so which parts of science process skills do you think these simulations were more effective especially on chemical reaction rates that we observed during our lessons?

Ehe, variables. When you are changing the temperature keeping the other variables constant actually the learner is learning that this is being changed and this one is fixed. Now knowing what it was the meaning of variables. then the other thing is the hypothesis, the prediction you are talking about. Sometimes you give a prediction which may not be the correct outcome or which may differ from the outcome that means a learner is also learning about the hypothesis. Then observation, what you see during the experiment what you see when the processes are happening in the chemical reaction that's the observation you record that, you record the time which the reaction took to get finished then at the end may know link your hypothesis to your results, interpretation, so that you evaluate your experiment.

Okay, you saw this happening during our lessons chemical reaction rates because we need to be very specific

in effect of temperature on reaction rates affect or change in concentration surface area on reaction rate and so on. All right, let us go to the next part. Do virtual experiments play any role in helping learners in understanding of factors affecting reaction rates?

Yes because when you change one factor go to the next one like this of particle size, state of division, sometimes we'll start with granules. The learner may notice that this is taking more time. They'll change it into a powder a learner notice that this is taking very short time. So, it means there is an effect on reaction rate it reduces the time of reaction. That means you will be comparing rate of reaction to a particular size or state of division.

Yes. I may also ask in doing those experiments learners were free to be able to stop and observe they were able to in words they were able to interact because these virtual experiments were not just like watching a video but learners could interact with the display. The could stop the reaction to see something as we were doing those experiments whenever we wanted learners to discuss something we would stop it, so that we discuss and then to continue when they feel like. Do that part of a learner's controlling the simulation, changing things on the simulation. Do you think it helps Learners in any way?

Yeah it assist learners to remove doubts in the mind if you are doubting you repeat it again until you are satisfied by getting the same result that mean this thing is working. Sometimes when you are doing an experiment you not sure if this one is the correct thing let me do it again. So that is a thing of repeating, stopping, repeating, stopping is assisting the learner to correct the misconception in the first experiment in the second one in case any different that means it is something wrong with third one you get the same thing you could hear to time your now correcting misconceptions. The doubts are removed from the learner's mind

Thank you. Do animations help learners in understanding of effects of various factors on rates of reactions? Animations now these are like different from simulations in that we are dealing at the molecular level, the particle level which is different from just in bulky chemicals.

OK we are now at particle nature of the reaction, where we are talking of a molecule colliding with another molecule, not just a liquid which is poured into another liquid I a beaker. Yeah it will assist.

We are talking about what we did I want you to be specific to what we did.

Yes like that one of the reaction of ozone with ehee nitrogen what, what where the molecules were colliding from one angle there was no reaction when the molecules collided from a different angle, which was said to be the correct orientation there was a reaction. It was illustrating the meaning of correct orientation. Sometimes when you just tell them they may not understand. This time they were seeing it.

Thank you very much. As simulations of any help in understanding of the Maxwell Boltzmann distribution curve of molecular speeds and reaction mechanisms?

Reaction mechanisms and?

The Maxwell Boltzmann distribution curve.

Yes. You are asking about the simulation?

The simulations that we carried out. Did they help learners to understand the Maxwell Boltzmann distribution curve and also reaction mechanisms?

Yeah on the change of temperature were we sometimes we say at 25 degree Celcius the rate of reaction will be faster than the rate of reaction at 15 degrees, Maxwell Boltzmann distribution curve was showing showing the number of particles or or the average kinetic energy of particles or the amount of particles with energy which is above the activation energy. It was illustrating that by means of a diagram. You could see that this is having more particles which are having kinetic energy which is above the activation energy.

So was that visualization helpful for learners.

Yes normally you would understand better what you see.

Do simulations play any role in Lena's attitude towards the topic. Do they in any way improve lenders interest and attitude towards the lessons that we presented to them.

Yes our learners these days they like these things of seeing. So if you bring it to learners they are getting more interested because that's their thing of seeing a lot of now it is it like seeing people not even listening but is same so even from the same part and also manipulation way asking them to do it again and stop and do it again and stop that's what they enjoy. That's their area they enjoy that very much.

Appendix 24: Contingency Tables on Learners' Conceptual Understanding of CRR concepts

EG Contingency Table showing distribution of participants' responses in different categories

Interview Question	SU	PU	LK	Total
2.1	4	1		5
2.2	5			5
2.3	5			5
3.1	5			5
3.2	3	1	1	5
3.3.1	3	2		5
3.3.2	2	3		5
3.4	4	1		5
3.5	2	1	2	5
4.1	4	1		5
4.2.1	5			5
4.2.2	3		2	5
5.1	5			5
5.2	5			5
5.3	2	1	2	5
5.4	4		1	5
6.1	4	1		5
6.2	5			5
6.3	3	2		5
6.4	3	2		5
6.5	5			5
7.1	5			5
7.2	1	2	2	5
7.3	2	2	1	5
Total	89	20	11	120

CG Contingency Table

Interview Question	SU	PU	LK	Total
2.1	2	2	1	5
2.2	2		3	5
2.3	1	1	3	5
3.1	1		4	5
3.2	2		3	5
3.3.1	1	1	3	5
3.3.2		2	3	5
3.4	1	3	1	5
3.5	1	2	2	5
4.1	3		2	5
4.2.1	1	1	3	5
4.2.2			5	5
5.1	3		2	5
5.2	3	2		5
5.3	1		4	5
5.4	2		3	5
6.1	2	1	2	5
6.2	1	1	3	5
6.3	1	1	3	5
6.4	1		4	5
6.5	1		4	5
7.1	1		4	5
7.2			5	5
7.3			5	5
Total	31	17	72	120

Appendix 25: Attitudes Before Treatment

(1: Strongly Disagree; 2: Disagree; 3: Agree; 4: Strongly Agree; School 1: EG School 2: CG)

School	ID	Q1	Q5	Q9	Q2	Q6	Q10	Q3	Q7	Q11	Q4	Q8	Q12	Sum_Pre
2	1	1	1	2	1	1	1	2	1	2	1	1	1	15
2	2	1	3	1	3	2	3	4	4	2	1	3	1	28
2	3	2	3	3	1	4	4	2	4	3	4	3	4	37
2	4	2	3	2	3	3	2	2	3	3	4	4	3	34
2	5	1	2	1	1	1	1	2	1	2	1	1	1	15
2	6	2	2	1	2	1	1	1	2	2	1	2	1	18
2	7	1	1	2	2	1	1	2	2	1	1	2	1	17
2	8	2	3	2	1	2	3	2	2	2	1	1	3	24
2	9	3	3	4	3	4	4	3	3	3	3	3	3	39
2	10	1	2	2	2	2	4	3	4	4	3	2	4	33
2	11	2	2	1	3	3	3	1	3	1	3	2	3	27
2	12	2	1	1	2	1	2	1	1	1	3	1	3	19
2	13	2	4	3	3	3	2	4	2	4	3	3	4	37
2	14	3	3	3	3	3	2	1	3	4	3	4	3	35
2	15	3	3	3	3	3	3	4	4	3	3	4	4	40
2	16	2	2	2	2	2	1	3	3	2	3	2	2	26
2	17	1	1	3	2	1	1	1	1	2	1	1	1	16
2	18	1	3	3	2	2	2	4	3	3	2	3	2	30
2	19	2	4	1	2	2	3	4	4	3	4	1	2	32
2	20	1	1	2	1	1	1	2	2	1	1	2	2	17
2	21	3	3	3	2	3	2	2	3	1	4	4	1	31
2	22	2	3	2	3	3	2	3	3	3	3	3	3	33
2	23	3	2	3	3	3	3	4	3	4	2	3	3	36
2	24	2	3	1	3	3	4	3	3	4	3	4	4	37
2	25	2	2	1	3	3	4	2	1	1	1	2	2	24
2	26	2	3	2	2	2	2	3	3	3	2	2	2	28
2	27	2	2	2	1	1	3	3	3	3	1	1	3	25
2	28	1	2	2	1	1	1	2	1	1	1	1	2	16
2	29	2	2	1	3	3	4	4	3	3	3	3	4	35
2	30	2	3	3	2	3	3	2	2	3	3	2	3	31
2	31	1	2	1	3	4	3	3	4	2	3	2	3	31
2	32	2	2	3	2	3	3	2	4	4	4	3	4	36
2	33	2	3	3	1	1	1	2	1	1	2	1	1	19
2	34	2	2	2	3	3	3	1	2	4	4	3	4	33
2	35	2	3	3	3	4	4	2	2	2	3	3	3	34
2	36	1	1	1	3	3	3	4	1	1	1	1	1	21

2	37	3	3	3	4	4	4	3	3	1	3	3	3	37
2	38	3	3	2	3	4	4	3	2	2	2	3	2	33
2	39	3	3	3	3	3	3	3	3	3	3	3	3	36
2	40	1	3	3	1	1	3	2	1	1	1	1	1	19
2	41	2	1	1	1	1	1	1	2	2	2	2	1	17
2	42	1	3	2	2	3	1	3	4	3	2	1	1	26
2	43	1	3	2	3	3	3	3	3	4	3	2	4	34
2	44	1	2	2	3	3	2	3	3	3	2	2	3	29
2	45	2	2	1	4	3	3	2	3	3	2	2	2	29
2	46	3	3	2	3	4	2	2	2	3	3	3	4	34
2	47	2	3	3	2	4	3	4	4	3	2	3	1	34
2	48	1	3	3	2	2	2	3	3	3	3	3	2	30
2	49	2	2	2	2	3	3	3	3	3	3	3	2	31
2	50	2	3	1	3	3	4	4	3	3	2	3	2	33
2	51	2	3	1	4	3	4	2	3	3	2	3	3	33
2	52	3	4	2	4	3	2	3	4	4	3	3	4	39
2	53	2	3	1	1	1	4	2	1	1	2	3	1	22
2	54	2	3	2	2	3	2	1	4	3	3	1	4	30
2	55	2	3	2	3	3	3	3	2	3	3	3	3	33
2	56	2	3	3	3	4	3	3	3	2	3	4	3	36
2	57	2	3	3	2	2	3	2	2	3	2	3	3	30
2	58	2	3	2	1	1	3	3	3	4	3	4	1	30
2	59	1	2	3	4	4	4	3	3	2	1	3	4	34
2	60	3	3	3	1	1	1	2	4	3	3	3	3	30
2	61	2	1	2	2	1	1	1	1	1	2	2	1	17
2	62	1	2	1	3	3	2	4	4	4	3	2	1	30
2	63	1	2	1	3	3	3	3	3	4	4	3	3	33
2	64	2	2	2	3	3	3	4	4	3	3	3	2	34
2	65	1	2	2	3	4	3	2	3	4	1	4	1	30
1	66	1	1	1	1	2	1	1	1	2	1	2	1	15
1	67	3	1	1	1	3	1	1	1	2	1	1	2	18
1	68	2	1	1	3	1	1	3	1	1	2	1	2	19
1	69	1	1	2	1	1	1	2	1	1	1	1	3	16
1	70	3	2	2	3	3	1	2	3	4	3	3	3	32
1	71	2	3	2	2	2	4	4	4	3	3	2	3	34
1	72	2	1	1	1	1	2	1	1	3	1	1	2	17
1	73	2	1	3	2	1	3	2	2	3	2	2	3	26
1	74	2	3	2	3	1	3	1	1	1	1	2	3	23
1	75	1	1	2	1	2	1	1	1	1	2	1	2	16
1	76	3	3	2	3	3	3	2	2	3	3	3	3	33
1	77	2	3	3	3	3	2	4	3	4	3	2	3	35
1	78	2	3	1	3	4	2	4	4	3	3	3	4	36
1	79	3	3	4	3	3	4	3	3	4	3	3	4	40

1	80	1	3	2	3	1	4	2	1	3	4	2	3	29
1	81	2	3	3	2	3	2	3	2	4	3	3	2	32
1	82	2	3	2	2	2	2	3	3	2	2	2	2	27
1	83	2	3	3	3	4	3	3	3	4	3	3	4	38
1	84	3	4	3	2	2	4	1	3	3	3	3	3	34
1	85	1	1	1	1	1	1	1	1	1	3	3	4	19
1	86	3	3	3	3	3	3	3	3	3	3	3	3	36
1	87	2	1	1	2	2	1	1	1	1	1	2	1	16
1	88	2	3	2	3	3	3	3	4	3	2	2	3	33
1	89	1	2	1	2	1	2	4	1	2	1	2	3	22
1	90	2	1	2	2	1	1	2	1	1	1	2	2	18
1	91	3	1	1	1	2	2	1	1	1	1	2	1	17
1	92	2	1	1	2	2	1	3	1	1	1	1	1	17
1	93	2	2	2	1	1	1	4	3	3	1	1	2	23
1	94	2	3	1	1	2	1	1	2	1	2	1	1	18
1	95	3	4	3	3	3	4	4	3	3	4	4	3	41
1	96	2	3	3	2	3	4	1	3	1	2	2	4	30
1	97	2	2	2	2	2	2	2	2	3	3	3	3	28
1	98	2	3	2	2	2	3	3	3	2	2	3	1	28
1	99	1	3	2	3	2	4	3	2	2	3	4	3	32
1	100	1	2	1	1	3	4	3	4	4	2	3	4	32
1	101	2	2	4	2	3	3	3	4	1	3	3	2	32
1	102	3	3	3	4	2	4	3	4	4	3	4	4	41
1	103	2	3	2	1	1	1	2	1	2	1	2	1	19
1	104	3	4	3	4	3	3	3	2	3	3	4	3	38
1	105	3	3	2	4	3	1	4	1	2	1	2	3	29
1	106	2	3	2	2	2	3	3	1	3	3	4	2	30
1	107	2	3	2	3	4	3	3	3	2	3	3	4	35
1	108	3	3	3	2	2	2	1	1	1	2	2	2	24
1	109	4	3	3	3	2	2	4	1	3	3	3	3	34
1	110	2	4	1	3	3	3	2	4	2	2	3	3	32
1	111	2	3	3	2	1	4	3	4	3	3	3	3	34
1	112	2	3	3	3	1	1	1	2	1	1	1	2	21
1	113	2	4	4	3	2	3	4	2	4	3	2	3	36
1	114	2	2	2	3	3	3	2	3	3	2	2	2	29
1	115	2	3	3	2	3	3	4	4	4	3	3	3	37
1	116	2	3	3	4	2	3	3	4	4	3	2	3	36
1	117	3	3	3	3	4	4	3	4	3	4	3	4	41
1	118	2	3	3	3	3	2	3	4	4	4	3	3	37

Appendix 26: Attitudes After Treatment

School	ID	Q1	Q5	Q9	Q2	Q6	Q10	Q3	Q7	Q11	Q4	Q8	Q12	Sum_Attitudes
2	1	1	3	2	3	3	3	3	3	4	2	2	1	30
2	2	1	3	1	2	3	3	4	3	1	1	2	2	26
2	3	2	3	3	3	4	4	2	4	4	3	3	1	36
2	4	2	3	3	3	3	2	2	2	3	4	3	4	34
2	5	3	3	3	1	2	1	4	4	4	4	3	3	35
2	6	2	3	3	3	3	3	3	3	4	4	2	2	35
2	7	3	3	3	2	3	4	4	3	4	3	4	3	39
2	8	2	3	4	3	4	4	4	4	4	3	4	4	43
2	9	1	1	1	1	1	1	1	2	1	1	2	1	14
2	10	2	3	2	4	2	3	4	4	3	4	4	4	39
2	11	1	3	1	3	3	4	2	3	1	3	1	2	27
2	12	2	3	2	2	3	2	3	3	3	2	2	3	30
2	13	2	4	3	3	3	2	3	4	4	3	3	4	38
2	14	3	3	3	4	4	2	3	2	3	3	4	3	37
2	15	3	3	3	3	4	4	4	4	3	3	3	4	41
2	16	2	2	2	2	2	2	3	3	2	2	2	2	26
2	17	2	1	1	1	1	2	2	2	1	2	1	2	18
2	18	2	2	2	1	1	1	1	1	2	2	1	1	17
2	19	2	3	1	2	4	2	4	4	3	3	2	3	33
2	20	1	2	1	1	1	1	2	2	1	1	1	1	15
2	21	3	3	3	3	2	1	2	2	1	4	4	2	30
2	22	2	3	2	3	3	2	2	3	3	3	3	4	33
2	23	3	2	3	1	1	2	3	3	3	3	2	3	29
2	24	1	3	1	2	2	3	3	2	1	3	1	1	23
2	25	1	1	1	1	1	2	2	2	1	1	1	1	15
2	26	2	3	2	2	1	1	2	2	2	3	3	2	25
2	27	1	3	2	2	2	1	4	4	2	1	1	1	24
2	28	2	3	3	3	3	4	4	3	3	3	1	3	35
2	29	2	3	3	1	1	1	2	2	1	1	1	1	19
2	30	2	3	3	2	3	3	2	3	3	3	2	3	32
2	31	1	3	2	3	3	4	3	3	4	3	2	4	35
2	32	2	2	3	3	4	3	3	4	4	2	3	4	37
2	33	1	2	2	1	1	1	1	2	1	1	2	2	17
2	34	2	3	3	2	1	1	1	2	2	2	2	1	22
2	35	2	3	3	3	3	3	1	1	1	2	3	3	28
2	36	1	1	1	3	3	3	3	3	3	1	3	3	28
2	37	3	3	3	3	4	4	2	2	2	3	3	3	35
2	38	2	3	2	3	3	4	3	3	2	2	3	2	32
2	39	3	3	3	3	3	3	3	3	3	4	3	3	37
2	40	3	2	3	1	1	2	2	2	1	2	2	2	23

School	ID	Q1	Q5	Q9	Q2	Q6	Q10	Q3	Q7	Q11	Q4	Q8	Q12	Sum_Attitudes
2	41	2	3	2	4	3	4	4	3	3	2	2	2	34
2	42	1	2	2	3	4	3	3	4	3	2	2	3	32
2	43	1	3	1	2	3	2	4	3	3	2	2	3	29
2	44	1	1	1	3	3	2	3	3	3	2	1	3	26
2	45	2	2	1	3	2	3	2	3	2	3	3	3	29
2	46	3	3	3	4	3	3	3	3	3	3	4	4	39
2	47	2	3	2	3	3	2	4	4	4	2	2	1	32
2	48	1	3	3	2	2	1	3	3	3	2	3	1	27
2	49	1	2	2	2	3	3	3	3	2	2	2	2	27
2	50	2	3	2	3	3	3	4	3	3	2	2	2	32
2	51	2	3	2	3	3	4	2	3	3	2	2	3	32
2	52	2	3	2	3	3	1	4	4	4	3	3	3	35
2	53	2	2	1	2	3	4	3	3	2	1	2	3	28
2	54	2	1	2	2	2	3	4	4	3	2	3	4	32
2	55	2	3	2	3	3	3	3	3	4	4	4	3	37
2	56	2	3	2	3	3	3	4	4	3	3	3	3	36
2	57	3	3	3	2	2	3	2	4	4	3	3	1	33
2	58	1	2	2	1	1	1	3	3	3	3	1	1	22
2	59	2	3	2	1	1	2	1	2	1	1	2	1	19
2	60	3	3	3	1	1	1	3	3	3	3	3	3	30
2	61	3	2	2	1	1	1	2	1	1	2	1	1	18
2	62	1	2	1	1	3	2	4	4	4	3	1	1	27
2	63	2	2	1	3	3	3	4	4	3	3	2	3	33
2	64	2	3	2	4	3	3	4	4	4	3	3	2	37
2	65	1	3	2	2	3	4	4	4	4	4	2	2	35
1	66	1	4	1	3	4	4	3	4	2	4	3	4	37
1	67	4	4	3	4	3	4	4	3	3	4	4	3	43
1	68	1	2	1	4	3	4	3	4	3	2	1	1	29
1	69	3	4	4	4	4	4	3	4	4	4	4	4	46
1	70	2	3	2	2	2	1	3	3	4	3	3	3	31
1	71	2	3	1	2	2	3	4	3	2	1	3	3	29
1	72	2	3	3	3	3	3	4	4	3	3	2	3	36
1	73	4	3	4	4	4	4	2	4	4	4	3	4	44
1	74	4	4	4	4	3	4	4	4	4	3	4	4	46
1	75	2	3	2	3	3	3	3	3	3	3	2	2	32
1	76	2	3	3	3	3	3	2	2	3	3	3	3	33
1	77	3	3	3	3	4	4	3	4	4	3	3	3	40
1	78	1	3	2	4	3	3	4	4	4	3	3	4	38
1	79	3	3	3	4	3	3	3	4	3	3	3	3	38
1	80	2	2	2	3	2	3	3	1	2	3	4	4	31
1	81	2	4	3	3	1	1	4	2	1	3	4	2	30
1	82	2	3	2	3	2	2	3	3	2	2	2	2	28

School	ID	Q1	Q5	Q9	Q2	Q6	Q10	Q3	Q7	Q11	Q4	Q8	Q12	Sum_Attitudes
1	83	2	3	3	3	3	4	3	4	4	3	4	4	40
1	84	3	3	3	2	2	2	1	3	3	3	3	3	31
1	85	2	2	2	3	3	3	3	3	2	3	2	3	31
1	86	3	3	3	3	3	3	3	3	3	3	3	3	36
1	87	4	4	3	3	3	3	3	4	3	3	3	3	39
1	88	2	3	3	4	4	4	4	4	4	4	4	4	44
1	89	2	1	2	3	3	3	3	1	2	2	2	2	26
1	90	2	4	2	3	3	3	3	3	4	3	3	3	36
1	91	4	3	4	3	4	4	3	4	4	3	4	4	44
1	92	2	4	2	4	3	4	3	3	4	4	3	4	40
1	93	2	3	3	2	3	3	3	3	3	2	3	2	32
1	94	2	3	3	3	3	2	4	4	4	3	3	3	37
1	95	3	4	3	4	4	4	3	4	4	3	4	4	44
1	96	1	3	3	3	4	4	3	2	4	3	2	4	36
1	97	3	4	4	4	4	4	3	4	4	4	3	4	45
1	98	4	3	4	4	4	4	3	4	3	4	4	3	44
1	99	2	3	2	3	3	4	2	2	3	3	3	3	33
1	100	1	4	1	3	4	4	1	4	4	3	4	4	37
1	101	1	2	2	3	3	3	3	2	3	1	1	2	26
1	102	3	4	3	4	4	3	4	4	4	4	4	4	45
1	103	3	4	4	4	4	4	4	3	4	4	4	4	46
1	104	3	3	4	4	3	3	4	3	2	3	4	4	40
1	105	2	4	3	3	3	2	3	2	2	1	3	3	31
1	106	3	4	4	2	3	3	3	3	3	3	2	3	36
1	107	2	2	2	3	2	3	3	4	3	2	2	2	30
1	108	3	4	4	4	3	4	4	4	3	4	4	4	45
1	109	1	3	3	3	4	2	3	1	3	1	3	3	30
1	110	1	3	2	3	3	3	2	3	2	2	3	3	30
1	111	2	3	2	3	3	3	4	4	4	3	3	4	38
1	112	2	3	3	3	4	3	3	4	3	4	3	3	38
1	113	2	4	4	3	4	4	4	3	4	3	3	4	42
1	114	2	2	2	3	3	2	1	3	2	2	2	2	26
1	115	2	4	3	3	3	3	3	4	4	3	3	3	38
1	116	2	4	3	3	3	4	3	4	4	3	3	3	39
1	117	2	3	3	3	4	4	3	4	4	3	4	3	40
1	118	3	3	3	3	4	1	1	4	4	3	3	3	35

Appendix 27: Computer Simulation-Based Instruction (CSBI)

Teaching in the EG:

The EG was taught by me using CSBI. Animations, visualizations and interactive virtual laboratory (VLAB) experiences were selected from simulations on CRR that were freely available on the internet. The reason for this is that the simulations should be readily available to other researchers and teachers. In selecting the simulations, I followed the principles used to reduce cognitive overload guided by Mayer's Cognitive Theory of Multimedia Learning (CTML). These principles include the *pretraining effect, the modality effect*, *the segmentation effect and the signalling effect*. Each lesson was one-hour long. Four lessons on CRR were planned in line with the following scheme:

The teacher uses a power-point presentation to provide learners with all the basic facts upon which the simulation is based. The *pretraining effect* suggests that before learners are exposed to the simulations they should be provided with all basic concepts in the simulations. This is also in line with the Cognitive Load Theory which advocates for fully guided instruction.
The teacher provides learners with worksheets. The worksheets will have three main sections which are: `**Predict**, **Observe** and **Explain**. Under **Predict** each learner will be required to complete a statement that guides them on the construction of a hypothesis and an investigative question. They are also guided in identifying independent and dependent variables as well as variables to be controlled for an investigation presented to them as a VLAB. The section on **Predict** is completed before the learners are presented with the simulations.
After completion of the Prediction task, learners are presented with the simulation such as a VLAB. In this presentation, the *segmentation effect* is followed in keeping with Mayer's CTML. This entails that the presentation should proceed at the learner's pace. Since the presentation will be done using a projector, the researcher will pause after short segments to reduce cognitive overload in accordance with CTML. As the presentation is paused the learners will use the opportunity to complete the **Observe** section of their worksheets. They complete statements that guide them in terms of the important observations from a segment of the presentation.

After the learners have observed the presentation, they are given an opportunity to complete the **Explain** section of the worksheet. Activities under the Explain section will include, drawing sketches of graphs of the results, interpretation of graphs and drawing of a conclusion. Learners will also be required to explain their observations in terms of the collision theory of reaction rate.

The lesson is concluded by a class discussion of the concepts covered through the simulation. The researcher collects the learners' worksheets to check on the quality of their work and to provide them with feedback in the next lesson.

The teaching scheme above was validated by an expert during the pilot study before it was used in the primary data collection phase of the research. This was done by presenting the lessons to a sample of learners who were not part of the main study. The teaching scheme was changed considering the findings of the pilot study. Four detailed lesson plans based on the above scheme were developed by me as the researcher and implemented as the treatment.

Appendix 28: Lesson Plan 1 *Lesson Plan 1* *Topic: CRR- Definition of Reaction Rate; Collision Theory; Temperature* *Time: 1 Hour*

Stage	Time	Concepts & Skills	Teacher Activity	Learner Activity
Stage 1 Introduction	5 min	Definition of rate	Teacher introduces the lesson by defining rate and giving examples of fast and slow reaction. Teacher defines average rate; instantaneous rate and initial rate.	Learners write down the definitions
Stage 2	8 min		Teacher give two examples of calculation of average rate and instantaneous rate.	Learners write down the worked examples and ask questions
Stage 3 Pre- Training & Demonstration of the collision theory	20 min	Collision Theory	Teacher introduces collision theory; Uses the PHET to explain the concepts; demonstrates using single collision how to use the PHET simulation; gives the learners the POE activity sheets with instructions; Teacher ask one learner to change the temperature starting at a low temperature and observe the effect on effective collisions determined by number of molecules of the product formed. Segmentation effect: Teacher ask learner to pause simulation and class observe the number of product molecules formed then increase temperature until energy equal to EA and then supply more energy than EA. The simulation is reset. Learner asked to change orientation and run the simulation. Collisions are launched at different angles and number of effective collisions are noted. The demonstration is repeated with many collisions. The simulation uses graphs of exothermic and endothermic reactions and these concepts are explained. https://phet.colorado.edu/en/simulation/reactions-and-rates	Learners complete the Prediction Stage of the POE before carrying activity to explore the change in temperature and change in orientation. Learners make Observations as they watch the simulation. They write down their observations. After demonstration, learners complete the Explanation stage.
Stage 3 Pre-Training: Effect of temperature on reaction rate using a V-Lab	10 min	Effect of temperature	Teacher show class how to use the V-Lab to investigate effect of temperature on rate of reaction between water and antacid tablet. The V-Lab is found at http://www.learnalberta.ca/content/secsu/html/matter_and_chemical_change/temperature/	Learners observe and learn how to use the V-Lab
Stage 4: Demonstration POE	15 min	Investigating Temperature	Teacher gives learners worksheets on POE activities. Teacher ask one learner to come forward. Teacher assist this learner to carry out the demonstration while other learners observe. Where necessary the V-lab is paused, or reset to start again.	Learners complete the Prediction part of the POE by identifying the variables and stating what will happen to reaction rate as temperature is increased. Learners write down the Table of results and complete the table during the Observation stage. After the demonstration learners calculates reaction rate at various time intervals. Rate is the inverse of time as explained during pre-training. Learners Explain any differences between their observations and their predictions
Conclusion	2 min		The teacher gives a brief summary of the lesson	

Appendix 29 Lesson Plan 2

Lesson Plan 2 Topic: CRR- Effect of concentration, surface area and temperature on rate. Time: 1H

Stage	Time	Concepts & skills	Teacher Activity	Learner Activity
Stage 1 Introduction	5 min.	Factors Affecting Rate	Teacher briefly introduces the factors that affect reaction rates: temperature; concentration; pressure; particle size/surface area and catalysts.	Learners write down the factors.
Stage 2 Pre-training	10 min	Concentration & Surface area	Teacher explains how to use the V-lab on effect of concentration and surface area on rate. Teacher show how to carry out the investigations, identify the independent variable; the dependent variable and the controlled variables.	Learners watch the V-lab and learn how to use the V-Lab
Stage 3: Demonstration	15 min	Concentration	Teacher gives out worksheets on POE. Teacher ask one learner to come forward. Teacher assist the learner to demonstrate the investigation of effect of concentration of sulphuric acid on rate of reaction between the acid and magnesium ribbon. The V-Lab is available at: http://www.learnalberta.ca/content/secsu/html/matter_and_chemical_change/	Learners complete the Prediction stage of the POE then Observe the demonstration. During the demonstration learners complete a Table of results. After the demonstration, learners calculate reaction rate as the inverse of time. They draw graphs of reaction rate against time using their data. Then they complete the Explain stage of POE by comparing their observations and their predictions and explain any discrepancy.
Stage 4: Pre-Training	5 min	Surface Area and temperature	Teacher explains how to use the V-Lab to investigate effect of particle size/surface area and effect of temperature on reaction rate. Available at http://www.learnalberta.ca.	Learners observe and learn how to use the V-lab
Stage 5: Demonstration	20 min	Surface Area and temperature	Learners given worksheets on POE. One learner assists in demonstrating investigation of surface area of zinc on rate of reaction between zinc and sulphuric acid. When learners had completed this activity, they proceeded to investigate the effect of temperature on reaction rate.	Learners complete the Prediction stage. During this stage they stage the variables and predict what will happen to the dependent variable when the independent variable is changed. During the observation stage they complete table of results as they observe the demonstration. After the demonstration, they calculate reaction rate, draw graphs and Explain their observations and compare with their predictions
Conclusion	5 min	Summary	Teacher provides a summary of he concepts learnt and collect learners' worksheets for evaluation.	

Appendix 30: Lesson Plan 3

Lesson Plan 3 Topic: CRR: Factors Affecting Reaction Rates Time: 1 Hour

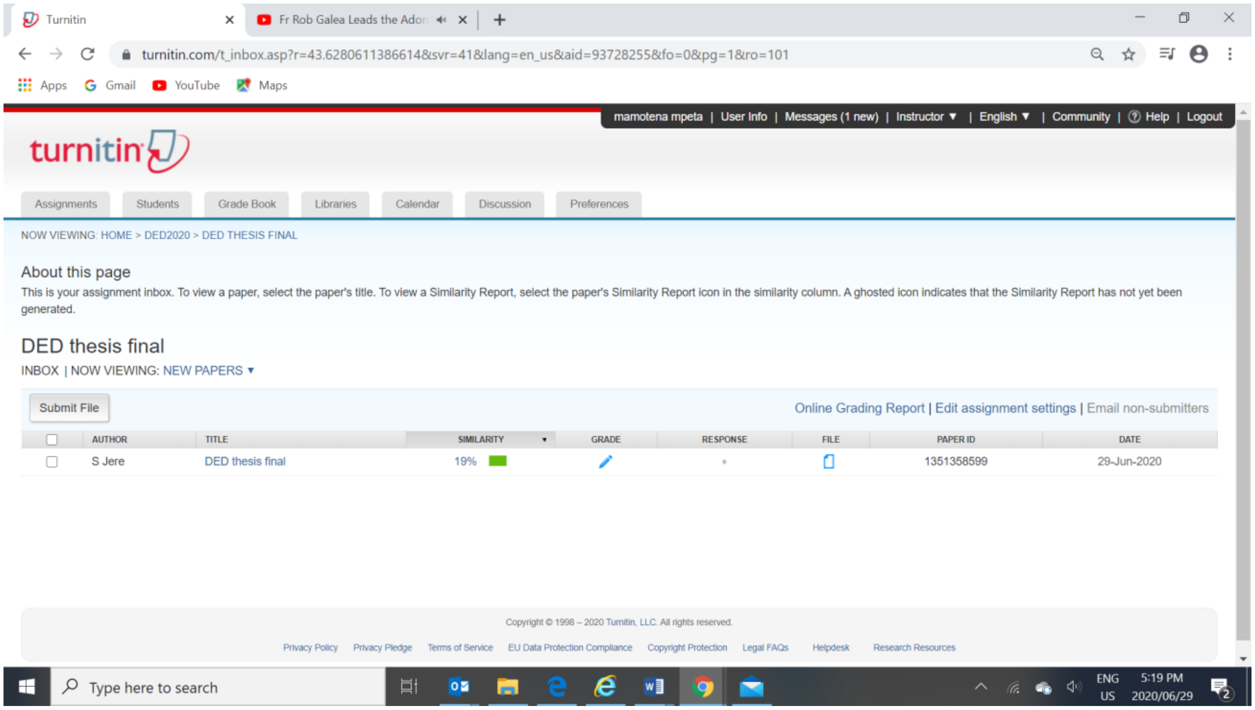
Stage	Time	Concepts & Skills	Teacher Activity	Learner Activity
Stage 1: Introduction	5 min	Factors affecting reaction rate in terms of the collision theory	Teacher introduces the lesson by explaining factors affecting reaction rate in terms of the collision theory	Listen and write down the factors and explain in terms of the collision theory
Stage 2: Pre-training	10 min	Effect of temperature, concentration & surface area	Teacher explains how to use the simulation of factors affecting reaction rate available at: https://cdn.pearsonplaces.com.au/cdn/	Learners learn how to use the simulation to investigate factors affecting reaction rate.
Stage 3: Demonstration	20 min	Investigation of temperature, concentration & surface area	Teacher gives learners worksheets on POE. Teacher assist one learner in demonstrating investigation of factors affecting reaction rates. Each demonstration is segmented for the learners to observe carefully what will be happening and the teacher clarifies any issues.	Learners complete the Prediction, then Observe the demonstration. After each demonstration learners Explain their observations.
Stage 4:	10 min	Catalysis	Teacher explains the concept of catalysis using energy profile diagrams. Catalysts alters the reaction pathway by using a reaction mechanism with a lower activation energy.	Learners take notes on catalysis.
Stage 5	10 min	Maxwell Boltzmann Graph	Teacher uses the PHET simulation of distribution of molecular speeds to introduce the Maxwell-Boltzmann distribution graphs: Simulation available at: https://phet.colorado.edu/en/simulation/gas-properties Teacher explains effect of change in temperature; concentration and addition of catalyst on reaction rate using the distribution curve.	Learners observe the simulation. Learners take notes.
Conclusion	5 min	Summary	Teacher summarizes the concept covered during the lesson	

Appendix 31: Lesson Plan 4

Lesson Plan 4 Topic: CRR- Energy Profile Diagrams Exothermic & Endothermic reactions, Reversible Reactions Duration 1H

Reaction Mechanism

Stage	Time	Concepts & Skills	Teacher Activity	Learner Activity
Stage 1: Introduction	5 min	Definition of exothermic and endothermic reactions	Teacher defines exothermic, endothermic reactions, Heat of reaction, enthalpy change, reversible reactions. Activation energy revised	Listen
Stage 2: Pre-Training	15 min	Energy Profile Diagrams & Reaction mechanisms	Teacher use the PHET simulations on Chemical Reaction Rates to demonstrate Energy profile diagrams and progress of reaction for reversible reactions. The simulation is available at: https://phet.colorado.edu/en/simulation/reactions-and-rates Teacher explain the effect of catalysts on reaction rates and how catalysts work to speed up the rate using energy profile diagrams. Teacher explains the concept of reaction mechanism and how catalysts change reaction mechanism.	Watch the demonstration of how to use the PHET simulations.
Stage 3: Demonstration	20 min	Energy Profile Diagrams & Reaction mechanisms	Teacher gives learners POE worksheets. Teacher assists one learner to demonstrate the use of the PHET simulation to investigate endothermic and exothermic reversible reactions.	Learners complete the Prediction phase, then observe the demonstrations, then they explain their Observations for each demonstration and compare with the predictions.
Stage 4: Chapter Summary	15 min	CRR	Teacher provides a summary of all the concepts on CRR explored in the 4 lessons.	Learners take notes
Conclusion	5 min		Teacher summarizes the main points	


Turnitin
Fr Rob Galea Leads the Ador
turnitin.com/t_inbox.asp?r=43.6280611386614&svr=41&lang=en_us&aid=93728255&fo=0&pg=1&ro=101
Apps
Gmail
YouTube
Maps
mamotena mpeta | User Info | Messages (1 new) | Instructor ▼ | English ▼ | Community | Help | Logout
turnitin
Assignments
Students
Grade Book
Libraries
Calendar
Discussion
Preferences
NOW VIEWING: HOME > DED2020 > DED THESIS FINAL
About this page
This is your assignment inbox. To view a paper, select the paper's title. To view a Similarity Report, select the paper's Similarity Report icon in the similarity column. A ghosted icon indicates that the Similarity Report has not yet been generated.
DED thesis final
INBOX | NOW VIEWING: NEW PAPERS ▼
Submit File
Online Grading Report | Edit assignment settings | Email non-submitters
AUTHOR
TITLE
SIMILARITY
GRADE
RESPONSE
FILE
PAPER ID
DATE
S Jere
DED thesis final
19%
1351358599
29-Jun-2020
Copyright © 1998 – 2020 Turnitin, LLC. All rights reserved.
Privacy Policy
Privacy Pledge
Terms of Service
EU Data Protection Compliance
Copyright Protection
Legal FAQs
Helpdesk
Research Resources
Type here to search
ENG
US
5:19 PM
2020/06/29