EXPLORING GRADE 12 LEARNERS' GRAPHICAL INTERPRETATION OF RATE AND EXTENT OF REACTION: A CASE STUDY OF KING CETSHWAYO DISTRICT GRADE 12 LEARNERS

By

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Submitted in fulfilment of the requirements for the degree

MASTERS OF EDUCATOINIS: SCIENCE EDUCATION

In the

Department of Mathematics, Science and Technology Education

FACULTY OF EDUCATION

UNIVERSITY OF ZULULAND

KWADLANGEZWA

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APRIL 2022

DECLARATION

I hereby declare that the thesis submitted for the degree of Masters of Education (M.Ed), at University of Zululand, is my own, and all sources quoted have been acknowledged by means of references. I also declare that I have not previously submitted this thesis to any other institution of higher education.

Signature: ____________________ Date: 04 April 2022

(Zanele Mary-Jane Qwabe)

DEDICATION

This thesis is dedicated to my family and friends. A specially feeling of gratitude to my loving husband, Norman Thamsanqa Nzuza whose words of encouragement supported me to press on. My daughters Lindelwa, Nomcebo and Ayanda and my sons Xolani, Sandile, Lwazi and Amathamsanqa have never left my side and are very special.

I also indebted to my friends Nonhlanhla and Lungile who supported me throughout the process. Lastly, my special parents Dumile and Magumeni for being there for me throughout the entire master programme.

ACKNOWLEDGEMENTS

I wish to thank Lord almighty for granting me an opportunity to conduct my studies in masters and to sustain me throughout the process.

A special thanks to Dr T.W. Chinaka for his countless hours of supporting, reading, encouraging, and most of all patience throughout the entire process. His guidance, expertise and invaluable support made this thesis to be a success.

Many thanks are also extended to Mr T Diwa for capturing and analysing the quantitative data. To the editor Khumalo Nontobeko thank you for the support.

I wish to thank KwaZulu Natal Department of Education and King Cetshwayo District in for allowing me to conduct research in their schools. Finally, I would like to thank principals, teachers, learners and parents in schools. Learners excitement and willingness to provide feedback made the completion of this research enjoyable experience.

ABSTRACT

Graphs are very important in all areas of science, and they are an essential part of tertiary, high school, and primary school curricula around the world. A solid understanding of graph interpretation is essential for understanding today's world and becoming a scientifically literate. However, graph interpretation is a complex and challenging activity. The aim of this study was to explore learners' graphical interpretation of the rate and extent of reaction topic. A mixed-method explanatory sequential design was adopted for this study. A purposive sampling technique was used to sample participants from the accessible population in King Cetshwayo District KwaZulu-Natal province in South Africa. One-hundred and forty-six (146) grade 12 Physical Sciences learners, formed the sample from King Cetshwayo District. A validated three-tier diagnostic questionnaire and semi-structured interviews were used to collect data. The findings indicated that learners rely on definitions to interpret graphs. Most of the learners failed to interpret the surface features of the graphs. Interpretations were ranked hierarchical (Curcio's levels) to measure learners' graphical literacy and most learners struggled with lower levels. The findings of this study are diagnostic and they assist module designers and educators in determining challenges learner's face when interpreting graphs in chemistry. Further studies are needed to determine how surface features can be employed to address graphical interpretation in chemical kinetics.

Keywords: Graphical Interpretation, Graphical Literacy, Surface features, Rate and extent of reaction, Johnstone triangle, Bertin's theory of graph interpretation.

LIST OF ABBREVIATIONS AND ACRONYMS

CAPS:	Curriculum and Assessment Policy Statement
FET:	Further Education and Training
NCS:	National Curriculum Statement
RER:	Rate and Extent of reaction
GL:	Graphical Literacy

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CHAPTER ONE INTRODUCTION

1.1 OVERVIEW

This study explored grade 12 learners' graphical interpretation of rate and extent of reaction. It also explored how learners interpret surface features of the graphs and ranked the interpretations using Curcio's levels of graphical literacy. The study was framed within the notion of Johnstone's triangle and Bertin's theory of graph interpretation where interpretation require translations in different levels.

1.2 BACKGROUND OF THE STUDY

The South African National Curriculum Statement (NCS) and Curriculum Assessment Policy Statement (CAPS) of the Further Education and Training (FET) phase, in the Physical Sciences curriculum, is divided into two sections namely Physics and Chemistry. The Chemistry section has three topics; matter and materials, chemical systems, and chemical change. Rate and extent of reaction is a topic under chemical change which deals with the amount of reactant used or product formed per unit time (Broster, 2012). Reaction rates measure how fast a reaction is progressing through monitoring of a suitable parameter that changes with time. The parameters can be the volume, pressure, or concentration of the reaction system. Rates of reaction are affected by many variables and graphs are used to summarise data sets and complex relationships between variables effectively. It should be noted that graphical representations are an important tool used to model abstract processes in fields such as chemistry. Modelling and understanding complex chemical systems rely on graphs, which are ubiquitous in the introductory chemistry curriculum. The practice of visually representing scientific data with graphs, diagrams, and tables is central to science. Rate and extent of reaction is an important topic in high school chemistry which is closely related to the Kinetic theory of matter, stoichiometry and chemical equilibrium. Rate and extent of reaction is fundamental to chemistry, and is one of the 10 "big ideas" in undergraduate courses as outlined by the American Chemical Society (ACS) Examinations Institute (2012).

Scholarly research in chemical education, physics education, and mathematics education reveal a widespread difficulty in understanding, interpreting and applying rates of change concepts among learners. There are many studies that have highlighted the difficulties and misconceptions of the teaching and learning of chemical kinetics that persist after instruction (Bain & Town, 2016; Potgieter *et al.*, 2008; Planini *et al*. 2013). Seethaler *et al.,* (2017) categorised challenges learners face with rate and extent of reaction topic into four broad groups namely; drawing and interpreting graphs to understand change over time, interpreting the sign in a rate of change, distinguishing average and instantaneous rates of change, and basic conceptual meaning behind derivatives and integrals.

The present study explored the first broad challenge among grade 12 Physical sciences high school learners. The ability of a graph reader to interpret graphs created by others or themselves is known as graph interpretation (Glazer, 2011). Graph interpretation is a fundamental skill that is necessary for all learners on a daily basis to make sense of and communicate information presented in graphs, which are ubiquitous in everyday life (Glazer, 2011). Students doing chemical science in both high schools and universities find it difficult to construct and interpret graphs, and sometimes have anxiety when faced with chemistry problems involving graph interpretation (Potgieter *et al.,* 2008; Secken *et al.,* 2015). One of the challenges faced by students in interpreting curved rate of reactions graph involve changes in both height and slope (Moore et al., 2014). Furthermore, learners struggle to interpret graphs where the rate has a negative sign. They commonly confuse the negative sign as the y – co-ordinate and then drop the negative sign (Doerr *et al.*, 2013).

The South African Physical Sciences National Diagnostic Analytical Reports or the chief marker reports from 2014 to 2019 revealed a decline in performance in rates of reaction and extent of reaction topic. The national performance on rates of reaction and extent of reaction topic has never exceeded 35%. The diagnostic report of 2014 showed that most of the matriculants lacked application of knowledge on the rate and extent of reaction topic. Even, simple recall questions were fairly answered. Learners failed to identify surface features, relate the gradient to the rate of the reaction, therefore, incorrect volume values from the graph were added (Seçken et al., 2015). Furthermore, the description of surface features on graphs was poorly done as learners failed to interpret the given data. The chief marker encouraged the teachers to help learners to interpret given data and identify variables by exposing learners to more exercises that require practical skills, starting from grade 10 (Seçken et al., 2015).

In 2015 the diagnostic report revealed that learners failed to identify the reaction rate involving the change in volume per unit time. The learners lacked basic skills to interpret graphs and could not draw graphs that represented the data in the table. A question that involved stoichiometric calculation was a challenge to most of them. Teachers were encouraged to integrate stoichiometry with rate and extent of reaction at Grade 12. The report of 2016 showed that many learners swopped the independent and the dependent variables. Many learners also had a challenge with the calculation of the average rate from the graph. The National Diagnostic Reports (2017 - 2019) stated the persistence of challenges in answering graph-related questions. Learners still struggled to identify variables, give correct reasoning for their answers, interpret, draw and analyse graphs. They also struggled to interpret the Maxwell-Boltzmann energy distribution curves. Despite recommendations and workshops the topic has always been problematic. The rate and extent of reaction can now be identified as a perennial challenge in chemistry.

Graphs are an external representation widely used in chemical kinetics and chemistry classrooms to explain the concentration changes that occur when the reaction progresses. The graphs can be fairly complex in that their surface features represent information about both the kinetic and the thermodynamic considerations of the reaction (Popova and Brezt, 2018). Kolomuc and Tekin (2011) suggest that the meanings of surface features such as peaks, valleys, peak height, and peak width is vital in graphical interpretation in science education. However, recent reviews (Kaya and Geban, 2012; Taştan *et al.*, 2010; Morrison *et al.*, 2014) have called for further research regarding learners' graphical interpretation of external representations such as surface features related to kinetics and reaction mechanisms. Thus the present study explored the interpretation of rate of reaction together with surface features.

Graphical literacy refers to an understanding of the nature of construction, production, presentation, reading, and interpretation of diagrams, maps, graphs, and other visual presentations and inscriptions. Graphical literacy challenges are widespread among primary school learners (Shah & Hoeffner, 2002; Shah et al., 2005) and secondary school (Lai et al., 2016; Lachmayer, 2008). However, most studies in science education has categorised the graphical interpretation into levels of literacy. Ring *et al*., (2019) suggested that literary levels are just hierarchical measures of graphical interpretation. Thus, the present study also classified the learner's graphical interpretations.

1.3 STATEMENT OF THE PROBLEM

While it is contestable that graphs play a pivotal role in the teaching and learning of chemical kinetics, the paradox is that the interpretation of graphs on rate and extent of reaction topic is still a major deterrent in learners learning of chemistry. Researchers such as Gultepe, (2016); Bektasli and Cakmakci, (2011) argue that graphs are used to simplify complex physical relationships and principles in chemistry. However, the actual learning by learners seems to be portraying a contradictory picture (Seceken *et al*, 2015). The case in point is that both high school and undergraduate learners have difficulties in sketching and interpreting reaction rate versus time graphs despite providing accurate verbal explanations (Kolomuc and Tekin, 2011).

The researcher has found that grade 12 Physical Sciences learners experience difficulty with interpreting graphs on the rate and extent of reaction topic in chemistry. The National Diagnostic Analytical Reports (2014 - 2018) revealed that challenges in interpreting graphs still persists among grade 12 learners. As a result, they cannot identify variables, give correct reasoning for their answers, interpret, draw and analyse graphs. These are some of the factors that make grade 12 learners fail Physical Sciences. The topic is important as it is related to topics such as stoichiometry and chemical equilibrium. The Diagnostic Analysis Report (2017) indicated that performance in graph questions on reaction rate and chemical equilibrium was poor.

The other factor that exercabate the problem is that compared to other topics of physical sciences chemistry, such as physical and chemical change, molecular structure and chemical equilibrium, the rate and extent of reaction is unusual because it requires learners to interpret experimental data using empirical graphs. Additionally, Rushton et al., (2014) are of the view that graphs in chemical kinetics are conceptually difficult for high school and university students to comprehend and interpret. It is because the concepts involve complex mathematics as well as qualitative explanations. Furthermore, the rate and extent of reaction topic require one to comprehend abstract and complex concepts of other chemistry-related topics, such as the particle nature of matter, the kinetic theory of gases, and statistical notions of chemical reactions.

The researcher as a Physical Sciences subject advisor of King Cetshwayo District of Education arranges different programmes such as winter classes, spring classes, boot camps, direct visits of subject advisors to learners and exclusive high flyer programmes that are aimed at assisting grade 12 learners to improve in Physical Sciences. Despite, the various programmes aimed specifically to improve the performance of the learners on the topic, the results have not drastically improved. For the past two decades, research in chemical education has reported that most students across the disciplines mathematics, physics, chemistry and biology have challenges that were categorised into four main groups namely: (i) interpreting graphs to understand change over time (Seethaler et al., 2017), (ii) interpreting the signs in a rate of change (Ivanjek et al., 2016), (iii) distinguishing types of rate of change (Tuminaro & Redish, 2004) and (iv) conceptual meaning behind derivatives and integrals (Planinic *et al.*, 2013). Research on graph interpretation has previously focused primarily on visual characteristics of data, such as graph format, and how such characteristics affect retrieval speed and accuracy of simple facts from graphs (Rowland *et al.*, 2004; Bollen *et al.*, 2016; Rasmussen *et al.*, 2016). Most graph interpretation research has focused on the use of graphs as representations and few studies have been conducted on graph interpretation in science education other than in maths education (functions) (Seethaler *et al.*, 2017). There has been a paucity in research related to the graphical interpretation of rate and extend of reaction related to the South African context. In the present study, the researcher sought to investigate the grade 12 Physical Sciences learners' graphical interpretation and literacy levels on the topic of rate and extent of reaction.

1.4 AIMS AND OBJECTIVES OF THE STUDY

The aim of this study was to explore learners' graphical interpretation of the rate and extent of reaction topic. In order to realise this aim, the following objectives were set:

1. To identify challenges encountered by grade 12 Physical Sciences learners when interpreting graphs of rate and extent of reactions
2. To determine how do grade 12 Physical sciences learners interpret and describe salient features of graphs of rate and extent of reaction.
3. To determine the specific graphical literacy levels of grade 12 Physical sciences learners on rate and extent of reaction.

1.5 RESEARCH QUESTIONS

Accordingly, the following research questions were addressed:

1. What are the challenges encountered by grade 12 Physical sciences learners when interpreting graphs of rate and extent of reactions?
2. How do grade 12 Physical sciences learners interpret and describe salient features of graphs of rate and extent of reaction?
3. What are the specific graphical literacy levels of grade 12 Physical sciences learners on rate and extent of reaction?

1.6 SIGNIFICANCE OF THE STUDY

The results obtained from the present study are capable of identifying the challenges learners face when interpreting graphs. Thus, the results can contribute towards the interventions used by teachers when teaching the topic rate and extent of reaction. These interventions can take the form of tutorials as well as extra time being spent focusing on problematic areas during lesson presentations. The results of this study could also inform curriculum developers in science education about the graphical literacy levels of physical sciences learners.

1.7 METHODS OF STUDY

1.7.1 Research paradigm

The researcher employed a pragmatism research paradigm guided by a mixed method design in order to investigate the research problem. The pragmatism paradigm is not committed to any one system of philosophy or reality. It focuses on what works best and can be used in both quantitative and qualitative approaches to address the research questions. Gay and Mills (2016) suggest that combining qualitative and quantitative approaches minimises the weakness of one approach within a single study.

1.7.2 Research design

This study was conducted based on a sequential explanatory research design. An explanatory sequential design combined quantitative (survey) and qualitative data (interviews) collection methods, with a focus predominantly on the quantitative approach (Macmillan & Schumacher, 2010). Gay and Mills (2016) recommend that using interviews one can explore learners' thinking in order to illuminate learners' graph interpretation.

1.8 SCOPE OF THE FIELD OF STUDY

The study focussed on exploring the grade 12 Physical sciences learners' graphical interpretation of the topic rate and extent of reaction. This is because the topic rate and extent of reaction is mainly taught in the second term of the Grade 12 Physical Science curriculum. The study involved one hundred and forty-six (n = 146) learners drawn from the King Cetshwayo District in kwaZulu-Natal province.

1.9 DEFINITIONS OF OPERATIONAL TERMS

Graph interpretation refers to a graph reader's ability to obtain meaning from graphs created by others or by themselves. Graph interpretation is a fundamental skill needed by all learners in their everyday lives to effectively interpret and communicate information found in graphs, which are pervasive in society (e.g. magazines, newspapers, television, and websites) (Glazer, 2011)

Graphical literacy is the ability to construct, produce, present, read and interpret charts, maps, graphs, and other visual presentations and graphical inscriptions (Glazer, 2011), in this study graphical literacy refers to the ability to interpret (decode), predict and infer from a selection of graphical representations as presented in the rate and extent of reaction topic.

Levels of Graphical literacy

Elementary level

During this level, students are required to extract a single piece of information that appears on one spot on the graph. This level consists of translating a graph to words, such as explaining the contents of a table or interpreting the graph at a descriptive level and explaining its structure. In other words, the elementary level entails reading the graph. It also involves extracting information from the display of data, recognizing graphical conventions, and relating context with data (Aoyama and Stephens, 2003).

Intermediate level: require students to analyse patterns among groups of graphing elements, to draw information from several sources, and to consolidate information into a more general statement.

Overall level: graph questions requiring students to draw conclusions based on their background knowledge and experiences.

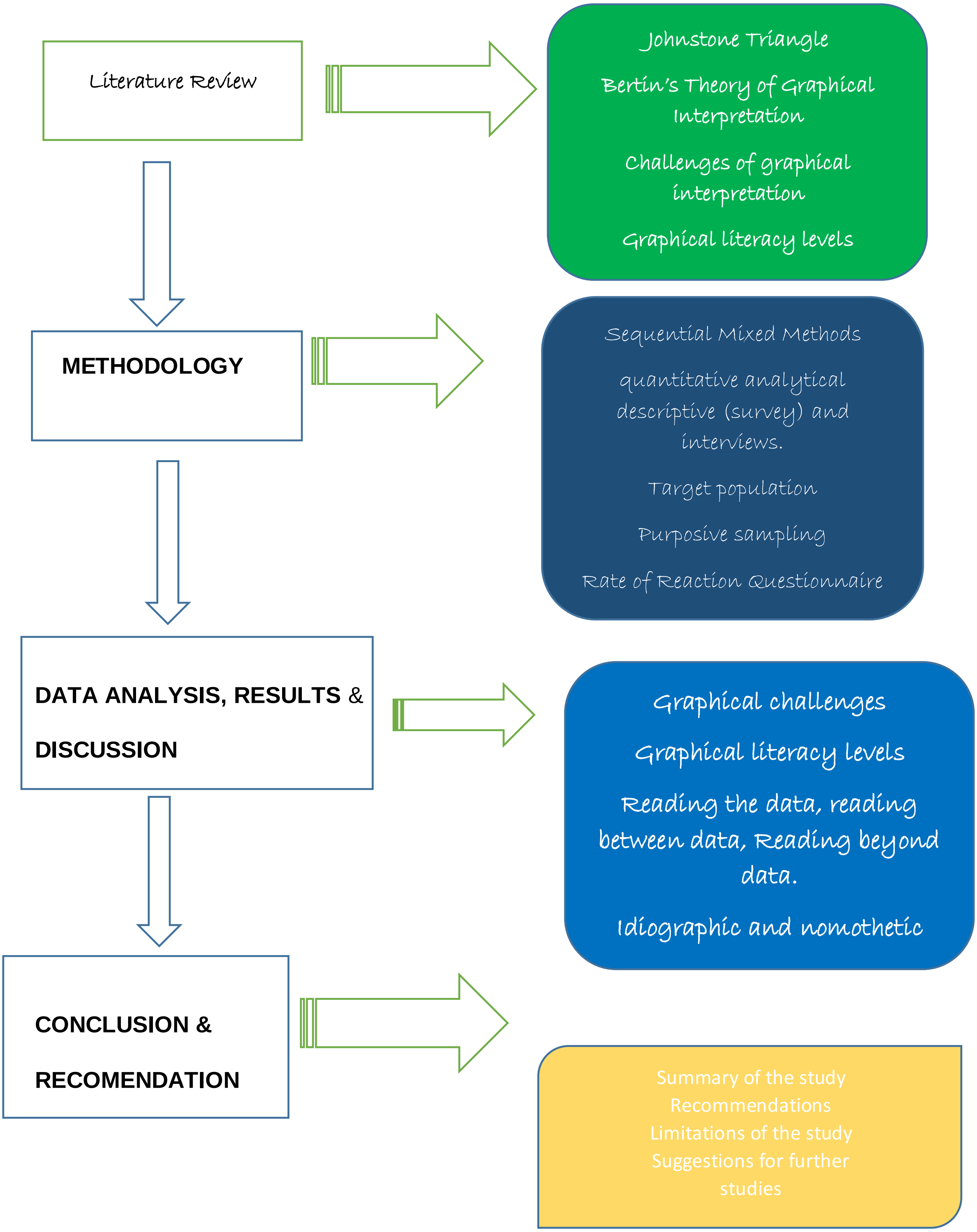
Surface features

they are an external representation widely used in physical sciences to explain how the rate of reaction change with time. Rate of reaction graphs surface features present both quantitative and qualitative information. The quantitative information can be used to calculate the instantaneous and average rate. While the qualitative may be primarily for the reaction mechanism and how the rate progress with time. The explicit features are described by Weinrich and Talanquer (2015) representing "the surface features of the representation" The graph includes the curve itself, the points along the curve, and the different points of the curve (starting point, peak, valley, ending point), peak height, and slope as well as axes with their corresponding labels.

Rate of a reaction, “measures how fast a reactant is consumed or how fast a product is formed. The rate is expressed as a ratio of the change in concentration of products or reactants to elapsed time” (Chang, 2006, p.558). The term ‘rate’ describes the change of a quantity per unit time. A chemical reaction rate can be defined as a change in a reaction parameter per unit time. The following are possible reaction parameters: concentration, mass, pressure, and intensity.

1.10 OUTLINE OF THE PLAN OF STUDY

The outline of this study from Chapter 2 to the end can be envisaged as follows:



CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the theories that form part of the theoretical framework of this study, as well as literature pertaining to the graphical interpretation of rates and extent of reaction. This study seeks to investigate the graphical interpretation and literacy levels of grade 12 Physical Science students. Theories of Bertin's graphical interpretation and the Johnstone triangle form part of the theoretical framework of this study. These theories acknowledge that interpretation of graphs has levels and requires one to translate among three domains of representation. This chapter also reviews the relevant literature in the field of challenges and graphical literacy about the rate and extent of reaction. This chapter is divided into two broad sections, namely the theoretical framework of the study and the scope of the literature review.

2.2 THE THEORETICAL PERSPECTIVES THAT FRAME THE EMPIRICAL STUDY

Different philosophies underpin various research studies. These philosophies are regarded as theoretical frameworks; they are the parameters upon which this study is discussed. In this study, the researcher briefly explains the key elements of the theories that underpin this study and also provides a rationale for adopting the theories in relation to graphical interpretation. Since graph interpretations are formed during formal and informal learning experiences, this study adopted Bertin's Theory of Graph Interpretation and Johnstone's triangle.

2.2.1 Bertin's Theory of Graph Interpretation

Bertin (1983) divided the stages of the graph reading process into three successive operations namely; external identification, internal identification and perception correspondence stage. The first stage, called external identification, involves reading line graphs and identifying the axes, units, intervals, and scales. The second stage of identification, the internal identification stage, is when the reader recognises the components and visual arrangement of the graph. The third stage is called the perception of correspondence stage, at this point, the viewer begins to discern the unique features of the graph and realises that the drawing has isolated the unique information from the vast array of possible correspondences. The advent of graphical skills in the early 2000s divided graphical questions into three levels (Bertin, 2001). At the elementary level, it's where students identify a single piece of information that can be found at one location on the graph. The intermediate level requires the students to notice patterns among groups of graphing elements, to take information from multiple places, and combine the information into a more general statement. Thirdly, the overall level requires students to develop a theory explaining the graph based on their background knowledge and experiences.

Leinhardt etal., (1990) state that there are salient features that are crucial in science education those include issues of representation, multiple representations, the extent to which a visual representation (graph) is symbolic, the conventions that go with each symbolic system, and the freedom of choice (scale). In the Next Generation Science Standards (National Research Council, 2012), analysis and interpretation of data are among the eight science practices. Analysing and interpreting data often requires making sense of visual representation, such as a graph or table, and being able to draw conclusions from it. Interpretation of data is a process students engage in several ways. In order to accurately interpret the visual representation of data, it must first be decoded (Glazer, 2011; Zagallo et al., 2016). The amount and type of information that is embedded in the representation can affect the difficulty of this step. The next step involves identifying relevant patterns within the data (Shah & Hoeffner, 2002). As studies have shown, this step can be difficult for many students (Jeong et al., 2007; Lai et al., 2016). It may be difficult to distinguish between important and unimportant features when using data. When learners are expected to conclude or explain the target phenomenon based on the data and patterns that are less relevant, it becomes problematic. Students may miss important information if the claims and explanations constructed from less relevant data do not effectively target the phenomenon that was studied (Zagallo et al., 2016).

In Mathematics education involving functions and graphs Bleich (2006) suggested tasks that consist of four parts. The tasks were analysed using action, situation, variable and focus. The action involves the interpretation and construction of graphs. Monk (2003) posits that the two are not mutually exclusive. The two are analysed using two dimensions, i.e "local-to-global" dimension, and a "quantitative-to-qualitative" dimension. Glazer (2011) defines interpretation as the act of making sense of (or gaining meaning from) a graph (or part of a graph), a functional equation, or a situation. Global features of the graph that can be interpreted include the general shape and intervals of increasing and decreasing. Gagatsis and Shiakalli (2004) note that global features are the most valuable for full comprehension of situations represented by graphs in both advanced mathematics and science education. A local interpretation (e.g., one that considers point-by-point attention) or global interpretation (e.g., trend recognition) can be made depending on the questions asked.

Bragdon et al., (2019) point out that when interpreting a graph, the students depends in part on what the graph represents. Most of the graphs used in science education represent situations and abstract functional relations of ordered pairs. Thus, interpreting a graph depends on the meaning of the symbolic space of the graph or the shift to the situation space. The interpretation that shifts between spaces is called translation (Bragdon, 2014).

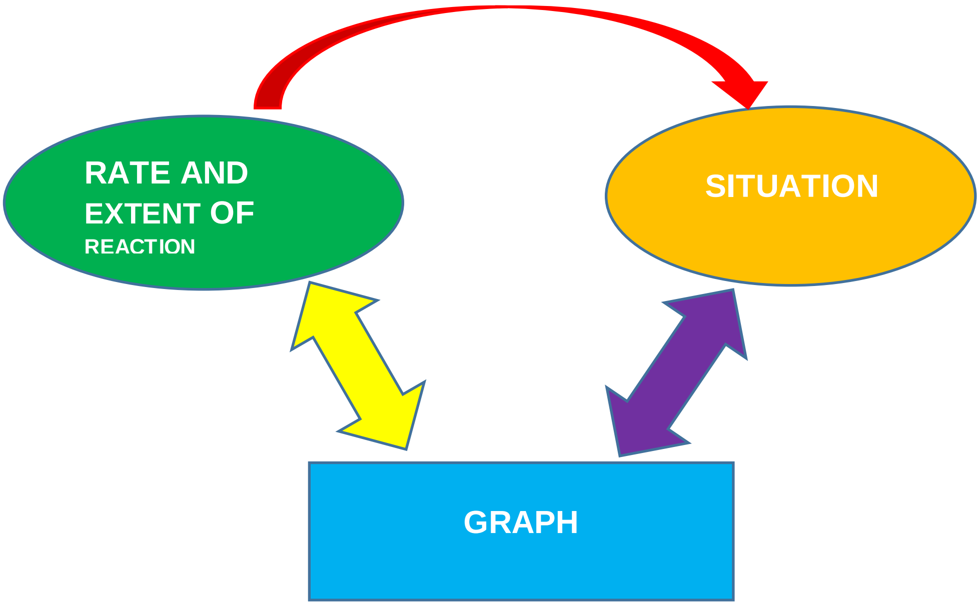


Fig 2.1 Movement among spaces that occur in an interpretation

In order to find a graph's y-intercept or determine what points have negative coordinates, there is a need to look at the graph within the context of the coordinate system in which it is embedded. On the other hand, determining the slope which is the rate of the reaction involves both interpreting the graph itself and shifting (often back and forth) from the graph to the reaction. The graph may also be interpreted outside of the graph when it describes a specific situation. As a result, interpreting it involves moving from the graphical representation to the actual situation.

Becker et al., (2017) state that chemistry students just like many others in physics, biology, and STEM subjects rely on surface features and less relevant features of graphs to make conclusions and interpretations. Talanquer (2015) reports that students either use neglect or use misconstrued reasoning when engaging in data analysis and graph interpretation. Graph interpretation risks being a mnemonic exercise as Becker et al., (2017) observe that students made conclusions in an experiment without taking note of the kinetic data given them. They bemoan the lack of analysis and interpretation by students since the Next Generation Science Standards encourages the presentation of data as evidence in data interpretation and analysis (National Research Council, 2012).

Graphical literacy is a term that refers to the ability to construct, produce, present, read and interpret charts, maps, graphs, and other visual presentations and graphical inscriptions (Readence et al., 2004). Graphic literacy views the graph as a visual language or skill that enhances learning. Clark and Meyer (2002) believe that adding texts to graphs improves learning, retention, and retrieval. Graphs are a vital communicative tool that spans mathematics and science education (Khalaf Al-Naqbi, 2004). Several researchers (Glazer, 2011; Zagallo et al.,2016; Jeong et al., 2007) agree that students must be able to construct, interpret, predict and infer from graphical representations.

To solve problems in rate and extend of reaction and in life, in general, requires distinctive skills (what). Using Bertin's theory of graphical interpretation helps to identify where skills deficiency lies when learning the rate of reaction concepts. The theory demonstrates that instead of characterising the problems students face when interpreting graphs, they must be classified. One distinct utility of Bertin's theory of graphical interpretation is its ability to explain the problems students have when interpreting graphs at each stage. In this study, identification of interpreting difficulties and the possible solutions constitute the focus of this study.

2.2.2 Johnstone Triangle

The idea that chemistry knowledge can be understood on three fundamental 'levels' or 'representations' as suggested by Alex Johnstone:(Figure, 2.2) the macroscopic, the symbolic, and the sub-microscopic. The macroscopic level includes all that people can see, smell and feel with their sensory organs. The seen level includes practical investigations and observations. The sub-microscopic levels are the atoms, molecules and ions that are dynamic in rate and extent of reaction. It is also unseen and consists of explanatory models. Representational level includes symbols, equations, mathematical formulae, graphs and diagrams. In the present study, the representation level consists of the rate and extent of reaction graphs. Although science occurs on a visible level, its explanations are often abstract or not visible. Johnstone (2008) states that an expert chemist can operate at all three levels with ease. He postulates that experts in chemistry view any subject topic at three levels, and “jump freely from level to level in a series of mental gymnastics”. However, students struggle to operate at all three levels simultaneously, as a result, they end up making some misinterpretations. Nevertheless, students often find the interplay of the levels difficult both to understand and to use. A lack of macroscopically experience is one problem that arises from such interplay (Ainsworth, 2008).

The ability to move from one level of the triangle to another is known as translational skill, which is a necessary skill for understanding the true meaning of the concepts taught and learned (Gilbert, 2008). The extent of translation across the three levels was investigated in two related studies as an important skill. Students' understanding of macroscopic, symbolic, and particulate redox reactions was investigated by Brandiet (2014). The findings showed that students seemed to have a better understanding of the macroscopic-symbolic levels than the macroscopic-sub-microscopic or the symbolic-sub-microscopic levels. In a similar study, Li and Arshad (2014) investigated the extent of how teachers translated among the three levels when teaching redox reactions. They found that most of their participating teachers emphasized the macroscopic level, followed by the symbolic and the least in the sub-microscopic level. It is important that students need to grasp the topic at all three levels in order to gain a deeper understanding of it.

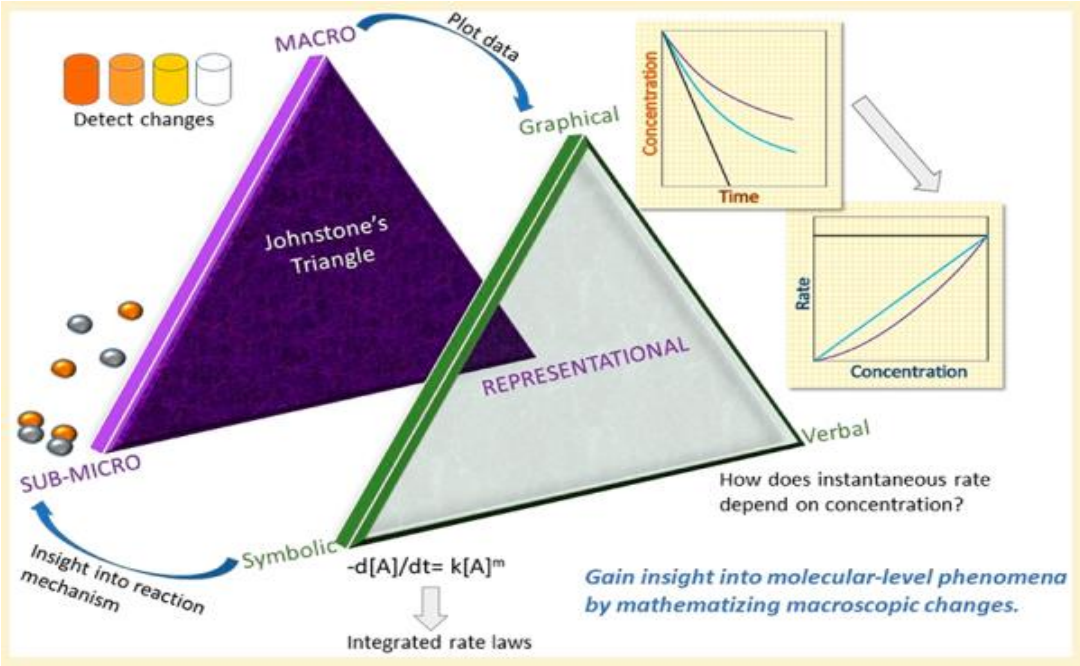


Figure 2. 2: Johnstone triangle adapted from Seethaler et al., (2017)

The utility of Johnstone's triangle framework is not restricted to chemistry alone. Wright et al, (2016) used the framework to study how students interpreted catalysis graphs. According to Adams (2012), Johnstone's triangle theory outlines the way to describe various components found in chemistry's three levels. The use of these three levels as models of illustration assists students' learning, makes interpretation of ideas less complicated and assembles a deeper appreciation of chemical kinetics (Ainsworth, 2008). However, (Treagust & Chandrasegaran, 2009) admit that students regularly find the interaction of the triangle level difficult to both understand and use.

However, Taber (2013) asserts that the symbolic or representational level is the language for communicating and representing chemical concepts. It should not be treated as a discrete 'level' of chemical knowledge that is one element of an ontological triad of macroscopic-sub-microscopic-symbolic. Taber (2013) views two levels (Figure, 2.3) the macroscopic and sub-microscopic, to be of vital importance when learning chemistry and representation or symbolic level facilitates the shift. Thus, representation such as graphs are treated as facilitators that enable students to shift between the macro and sub-microscopic levels. However, the present study views the symbolic or representation as critical in interpreting graphs. Graphical representation is fundamental in interpreting chemical phenomena.

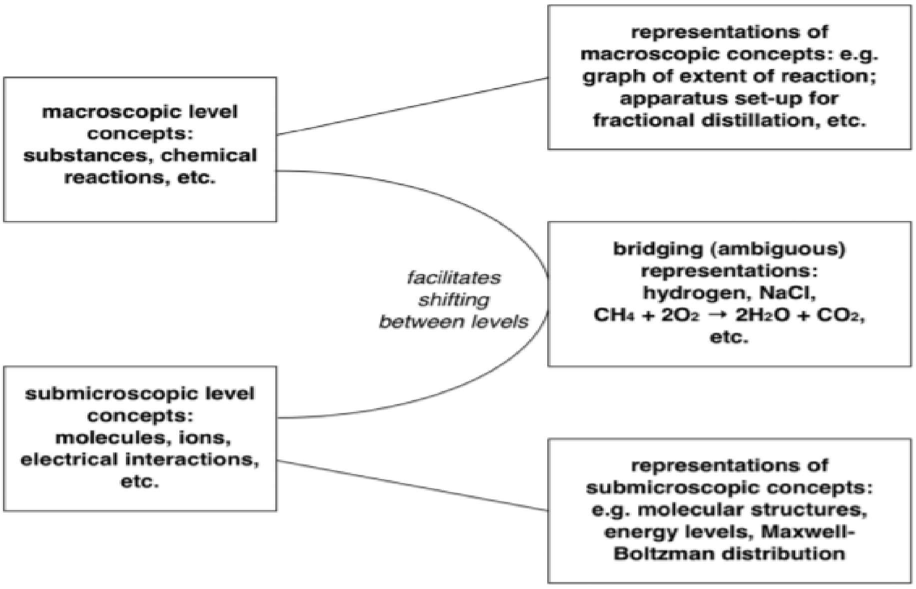


Figure 2. 3: The symbolic domain as providing resources for representation and communication of chemical concepts, and in particular for supporting the development of explanations relating the two conceptual levels.

Taber (2012) argues that the macroscopic apex of Johnstone's triangle also brings challenges. Though chemistry is an important science for understanding and developing materials, introductory chemistry makes little use of the materials that learners are already familiar with. Chemistry is primarily about substances, and substances are already a major abstraction from real-life experience (Taber, 2012). Thus the macroscopic has an element of abstraction which is found in the sub-microscopic domain/ level. While studying introductory physics, students are instructed to simplify and abstract concepts such as frictionless bearings, perfectly rigid supports, negligible air resistance, etc.

Likewise, in chemistry lessons the real world of materials is simplified by using pure substances. These are themselves quite abstract notions, that students are asked to relate to the phenomena of the subject – their observations of different substances (many with unfamiliar names) and their reactions. Thus, Taber (2012) suggest that there is high conceptual demand even at the 'macroscopic' corner of the triangle. In analysing the domains of chemical knowledge offered above, symbolic knowledge can't easily be separated from both macroscopic and sub-microscopic knowledge, since it depicts and communicates the concepts and models developed at these two levels.

Seethaler et al., (2017) isolate the representational or symbolic level (Figure, 2.4) and use colour codes to identify levels of graph interpretation difficulty. The representational level can be described as a "triangle within a triangle", involving the navigation of graphical, verbal, and spatial components. Thus, the symbolic level is used as an entity on its own when describing students' difficulties in chemical kinetics. The representational triangle has three sides, namely words, graphs and words. Colour codes are used to represent the difficulty faced by the students e.g. (graphical representations (yellow), a sign of the rate of change (blue), the distinction between average and instantaneous rates of change (lavender). In this study, the whole Johnstone triangle was used though the emphasis was placed on the symbolic/ representational level.

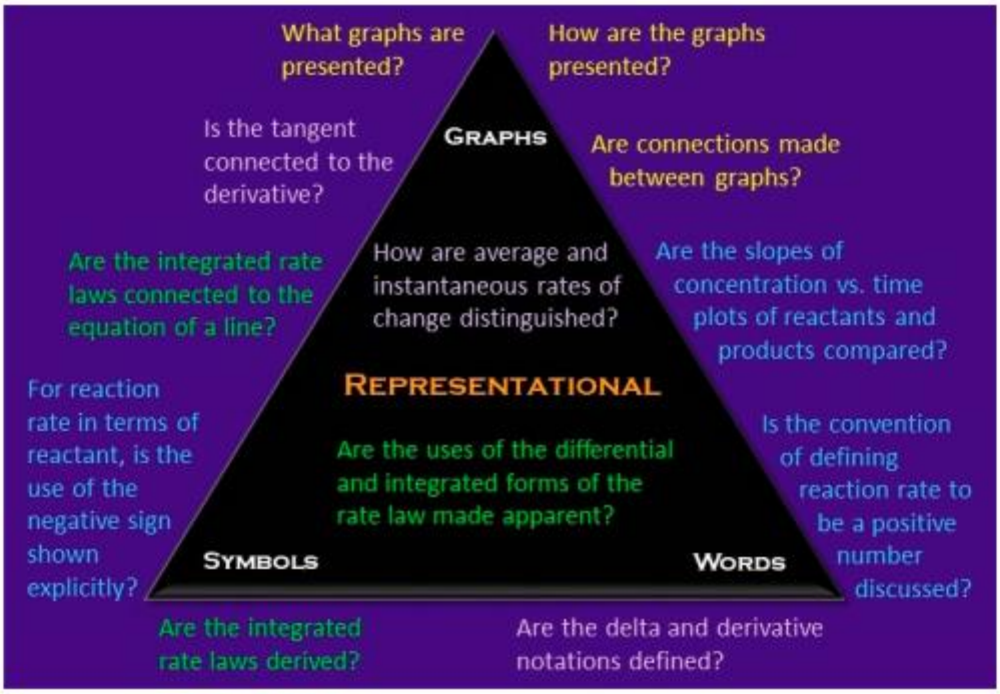


Figure 2. 4: Supporting students to navigate the representational level of Johnstone's triangle. Colour indicates the category of student difficulty

For the purposes of this study, an effective framework should then be one that is consistently applied in analysing students' graphical interpretation difficulties in rate and extent of reaction. The Johnston's triangle is preferred as a guiding tool for the development of the framework and analysis of the student graphical interpretation in general. Numerous research (Taber, 2009; Tuminaro and Redish, 2004; Gultepe, 2016; Horsewell, 2017) in chemistry, physics, and mathematics education have used the Johnstone triangle as a theoretical lens to identify students' difficulties when learning sciences. In chemistry education, Johnstone's triangle has sparked further discussions and research, particularly regarding its interpretation and application. It nevertheless highlights how scientific knowledge can be understood at more than one level or representation, helping students make explicit links between them.

One of the most widely adopted and applied ideas in chemistry education is Johnstone's triangle (1991). It was unquestionably due to Johnstone's accurate and important argument: Chemists have to deal with three distinct levels of formal concepts which need to be related to one another and to phenomena observed and there are many ways to represent it symbolically, not only through specialised technical vocabulary. Chemistry is intrinsically symbolic, and the processes of learning, teaching, and applying chemistry frequently involve re-descriptions both within and across components of the specialised 'language' used to describe chemical ideas at threeChemistry is intrinsically symbolic, and the processes of learning, teaching, and applying chemistry frequently involve re-descriptions both within and across components of the specialised 'language' used to describe chemical ideas at two levels of description. levels of description.

2.2.3 Conceptual Framework

A suitable conceptual framework was designed through integrating the Johnstone triangle and the Bertin's theory of graphical interpretation. The Johnstone triangle guides the arrangement of the questions under rate and extent of reaction and Bertin's Theory was used for interpretation of graphs.

Rate and extent of reaction

The chemistry topic on rate and extent of reaction is done in term 2 in grade 12 Physical Sciences (CAPS). It consists of three topics namely: rates of reaction, measuring rates of the reaction, and mechanism of reaction and of catalysis. The three sub-topics lay the fundamental base of the conceptual framework (Figure 2.5). The Johnstone triangle and the symbolic level were used to analyse students' difficulties in interpreting graphs. Shifting levels among the three domains enabled the identification of challenges in interpreting graphs. Lastly, Bertin's theory was used to analyse the translation shifts that students encounter when interpreting graphs.

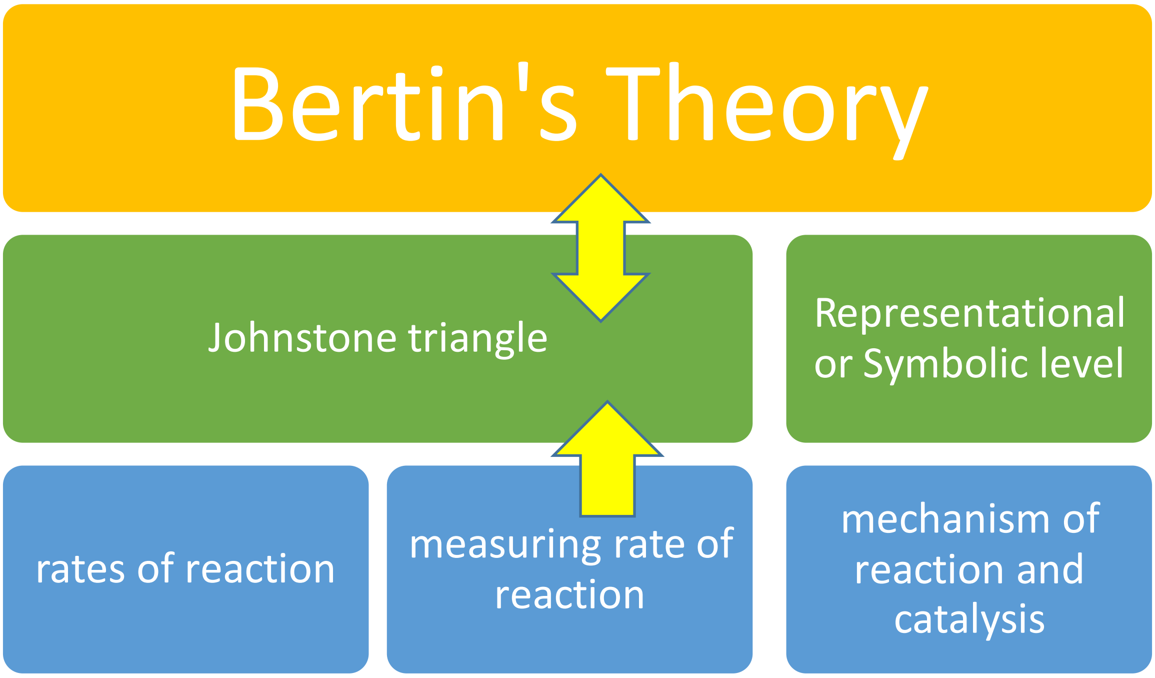


Figure 2. 5: Conceptual Framework

It is envisaged that applying the whole framework to the study should reveal the knowledge domains that emerge when interpreting graphs in rates and extent of reaction.

2.3 Challenges/ difficulties when interpreting graphs of rate and extent of reactions

As part of the learning process in chemistry, students are required to describe reaction rate concept and create a model of its relationship using descriptive concepts, particulates, and mathematics to further enhance their understanding (Cakmaci *etal*., 2003). The concepts of rate and extend of reaction are abstract, complex and cannot be explained by the lecture method. Graphs are visual aids used to summarize data and represent relationships between variables. Chemical kinetics data is easy to read and understand when presented in graphical form than presented in a prose. The ability to read and interpret graphs requires mathematical thinking, so graphs are often considered as a mathematical tool. In addition to mathematics, graphs are used in various fields of science like statistics and social sciences. The purpose of graphs in science education is to increase students' understanding of scientific concepts, develop conceptual frameworks, and summarize content. In addition, graphs can enhance students' science process skills, such as explaining the relationship between various data and drawing conclusions from them (Kali,2005).

A graphical representation of reaction rate shows expressions of reaction rate, order reactions, factors influencing reaction rate, and molecular kinetic energy distributions. In order to understand and appreciate the concept of reaction rate correctly, students must be able to read and interpret graphs (Secken and Zan, 2019). Graphs are extremely important in all fields of science, and they are essential for curricula for universities, secondary schools, and even primary schools around the world. It is through different subjects that students are introduced to graphs, but in high school, it is mainly through mathematics and physical sciences. Since most students are introduced to graphs quite early, high school educators usually assume that students have mastered the skill of interpreting them. Several studies in science education have reported on students' difficulties in understanding and interpreting graphs in different contexts (Planinic et al., 2013; McDermott et al. 1987; Glazer, 2011). The activity of graph interpretation might be developed and viewed in two contexts, which are inquiry and reading (Gal, 2002).

Inquiry contexts involve the engagement of researchers with actual data where they make inferences and report on findings and conclusions. On the other hand, reading contexts of graphs emerge in everyday situations where individuals see and interpret graphs, thereby contributing to general scientific literacy. Despite many types of graphs, all branches of science at all levels need to be able to create clear, understandable visualisations of data as well as read and interpret graphs. A graph reader's ability to interpret graphs, whether created by others or themselves, is called graph interpretation. In today's world, students need to interpret graphs constantly in order to make sense of the information presented in them. This skill is fundamental in making sense of the information presented in graphs, which is all around us (Glazer, 2011). Graph interpretation can be divided into three major levels namely; the elementary comprehension level, intermediate level, and advanced comprehension level (Curcio, & Bright, 2001). In the elementary level**,** students extract information from a single location on the graph. While in the Intermediate level, students are encouraged to notice patterns among groups of graph elements, gleaning information from multiple sources and synthesising it into a broader statement. Lastly, in the

Advanced level, students are required to use their background knowledge and experiences to develop a theory about the graph.

Several studies in science education have reported that students struggle with reading graphs, making sense, and interpreting them (Trafton & Trickett, 2001; Glazer, 2011; Lira, & Desutter, 2016). The challenges were grouped into four categories by Shah et al., (2005) the slope or gradient, interval, and points, graph as a picture and graph as discrete points. The gradient has an important role in understanding the rate of a reaction. The progression of the rate of the reaction is closely related to the steepness of the gradient in a chemical reaction. Leinhardt et al., (1990) reported one of the students' challenges when interpreting the line graph which involves students confusing the height of the graph with the gradient. Furthermore, students incorrectly interpret line graphs as pictures. More often, students do not face challenges when defining the rate of reaction but they have challenges realising the gradient of the (concentration versus time) graph as the rate. This challenge spans across physics, mathematics, biology and chemistry (Lemke, 2005).

Studies by Doerr and Arleback (2013) have revealed that students encounter challenges when interpreting negative rate of reaction. The negative sign shows the rate slowing down and it is important to comprehend the two-way directions of the rate of reaction. Bain and Towns (2016) report that students have challenges in distinguishing between average and instantaneous rates. They also have challenges with how the rate of reaction progress over time and confuse the constant and the variables of the rate of change. Integrating process skills of graphing and chemical events at the sub-micro level is also difficult when students try to generalise the change of rate over time. When they encounter all these difficulties relating to the interpretation of the graphs, they rely on the domain context and the question problem format.

Bollen et al., (2016) view the three-way representation rates in words, graphically and symbols as a challenge to students. The average and instantaneous rates can be described in words. Graphically it is the slope or gradient and in symbols ($\Delta C/\Delta t$). Students struggle with matching text representation with graphs. Bain and Towns (2016) also agree that students have challenges in translating between different graphs. They expect the shape of the graph to remain the same even after exchanging the axes. Knowing how the shape of the graph changes when the variables are changed is crucial in graph interpretation. Bektasli and Cakmakci (2011) working with Greek high school students found that they often confuse the words amount and rate of change of amount especially the rate of consumption of reactants with the number or amount of reactants. In science education, recent reviews across disciplines in both high school and tertiary level has shown four major areas that need attention on the rate of reactions drawing and interpreting rate of reaction graphs (Potiger et al.,2008; Planinic et al., 2013; Wemyss, & van Kampen, 2013)

- interpreting the sign of the rate of reaction,
- Identifying the average and instantaneous rates of change
- Interpreting rate using derivatives and integrals

The area under the graph is another challenge students' encounter in the rate of the reactions and mechanism of rate of reaction. Ivanjek et al., (2017) argue that students can calculate the area under the graph but often struggle to interpret the area as a quantity of interest. As compared to subjects such as Physics, Chemistry and Biology students struggle less with the interpretation of area in Mathematics. Students may have difficulty interpreting areas under graphs in situations other than those they have encountered previously.

Zagallo et al., (2016) contend that the challenges students encounter can be explained using the processes students engage in to interpret graphs. When interpreting a graph, students must decode the visual data which involves extracting embedded data. The difficulty of this step largely depends on the types of representation and the amount of information embedded. The kind of representation produces a challenge which Kanari and Millar (2004) describe as a graph as a picture. Visual features of a graph may be incorrectly interpreted especially in rate versus time and rate versus concentration graphs. Another challenge that is shared between Chemistry and Biology is found in catalysis. Previous work by Cakmakci, (2010); Harle and Towns, (2013) focuses on students' graphical interpretation involving catalysts, revealing that the interpretations were based on definitions related to increasing the speed of a reaction and lowering the activation energy. The students struggled to integrate the mechanism, physical interaction and the shape of the graph. Students face a plethora of challenges in catalysis as reported on the effect of catalyst on rate, mechanism, and conceptual challenges in interpreting graphical representations (Çakmakçı, 2009; Taştan et al., 2010)

2.4 Interpretation of salient features of graphs of rate and extent of reaction

Surface features are an external representation widely used in Physical Sciences classrooms to explain the rate changes that occur throughout reaction. The rate of reaction graphs can be quite complex, as both kinetic and thermodynamic information is represented by their surface features. The graphs also include quantitative information that can be used to calculate the different types of rate of reactions. Thus, in physical science, the axes of rate of reaction graphs often display units and the diagram's surface features.

Prins (2010) refers to the salient explicit features as the surface features, for which a rate of reaction graph includes the curve, the gradient along the curve, the starting point, and the end point. The deep structure level refers to the meaning encoded in the surface features, as described by Seufert and Brunken (2004). Understanding the rate of reaction graphs associated with chemical reactions has been identified as an anchoring concept for learning chemistry (Meek et al., 2016). The rate of reaction graphs are widely used as a tool to represent the progression of the rate and they have the potential to assist students in comprehending rate changes that occur throughout a reaction (Raker et al., 2013).

There is a dearth of research when it comes to the investigation of students' graph interpretation of salient surface features of the rate of reactions. According to Kaya and Geban, (2012) students hold a variety of alternative conceptions, such as the perception that temperature increases activation energy when it comes to the understanding of mechanisms of reaction. In recent reviews, further research has been suggested regarding students' understanding of external representations of kinetics and reaction mechanisms to investigate possible sources of students' difficulties with respect to these concepts (Kolomuç & Tekin, 2011; Bain & Towns, 2016).

Several challenges students face while drawing and interpreting graphs are listed in Lapp and Cyrus's (2000) study, they include: (a) prior knowledge of the graph's content, (b) difficulty contextually understanding concepts, (c) poor understanding of how graphs work or insufficient skills at putting that knowledge into practice, and (d) difficulties defining variables and connecting graphs to variables. Popova and Bretz (2018) maintains that chemistry students struggle with understanding the energetics of chemical reactions. Thirty-six students participated in a qualitative study and data was collected using semi-structured interviews. The study investigated how students extract and integrate encoded information in reaction coordinate graphs. Findings revealed that students had difficulties explaining the salient surface features such as peaks, valleys, peak height, and peak width. In the present study, salient surface features of the rate of reaction were explored. In a study to examine high school and university student conceptions about chemical kinetics including graphs

Cakmakci (2005) collected data using questionnaires and semi-structured interviews. The findings revealed that most high school students face challenges in defining the rate. The students conflated the rate of reaction and extent of reaction. Students were unable to interpret the graphs related to factors that affected reaction rates. Additionally, they were unaware of the fact that reaction rates must be measured experimentally. Interviews revealed that high school students confused intermediate with a catalyst and activated complex. Both high school and university students had challenges with the surface features of the graph product versus time.

Popova and Bretz (2018) view the interpretation of surface features as a cognitive challenge. Interpreting features of representations can be challenging since the explicit features often represent chemical species and processes that are implicit and beyond our direct perception. In developing representational competence, it is important to be able to connect the visible surface features of the representations with the abstract chemical concepts that they encode (Seufert & Brunken, 2004).

The present study explores how high school Physical Science students interpret and describe surface features of the rate of reaction graphs. Kozma and Russell (2005) define representational competence as the ability to communicate effectively about chemical phenomena using external representations which are surface features in the rate of the reaction graphs. In chemistry, external representations provide simplified depictions of complex, abstract, sub-microscopic chemical phenomena. Further research into how students understand external representations of kinetics and reaction mechanisms so as to investigate the possible causes of students' difficulties with these concepts is recommended (Bain & Towns, 2016; Kaya & Geban, 2012).

2.5 Students graphical literacy levels on rate and extent of reaction

Readence, et al., (2004 p.4) defined graphical literacy “as to the ability to construct, produce, present, read and interpret charts, maps, graphs, and other visual presentations and graphical inscriptions”. Graphical literacy is an important aspect of science education since it is a visual language and abstract language that enhance learning (Taylor, 2010). Studies on retention of knowledge (Clark & Mayer, 2002; Paivio, 1991) suggests that adding texts to graphs improves learning. When information is encoded both verbally and visually, it is easier to retain and retrieve, according to dual-coding theory.

Science education literature has well-documented skills for constructing and interpreting graphs as well as instructional strategies designed to help students develop graphical literacy in science. There is still a paucity of topics relating to graphical literacy in Chemical education. Graphic/visual literacy is growing in importance yet is given less attention at the high school level than the time given to reading and writing. Visual presentations of abstract concepts are often difficult for students yet are ignored in textbooks. Researchers have called for increased attention to graphic inscriptions to teach students how to interpret in the classroom (Roth, 2002).

There is overwhelming evidence (Harsh & Schmitt-Harsh, 2016; Glazer, 2011; Phage, Lemmer, & Hitge, 2017) that in science education students of all academic levels and nationalities face difficulties in developing and interpreting graphs. The topic of rate and extent of reaction entails describing the rate of reaction. Student development and interpretation of graphs which represent the rate of reaction are critical to their understanding of chemical kinetics. Graphic literacy and the ability to interpret and create graphs that represent a variety of relationships are amongst the most important skills to teach in science-related courses. A review of the literature, identifies nine major challenges that students have regarding graphical literacy within the context of graph interpretation. Additionally, research shows that challenges with graphical literacy span through the schooling system starting with primary schools (Shah &

Hoeffner, 2002; Taylor, 2010), university students (Van Tonder & De Lange, 2002; Harsh & Schmitt-Harsh, 2016).

Table 2. 1: Nine Graphical literacy challenges encountered by students

Graphical Literacy	**Students Challenges**
1. Graphs as Picture Errors	The graph is considered by the student to be a picture of the event or situation and is not seen as a mathematical representation.
2. Slope/Height Confusion	Students read axes values and assign them to the slope
3. Variable Confusion	Students are unable to relate one type of graph to another.
4. Non-origin Slope Errors	Students can determine the slope of a graph successfully but will often have trouble determining the slope of a line or tangent line if it does not go through the origin
5. Area Ignorance	Students are not able to interpret areas under the curve for graphs
6. Area/Slope/Height Confusion	Students will often perform slope calculations or use inappropriate axis values when area calculations are required.
7. Confusing an Interval with a Point	Occurs when students focus on a particular point rather than an interval
8. Conceiving a graph as constructed of discrete points:	Students interpret graph as a series of data points rather than a continuous graph.
9. Student difficulties with graph construction that result from students'	choice of graph format or visual features such as colour, size, aspect ratio, scale, and legend/labels.

Gulpte (2015) investigated high school students graphing skills and conceptual understanding when drawing graphs for chemical reaction (freezing, ionization of weak acids). The instrument was an achievement test that consisted of ten questions of which five were non- chemistry and the other five were chemistry graphs. Students with good conceptual understanding had strong graphical literacy levels. Alternative conceptions were also reported to be underlying challenges that hindered the drawing of the graphs. Thus, in this report study graphical literacy seem to be affected by conceptual knowledge in chemistry. Students' understanding and interpretation of how chemistry concepts relate to each other is directly related to how well they understand and interpret graphs (Seçken & Yörük, 2012).

Grade 8 students were investigated on graphical literacy which included single data points, trends, and extrapolations (Mang et al,.2019). The study explored graphical literacy as a generic ability for descriptive graphs. The results showed that students had high graphical literacy levels. There was also a high correlation between graph reading skills and academic achievement and motivation. However, this study is topic and discipline-specific. The whole spectrum of graphical literacy was covered based on Curcio's three levels. Graphical literacy in physical sciences was investigated by Phage (2016) on graphs on kinematics. The findings revealed that there was a poor performance by the students on finding the gradient and reading coordinates. Mathematical knowledge could be hardly transferred to the physics context. Lack of content knowledge was the deterring factor that reduced the graphical literacy scores. The study recommended that Physical Science educators need to undergo constant training on data handling and graph interpretation. In the same vein, the study by Van Tonder (2017) designed a diagnostic questionnaire to measure graphical literacy in biochemistry. The mean scores were low and were influenced by gender and ethnic differences. Data analysed using Kimura's seven levels of graphical literacy showed that very few reached the last level F.

The majority of the students exhibited challenges with slope confusion. It should be noted that interpreting and graphical literacy of graphs does not rely on the characteristics of a graph or design elements but on the content knowledge and objectives of the reader (Shah et al., 2005). The visual characteristics of graphs such as colour and the dimensions of the graph also influence the interpretation of graphs. Lachmayer et al., (2007) view prior knowledge as playing the role of how the graph is decoded (graphical literacy) and on the depiction of information. Thus graphical literacy is largely influenced by prior knowledge and exposure to graphs in Science education. As a result of graphical literacy, a student can deduce meaning from graphs based on different cognitive abilities. Vekiri (2002) identifies logical reasoning, visual and spatial thinking to be the driving factors toward understanding graphical literacy. While on the other hand, Åberg-Bengtsson and Ottosson (2006) different factors that are crucial in graphical literacy such as mathematics knowledge and content knowledge.

2.6 SUMMARY AND CONCLUSION

This chapter discussed the literature review which was related to the interpretation of graphs and graphic literacy in Chemistry education, generally, and in rate and extent of reaction, in particular. Bertin's theory of graphical interpretation and Johnstone's triangle constituted the theoretical framework of this study. Graphical interpretation requires a learner to translate among the three domains, which are macro, representation and sub-microscopic. The graphical literacy levels can be categorised hierarchically. The researcher further reviewed the relevant literature on challenges on graphical interpretation, surface features of the rate of reaction graphs and graphical literacy. The literature reviewed concurred that both high school and university students face similar challenges in chemical kinetics. In the next chapter the research design, research population and sample, research instrument, research methodology, and ethical considerations will be discussed.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter focuses on the research design, methodology, and procedures that are used in this study**.** The research design and methodology incorporated Mouton's (2011) ideas about how to construct a research study. Using these ideas, the research design is associated with the blueprint of the house, while the research methodology is associated with the construction process. According to Mouton (2009), the blueprint represents the researcher's beliefs about the knowledge to be constructed should start before the research design and methodology. This chapter describes the research paradigm and design, sampling, and the two-phase processes that were implemented in collecting data in order to address the research questions of the study. Measures of trustworthiness, ethical and safety issues are also presented in this chapter.

3.2 Research paradigm

A research paradigm is a ‘‘system of beliefs and practices that influence how researchers select both the questions they study and methods that they use to study them" (Morgan, 2007, p.49). In educational research, the concept paradigm is used to describe the researcher's worldview that informs the meaning or interpretation of research data (Kivunja & Kuyini, 2017). The word paradigm can be described as a philosophical way of thinking and has its etiology in Greek where it means pattern. The research problem, objectives, and questions of this study are multifaceted in nature. This study adopted the pragmatism paradigm employing a mixed-method approach. This approach is based upon the idea that theories can be contextualised and generalised by analysing their "transferability" to other situations. It is based on the fundamental belief that qualitative and quantitative methods can complement one another by highlighting the advantages and disadvantages of each type of research.
Morgan (2007) describes the complementarity of qualitative and quantitative methods as means of attaining shared meanings and joint action. Mixed-methods integration leads to "shared meaning" that promotes inter-subjectivity by disrupting the division between 'complete objectivity' and 'complete subjectivity' (Morgan, 2007).

Pragmatism is mainly concerned with what works and it "sidesteps the contentious issues of truth and reality" (Feilzer 2010, p.8), and "focuses instead on 'what works' as the truth regarding the research questions under investigation" (Tashakkori & Teddlie, 2003b, p. 713). This paradigm puts the research problem at the centre and applies all approaches to its understanding (Creswell, 2016). A pragmatic approach allowed the researcher to collect and analyse data in ways that provide insights into the research problem, without regard to any other paradigm. Thus, the methodology of this study relied on the mixed-methods research paradigm where data were collected using questionnaires and interviews.

3.3 RESEARCH DESIGN

As the logic or plan of a study, a research design reveals how the research will be conducted. The outline of an architectural design is synonymous with the outline of the research design. A research design describes how all of the major components of a research study- samples, groups, measures, treatments or programs all work together to answer the research questions (Mills & Gay, 2016). The purpose of research design is to "structure, plan, and execute" the research. This study adopted a mixed-method explanatory sequential research design which included a quantitative analytical descriptive (survey) and interviews.

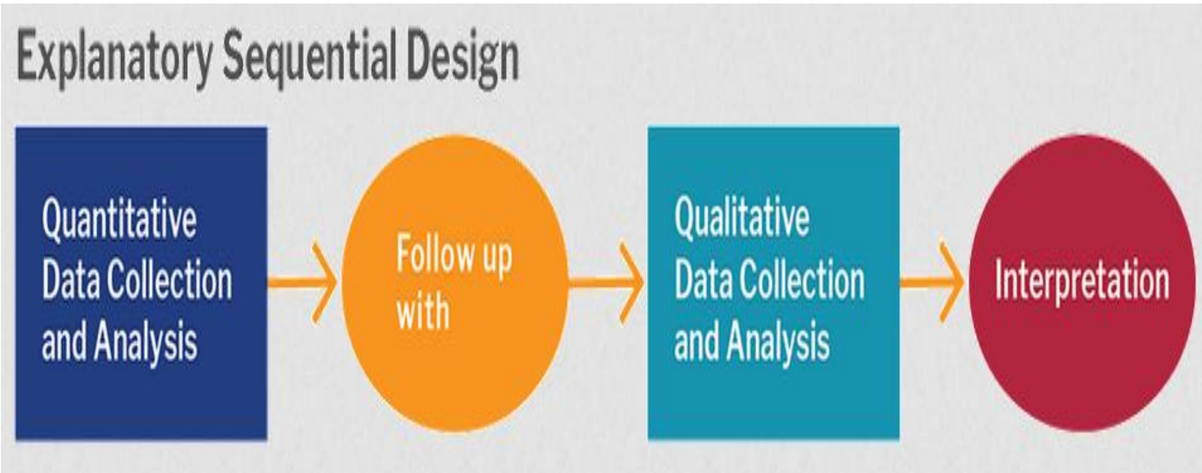


Figure 3. 1: Explanatory Sequential design

In a mixed-method sequential explanatory design, the quantitative approach is followed by the qualitative approach (Creswell, 2016). In the current study, the quantitative method was the dominant method, followed by the qualitative one.

According to Mills and Gay (2016), the design is abbreviated as Quan-qual showing the dominant with a capital letter. Creswell (2016) states that a sequential explanatory design allows quantitative results to inform the qualitative data collection process. The explanatory sequential design has the following major advantages:

- The convergence of different methods enhances the validity of research
- The different aspects of the inquiry can complement one another, it promotes complementarity

3.4 POPULATION AND RESEARCH SAMPLE

The target population of this study was all grade 12 Physical Sciences students who enrolled at the beginning of the 2021 academic year in the King Cetshwayo District, one of the 12 districts in KwaZulu-Natal province in South Africa. Therefore, the accessible population was one hundred and forty-six (n = 146) in King Cetshwayo District. Macmillan and Schumacher (2010) defined an accessible population as a sub-population of the target population that is close enough to the researcher. Target population is the group of individuals that the intervention intends to conduct research in and draw conclusion from. Three schools where the research was conducted were selected mostly for convenience purposes since the researcher had direct access to these schools as a subject advisor. The ages of the participants ranged from 16 to 20 years. To balance gender, a sample of 10 (5 males and 5 females) participants were purposively selected for semi-structured interviews. The sampling for this phase of the study was based on the students' performance in the diagnostic questionnaire test. The study was conducted for three weeks during the schools' second term of the 2021 academic year.

3.5 DATA COLLECTION

3.5.1 Instruments

A diagnostic questionnaire and interview schedule were used as instruments in this study. In diagnostic tests, researchers have access to a powerful data collection method and an impressive array for collecting numerical data rather than verbal (Mills and Gay, 2016). Diagnostic questionnaires are "instruments that are used in educational research and include a series of questions or activities that are focused in a certain field and are expected to be answered by students" Lambrianou, (2009, p.2).

The Rate and Extent of Reaction Diagnostic test (RER) were developed using the procedures outlined by Tsui and Treagust, (2010) and the Chu, Treagust, and Chandrasegarana, (2007). The procedure involved a three-staged developmental process of the (RER) namely:

- defining the content area boundaries
- literature review of alternative conceptions in rate and extent of reaction
- validation of diagnostic questionnaire followed by a pilot study.

3.5.2 Rate and Extend of reaction diagnostic test (RER)

The (RER) was developed by the researcher in order to illicit students' interpretation of graphs (Appendix E). The test consisted of 10 three-tier multiple-choice questions. The rate and extent of reaction concepts covered in the (RER) were rates of reaction, factors affecting rate, nature of reacting substances, concentration [pressure for gases], temperature, and presence of a catalyst. Three-tier multiple-choice questions were made up of content-based questions (first-tier), Interpretation/justification (second-tier), and a corresponding confidence scale (third-tier). Three-tier formats are essentially two-tier formats with a confidence scale that lets students identify their confidence level in their answers to the reason and answer tiers (Yan and Subramaniam, 2018). The development of the (RER) was further guided by Kalni (2015), who opined that students' responses in the normal multiple-choice test do not ordinarily show the interpretation of the questions. Chandrasegaran, Treagust, and Mocerino, (2007) claimed that in multiple-choice questions students tend to guess and overestimate their knowledge. Three-tier multiple-choice questions overcome the limitations of two-tier multiple-choice questions. It is difficult to tell whether a correct response reflects good understanding or is based on guesswork (Caleon & Subramaniam, 2010a).

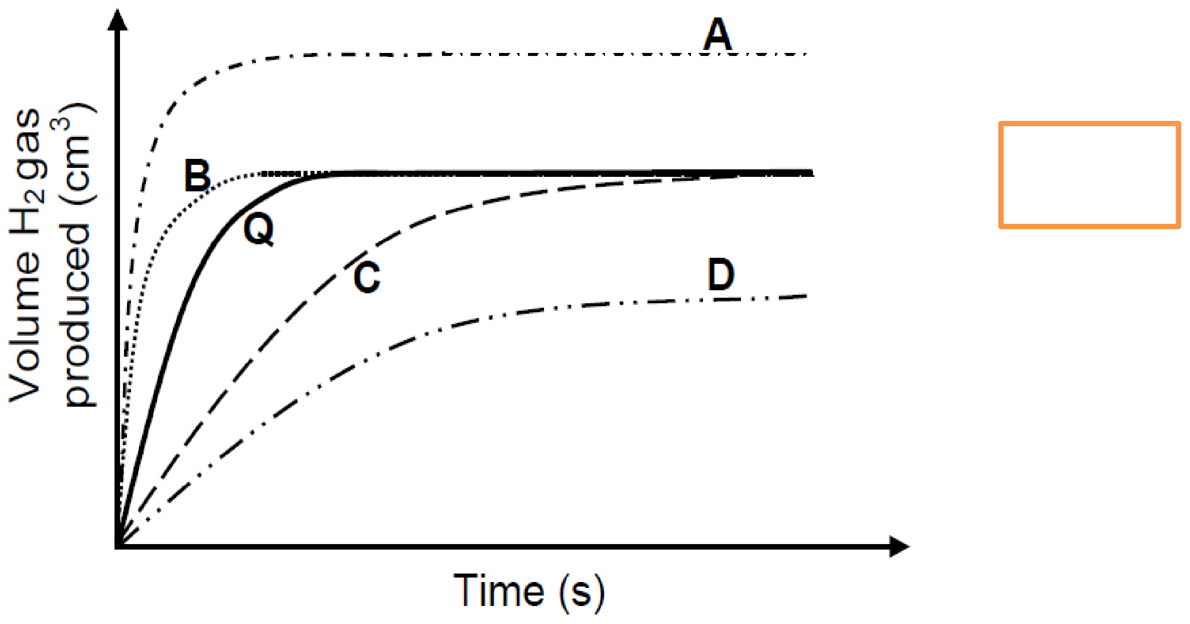
The first stage of the instrument development involved defining the content boundaries of rate and extent of reaction. South Africa's high school National Curriculum Statement (NCS) for physical sciences (rate and extent of the reaction) was used to define the content scope of the study, encompassing reaction rates, factors affecting rates, concentration and temperature. The factors which affect the rate of reaction were limited to concentration, surface area, and temperature only. Questions 1 to 4 were based on reaction rate, and measuring rate of reaction (figure 3.2), questions 5 to 7 and mechanism of reaction were 8 to10.

The question below was under measuring rate of reaction and learners were required to predict the correct shape of graph of weak acid and excess magnesium powder.

Question 2

Graph **Q** (the solid line) below was obtained for the reaction of 100 cm^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 100 cm^3 of a 0,1 $mol·dm^{-3}$ CH_3COOH solution with excess magnesium powder?



Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

Identification of alternative conceptions by reviewing literature and by reading physical sciences chief markers' reports was the second stage that was used to select distractors in the instrument. Accordingly, distractors in the multiple-choice questions were based on alternative conceptions related to graph interpretation (Bain & Towns, 2016; Glazer, 2011; Kerstiensa *et al.*, 2017; Lehrer and Schauble, (2007). Table 3.2 shows some of the distractors on the rate and extent of reaction obtained from the literature that was used in setting the diagnostic questionnaire.

Table 3. 1: Alternative conceptions rate and extent of reaction

The rate of the reaction must be defined in a manner that is not dependent on which reactant or product is used to measure it. *The reaction rate should incorporate reaction stoichiometry when it is defined.*	
Inability to define rate of reaction (e.g. defining reaction rate as reaction time)	Çakmakci et al., 2006; Bektaşli & Çakmakci, 2011
Rate is generally defined as the change in concentration of a reactant or product as a function of time. *Chemical reactions may occur at a wide range of rates, and a key aspect of rate is related to the concentration of species involved in the reaction.*	
Inability to define rate of reaction (e.g. defining reaction rate as reaction time)	Çakmakci et al., 2006; Bektaşli & Çakmakci, 2011
Reaction rate is the time required for reactants to form products (or simply reaction rate is reaction time)	Akkuş et al., 2003; Çakmakci, 2010; Çalik et al., 2010; Taştan-Kırık & Boz, 2010; Kolomuç & Tekin, 2011; Yalçınkaya et al., 2012
Reaction rate is the amount of substance turning into products per unit time at a constant temperature and concentration	Bektaşli & Çakmakci, 2011; Taştan-Kırık & Boz, 2012; Yalçınkaya et al., 2012
The reaction rate is the collision of A and B in a given time	Kolomuç & Tekin, 2011
Increasing the concentration of reactants increases the reaction time	Kurt & Ayas, 2012
The rate of reaction is/isn't affected by the concentration of reactant that take part in the reaction	Kolomuç & Tekin, 2011
Reaction rate depends on both the concentrations of reactants and the products	Yalçınkaya et al., 2012

3.5.3 Reliability and validity of RER

Reliability and validity measure the quality of the research instruments. Reliability is concerned with the degree of consistency, stability and repeatability of the attributes to be measured (Gay & Mills, 2016). The validity of a diagnostic questionnaire can be described as the extent to which the instrument measures what it is supposed to measure (Schumacher & McMillian, 2010). In this study, the content validity was viewed as a degree to which the content (rate and extent of reaction) of the diagnostic questionnaire covers the extent and depth of the topic. In order to check the content validity, RER was examined by four FET Physical Sciences teachers. The first stage of content validity was established by presenting the test and its content, concepts, and skills as outlined by the Physical Sciences CAPS document to teachers to ensure that the content of the test falls within the scope. A content validity checklist guided by Yamada (2010) was given to the four educators. The checklist required the four educators to check the following:

- The questions test students' interpretation of the rate and extent of reaction.
- Confusing and ambiguous test items are eliminated to ensure that the questions would not be misinterpreted.
- The vocabulary is at the correct level of difficulty for the learners.
- Ensuring that each question has only one unequivocal intended response in each tier.

The responses from the four educators were taken into consideration and the test items were adjusted accordingly. The feedback from the reviewers indicated that the diagnostic questionnaire could effectively assess the students' interpretation of graphs of rates and extent of reaction.

3.5.4 Reliability of the RER

The reliability of the instrument is ensured when it consistently yields the same results when the characteristics being measured remain the same. A three-time diagnostic questionnaire was conducted to ensure reliability in form of repeated measurements. The refinements from the four teachers enhanced the clarity of questions and assured test-retest reliability. The teachers marked the scripts of the test using the same rubric and when they obtained the same scores an interrater reliability measurement of the agreement was calculated using Cohen's kappa coefficient. Lastly, Cronbach's alpha reliability of the pilot test was found to be 0.76 which is acceptable for group measurements (Chandrasegaran, Treagust & Mocerino, 2007; Tsui & Treagust, 2010; Rantanen, 2013).

3.6 INTERVIEWS

Interviews are one important data collection method (Creswell, 2016) and represent important sources in mixed-method research. Interviews can be placed on a continuum of structured, semi-structured and unstructured (Kumar, 2019). Semi-structured interviews are popular because of their flexibility and ability to probe and shed light on students thinking. Semi-structured interviews were used to probe the interpretation of the rate and extent of reaction graphs. Interviews allowed the researcher to investigate the students' thinking with regard to their interpretations. The semi-structured interview schedule enabled the researcher to probe in case responses lacked sufficient detail, depth, or clarity. Kumar (2019) describes interview schedules as qualitative tools that seek to illuminate an interviewee's point of view. This study opted for semi-structured interviews because the interview method involves the use of open and closed questions. To ensure consistency across all participants, the researcher used a set of pre-planned RER questions (Annexure E).

Treasure and Chadwick (2008) advocate that interviews establish friendly dialogues that permit probing for clarification. The main advantages of interviews are summarised by Imenda and Muyangwa (2006, p. 77):

- Direct contact between participants and the researcher leads to specific and constructive suggestions.
- Detailed information can be obtained through in-depth probing. Furthermore, the researcher can test the limits of the respondent's knowledge.
- Few participants are needed to gather rich and detailed data.

Many researchers have widely used interviews in probing students' interpretations (Bains & Towns, 2016; Glazer, 2011; Curcio, & Bright, 2001; Treagust, 2008). If interviews are skilfully done, they are one of the most effective ways to elicit detailed information on students' interpretations.

3.6.1 Interview schedule

Interview schedules are questions that are developed to guide interviews and provide responses predetermined by the interviewer as a method to engage the participant and establish the narrative terrain (Gay and Mills, 2016). Through the semi-structured interview schedule, the researcher was able to probe in case answers lacked sufficient detail, depth, or clarity. The interview schedule was developed by the researcher in order to elicit more detailed information about students' interpretation of rate and extend of reaction graphs. Ten students were interviewed a week after administering the diagnostic questionnaire. Students were grouped into three groups (high, middle and low performance) based on their scores in the RER. In order to ensure a balanced representation of genders, purposive sampling was done to select six girls and boys. A total of three questions were used in the semi-structured interviews. The questions focused on the three subtopics of chemical kinetics, namely rates of reactions, concentration and temperature dependence of rates of reactions and reaction order. Each interview lasted for 20 minutes and was recorded on a tape recorder.

3.6.2 Trustworthiness of the interview data

In the qualitative approach, internal and external validity and reliability are replaced by the criteria of trustworthiness and authenticity. Four indicators are used to determine trustworthiness in qualitative research: credibility, transferability, dependability and confirmability (Kumar, 2019). Credibility refers to the truthfulness and accuracy of results; transferability is the extent to which results can be transferred to other contexts. Dependability is the extent to which similar findings would be obtained if a similar study was undertaken at a different location or time using participants who have similar characteristics. Confirmability is the extent to which the results are free from bias so that findings can be replicated by other researchers (Creswell, 2016).

In order, to meet the criteria of trustworthiness, the interviews were transcribed and themes coded. The interpretations done by the researcher were based on contextual detail and patterns that emerged from the graphical interpretations. In order to provide credibility to the research findings, the researcher used probing and iterative questions. Furthermore, students were asked to read the transcripts collected in order to verify that what was written correctly reflected what they had said, thereby adding credibility to the findings. Previous research findings were also examined by the researcher so that the findings of the current study could be validated against the body of existing knowledge to ensure credibility. Grade 12 students took part in the study and the rate and extent of reaction topics done in Physical sciences were taught and this established authenticity of the study.

3.7 PILOT STUDY

Pilot studies are small-scale versions of the major study that are carried out in preparation for it (Creswell, 2016). Pilot studies are sometimes referred to as feasibility studies, baseline studies, or trial runs. In this study, a pilot study was done to test the diagnostic questionnaire and the interview schedule. The instruments were piloted on twenty students in the population but outside the sample space of the study. The advantage of a pilot study is that it can point out any potential pitfalls, problems in the protocol, or unsuitable methods and instruments that may manifest in the main project. The feedback from the respondents was used to check statistical, and analytical procedures, adequacy of research instruments and assess the feasibility of the study. On the basis of the feedback received from the pilot study, which expressed a concern regarding the lack of time to proofread the answers and complete the test, the time for the diagnostic questionnaire was extended from 25 to 40 minutes. Participants in the pilot study took the RER the same way as those in the main study. Following an interview with six students, the appropriate adjustments were made based on the feedback and the observations. The time was decreased from 25 to 20 minutes for each interview.

3.8 METHODS OF DATA ANALYSIS

The completed RER was submitted to a statistician for data capture and coding. Thereafter, descriptive statistics were used to analyse quantitative data. Descriptive statistics included finding the mean, standard deviation, minimum and maximum score values, and constructing charts. The data were analysed using the Statistical Package for Social Sciences (SPSS) version 25. Qualitative data from interviews were tape-recorded and transcribed. All the recorded audio files were transcribed verbatim. Students' responses were analysed using scientifically completed responses (nomothetic) and classification of explanations (ideographic). Triangulation was then achieved by matching interview transcript responses with questionnaire written responses. Macmillan (2010) asserts that interview transcripts elicit light on the sequencing and evolution of students' ideas.

3.9 ETHICAL CONSIDERATIONS

Ethical and safety issues are critical issues in research in order to collect credible data. The ethical commitment involves doing what is right and appropriate in engaging with participants, observes Gay and Mills (2016). Approval letters from the university's Higher Degrees Committee and the University Ethics Committee approved the study. This study was conducted in public schools and thus all the necessary ethical considerations were adhered to. The following considerations and permission were sought:

- A letter requesting permission to conduct research was submitted to the KwaZulu-Natal provincial Head of Department of Basic Education seeking permission to conduct research in the selected schools in King Cetshwayo District.
- A letter was also sent to the director of King Cetshwayo district requesting permission to conduct research in high schools within the FET band in the district (see Appendix D).
- A letter was also sent to the principals of the target schools seeking permission to conduct the research.

The study was guided by the following six ethical considerations:

3.9.1 Protection

The students were informed that the diagnostic questionnaire results would not be used by the Department of Education (DBE) for assessment purposes. In order to ease students' anxiety about writing the diagnostic questionnaire under the school examination conditions, they were advised not to study beforehand.

3.9.2 Confidentiality

Confidentiality and anonymity are ethical practices intended to protect the privacy of human subjects while collecting, analyzing, and reporting data. They protect the privacy of those participants who voluntarily agree to participate in the research. In this way, participants become more comfortable in completing a survey or participating in an interview if they have some assurance that the researcher will not reveal the provided information they have provided (Creswell, 2016). The confidentiality of the research data was ensured by assigning pseudo names and numbers to both to the diagnostic questionnaire and interviews. The participants were informed that their names were not required and that all the data collected from them would be held in confidence.

3.9.3 Voluntary participation

Participants and respondents of this study voluntarily participated without undue influence. They were informed that they may withdraw from taking part if they wish to do so as there was no misrepresentation, threat or promise of payment. The information obtained from the study was treated as strictly confidential, meaning that under no circumstances was it used for any reason other than its academic purpose.

Participants were given the option not to answer certain questions they felt uncomfortable with (Kumar, 2019). Participation in the research was completely voluntary. The participants were informed that they could withdraw from the study at any time without penalty or being forced to provide reasons by the researcher.

3.9.4 Informed consent

Participants were informed, before giving their consent, that their rights, dignity, and confidentiality would be respected during the course of the study. Kumar (2019) views informed consent as a means that explains the subject's rights, the purpose of the study, the procedures to be undertaken, and possible risks and benefits that may arise from the study. Participants in the study were told about the informed consent process so that they could make an informed decision on whether or not to participate in the study. One of the main ethics issues frequently pointed out is that of informed consent. According Macmillan and Schumacher (2010. 198), "informed consent is a process that involves informing the subject about his or her rights, the purpose of the study, the procedures to be undergone, and the potential risks and benefits of participation". The informed consent process was explained to the students with the sole aim of the participants making an informed decision about enrolling in the study or to discontinue participation.

3.9. 5 Provision

The participants were informed that the study had the potential to let Further Education Training (FET) teachers discover awareness about their graphical interpretations in rate and extent of reaction. The participants in this study were adequately informed of the valuable and meaningful contribution they would make as they participated in the study regarding graphical interpretation in Physical Sciences.

3.9.6 Researcher avoiding bias

Macmillan and Schumacher (2010) view bias as an attempt to either conceal or emphasize something in a disproportionate way than what has been truly discovered based on research. Bias is different from subjectivity. In this study, the researcher did not influence or change the outcomes in any way.

3.10 SUMMARY

In this chapter, the research design of the study and justification of the mixed methods research paradigm, as a technique for determining the graphical interpretation of RER, were discussed. Descriptive statistics analysis using SPSS and interviews were used to analyse the students' interpretations. Last but not least, ethical considerations were presented and discussed. The results of the study are presented in chapter 4.

3.11 SUMMARY AND OUTLINE OF THIS STUDY'S RESEARCH DESIGN

The summary of the research design of this study is outlined in Figure 3.5.

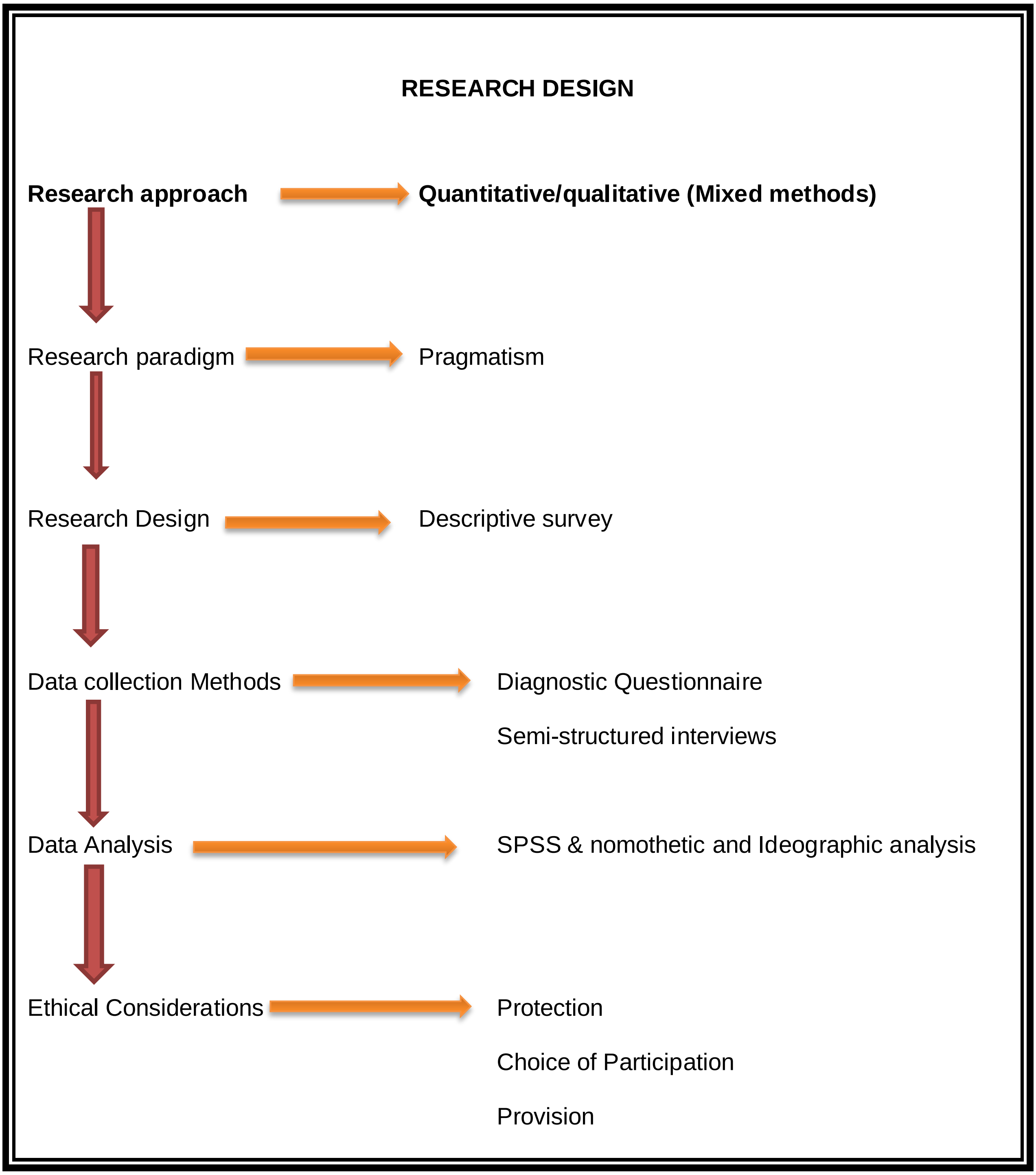


Figure 3.5: Outline of the research design

CHAPTER 4 DATA PRESENTATION AND INTERPRETATION

4.1 INTRODUCTION

The purpose of this chapter is to present findings in the current study. Additionally, this chapter also presents the analysis and interpretation of different forms of data which answered the following research questions:

4. What challenges do grade 12 Physical Sciences students encounter when interpreting graphs of rate and extent of reactions?
5. How do grade 12 Physical sciences students interpret and describe salient features of graphs of rate and extent of reaction?
6. What are the specific graphical literacy levels of grade 12 Physical sciences students on rate and extent of reaction?

4.2 BIOGRAPHICAL CHARATERISTICS OF PARTICIPANTS

For the purposes of this study, the researcher selected a sample group of one hundred and fifty-six grade 12 physical sciences students from King Cetshwayo District. The age of the participants ranged from 16 to 20 years. The modal age was 17 and the total number of females and males were 88 and 58 respectively.

4.2.1 Gender Distribution

The gender distribution of the research sample (n = 146) of grade 12 Physical Sciences respondents (60% females and 40% males) is presented in Table 4.1.

Table 4. 1: Gender distribution of the participants (n=146)

Gender	Number of students	Percentage (%)
Females	88	60
Males	58	40
Total	146	100

4.3 Challenges when interpreting graphs, the rate and extent of reactions

The first research question was to ascertain the challenges Physical Sciences students encounter when interpreting graphs of the rate and extent of reactions. The purpose of the diagnostic questionnaire was to identify the challenges or difficulties students face. A three-tier diagnostic test in the rate and extent of reaction was administered in the first phase of the study. Responses to the diagnostic questionnaire were categorised as suggested by Caleon and Subramaniam (2010) that the confidence expressed on alternative conception (CAC) by the student can be used to measure the strength of the alternative conception. However, in the present study, the confidence expressed was used to measure the strength of the challenges faced by the students on the rate and extent of reaction. The strength of confidence on challenges (CC) values enabled the researcher to shed light on the graph interpretation difficulties. The CC was calculated by adding the average confidence ratings of the answer and response tiers and then that was divided by the total number of students who chose the same answer and response tier. The ratings were then grouped into three categories, based on the classification proposed by Caleon and Subramaniam (2010), and Yan and Subranaim (2017), as follows:

Table 4. 2: Strength of the challenge faced by the respondents

Category	Range	Interpretation
Spurious	CC < 3.5	Expressed due to lack of knowledge or guessing, low confidence
Moderate	4.0 < CC ≥ 3.5	Expressed with medium level of confidence
Strong CC	CC ≥ 4.0	Expressed with high level of due to lack of understanding or wrong reasoning accompanied .

Challenges held by at least 20% of respondents based on two tiers were identified. Yan and Subramaniam (2017) suggested that in a diagnostic test challenges with a frequency of least 20% of the respondents should be regarded as serious.

The data on tables and graphs below constitute a summary and analysis of findings gathered to explore the challenges students encountered when interpreting graphs. Table 4.1 below illustrates the summary of descriptive statistics for the percentage performance in the diagnostic questionnaire. The mean was 46.63 % with a median of 43% and the standard deviation was 16.6%.

Table 4. 3 Descriptive statistics for overall performance RER questionnaire

	N	Median	Variance	Mean	Std. Deviation
Marks	146	43	38.47	46.63	16.629

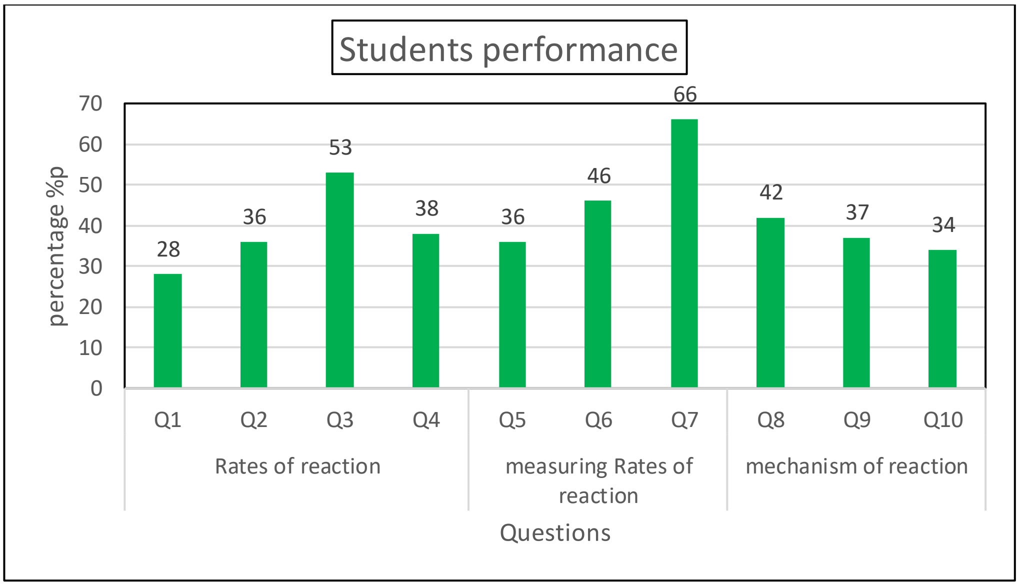
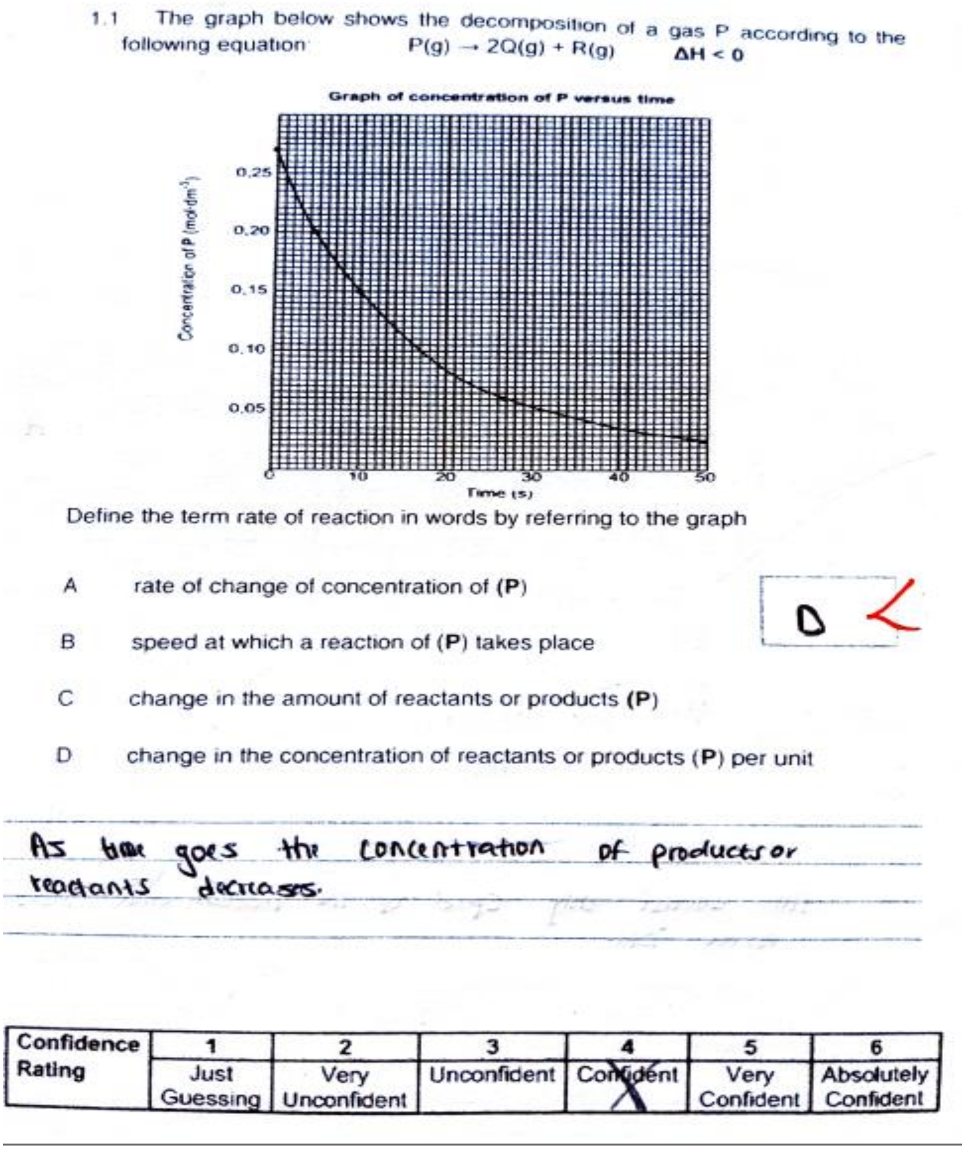


Figure 4. 1: Students' performance on individual questions

The data analysed in Figure 4.1, showed that students performed poorly in some questions of the diagnostic questionnaire. There was poor performance across all the three sub-topics. The lowest performance was recorded in rates of reactions questions, especially in Question 1 to Question 4 where the performance was within the range of 38.75%. Generally, the performance of students was low across the different concepts of rates and extent of reaction tested. One of the students' responses in Figure 4.2 showed a challenge of failing to interpret the context of the graph. The student relied on the definition of rate and not on the information presented by the graph. The answer was on the rate of change in concentration. The confident rating was calculated and the CC > 4.0 showed that the responses were expressed with high levels of confidence. Thus, the first challenge identified was that of not using the context of the graph and relying on the definition of rate of reaction. The graph required the change of concentration of P versus time. There was no need to mention products or reactant since one of the axis was labelled concentration P.


1.1 The graph below shows the decomposition of a gas P according to the following equation: $P(g) \rightarrow 2Q(g) + R(g)$ $\Delta H < 0$

Define the term rate of reaction in words by referring to the graph

A rate of change of concentration of (**P**)

B speed at which a reaction of (**P**) takes place

C change in the amount of reactants or products (**P**)

D change in the concentration of reactants or products (**P**) per unit

D

As time goes the concentration of products or reactants decreases.

Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

Figure 4. 2: Students response on rate of reaction

As shown in Figure 4.3, the second challenge identified was that of interpreting the role of enzyme on the rate of the reaction. The responses show that learners thought that the enzyme catalysed reaction will be faster and would not be compared to the un-catalysed reaction especially when they reach equilibrium.

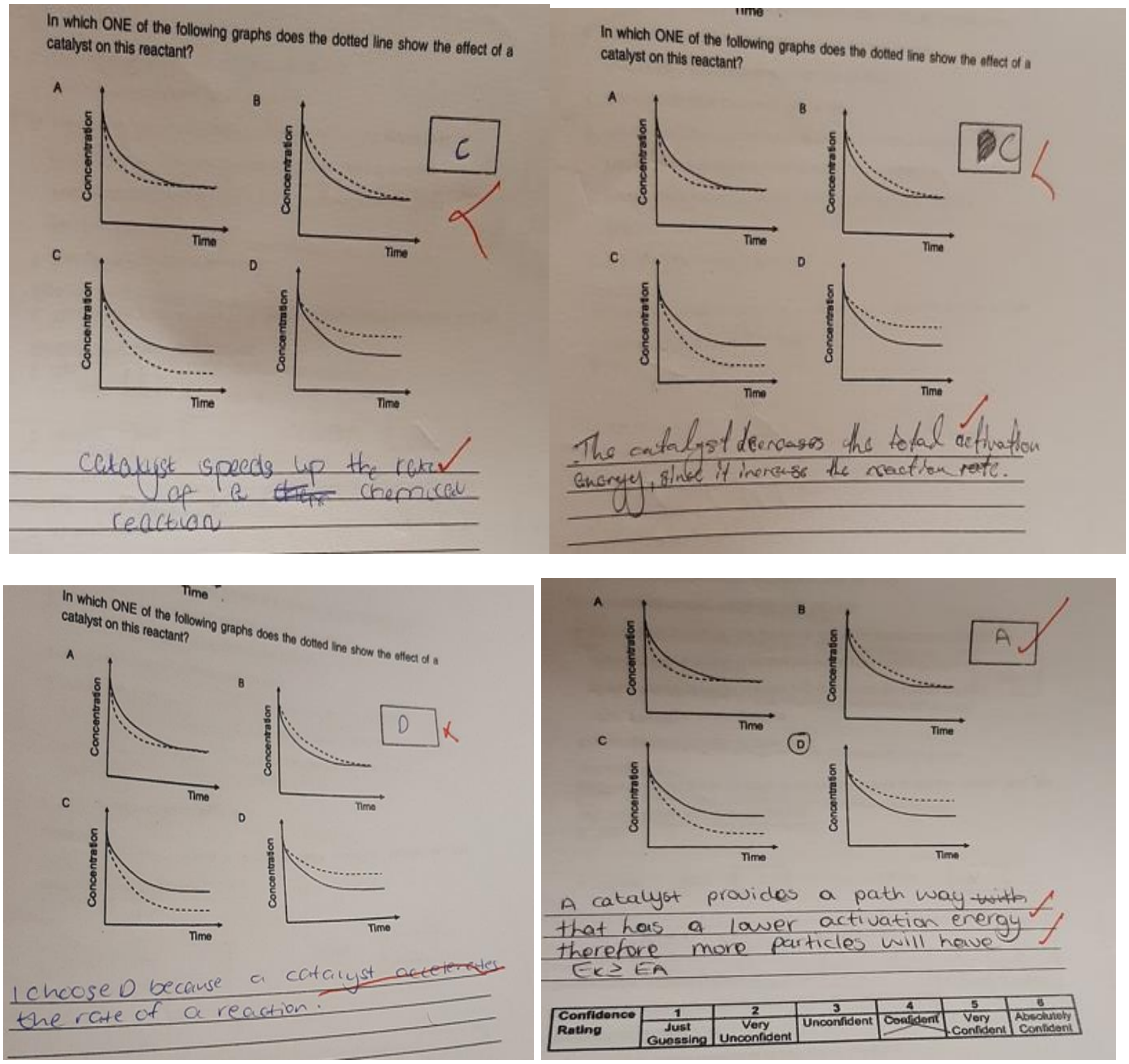


Figure 4. 3: Students' responses on the role of the catalyst on the rate of reaction

The catalyst increases the rate of reaction and the starting point and endpoints of the graph remain the same. At the same time, the catalyst provides an alternative path with lower activation energy and the enthalpy of the reaction remains the same. The responses showed that the justifications were correct but the graphical interpretation was wrong. The starting points and endpoints should be the same on the graph. The measure of confidence on the response was CC > 4 which means the students had high confidence. The three responses show that the students relied on the definition of the enzyme to make their graphical interpretation.

The reaction rate versus time graph of reactants with one in excess touches the axes. In Figure 4.4 below the student confused the volume versus time with the reaction rate versus time. The reaction rate decreases with time and it's inversely proportional to time. In both cases, the graph as a product formation versus time is being explained. The strength of confidence in the responses was moderate 3.5< CC< 4 which means that the students were not very confident with their responses.

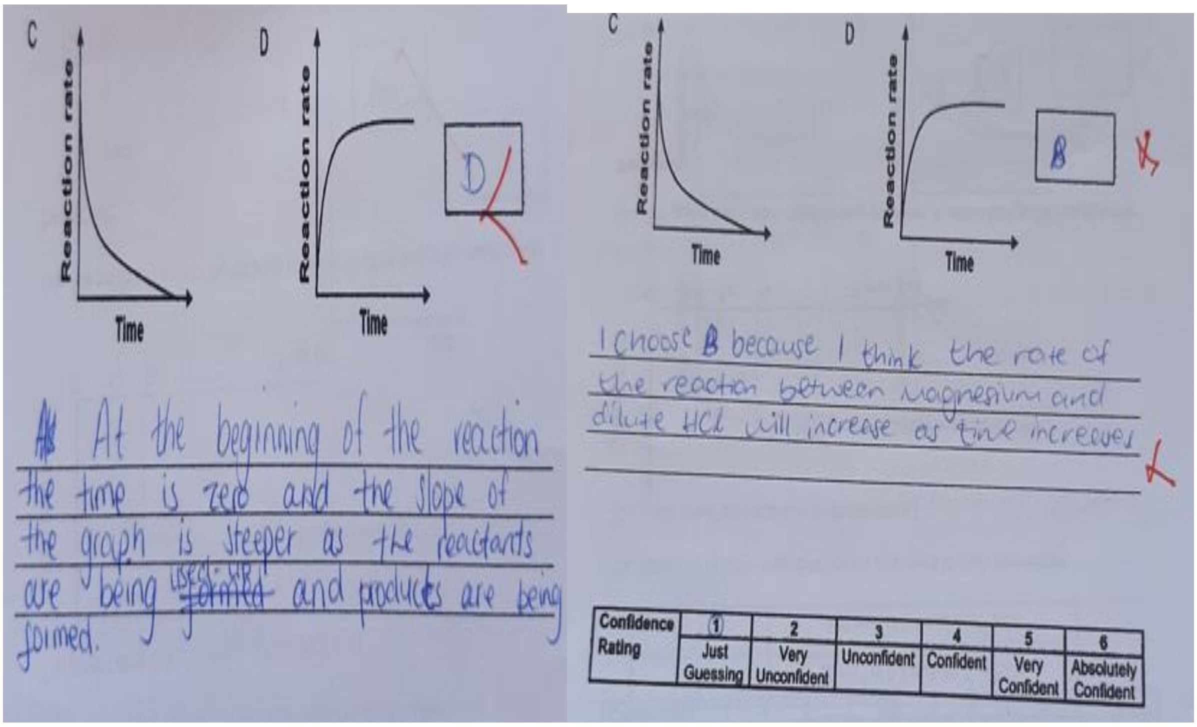


Figure 4. 4: Students responses on reaction rate versus time

The following challenges were identified on the sub-topic of rates of reactions

- Rate of reaction identified with definition
- Catalyst increase the rate of reaction and the shape of the graph
- Rate vs time graph interpreted as a product formation versus time.

4.4 Measuring rates of Reaction

The question compared how the volume of Hydrogen gas would be produced between 0.1M HCl and 0.1M CH_3COOH. The magnesium powder was in excess. The responses in Figure 4.5 below show various justifications. Option C was correct as the weak acid would react slowly as compared to the strong acid. Thus, the graph would shift to the right and the slope of the gradient will be gentle. The strength of the confidence responses was CC< 3,5 which showed a lack of knowledge. The challenge on this question was to interpret the shift of the graph to the right. Understanding a slope and height in measuring rate graphs has an important role, especially in the transition from one reactant to another. For example, when a volume-time graph (v-t graph) is given, students need to know the difference between the slope and the height. The starting point and the endpoint should be the same. The challenge was that of knowing when to use slope and height for the interpretation of volume vs time graph.

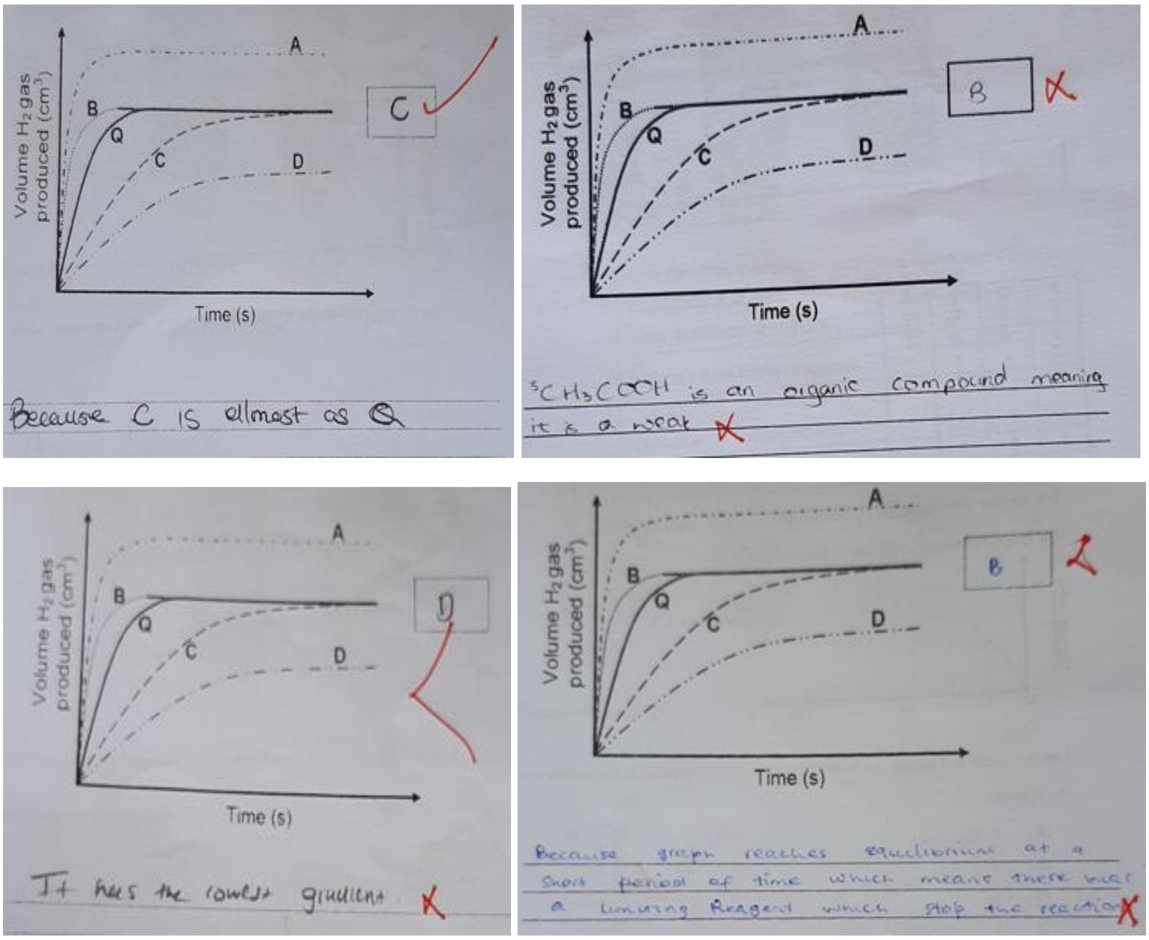


Figure 4. 5: Responses on measuring rates of reaction

4.5 Mechanisms of rates of Reaction

The performance by students was also low on the question of how the graph shifted when temperature increased. Figure 4.6 shows that the first-tier was answered well but the justification was not linked to the graph. Most of the students could not explain how the graph shifted and molecules with the activation energy increased. The Maxwell-Boltzmann curve is affected in both areas under the graph and the shift to the right. In Figure 4.6 below there is an indication that some of the students did not understand the meaning area below the graph. Most of the respondents in this study were no exception to this challenge, especially on the qualitative aspect of the Maxwell-Boltzmann graph where they had to interpret how the area under the graph changes. Justifications in Figure 4.6 indicate that the responses were far from mentioning the area under the curve. This shows that the students can get the correct answer with wrong interpretations.

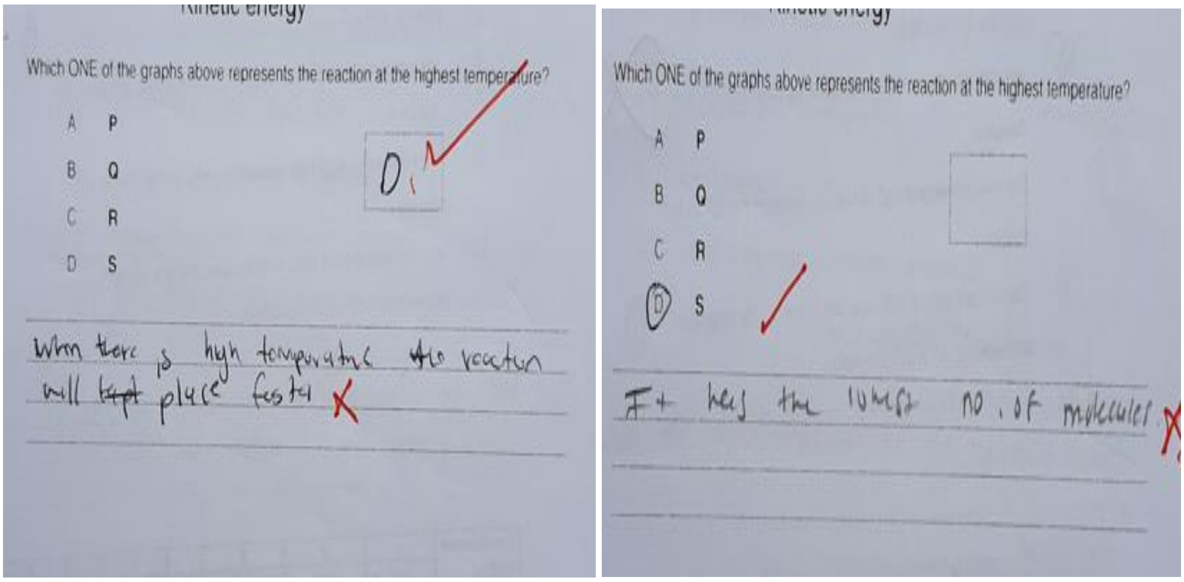


Figure 4. 6: Responses on Maxwell-Boltzmann curve

4.6 Interpretation of salient features of graphs of rate and extent of reaction

After completion of the analysis of the diagnostic (RER) questionnaire, a sample of 10 participants of varying abilities was purposively selected on the basis of their performance in the questionnaire. The criteria for selecting the 10 participants considered those who scored below average, average and above average in the questionnaire. To maintain anonymity, the students were assigned alphabetic letters from A to J. The interview questions were prepared to determine students' interpretation of salient features of the graphs. Structured interviews were conducted and an interview schedule was used to maintain uniformity on the questions asked of each student. Findings from the interviews addressed the sub-questions, on how do grade 12 Physical sciences students interpret and describe salient features of graphs of rate and extent of reaction? The results of the interviews were transcribed and the responses were analysed using nomothetic and ideographic methods, as suggested by Crossman (2016). In chemistry education, a nomothetic approach is used to assess scientifically complete responses (Kabapinar,2008).

At the heart of the nomothetic approach lies the assessment of students' responses based on ideas accepted by the scientific community. On the other hand, an ideographic approach "explores students' understanding in its own terms without assessment against established scientific ideas. The responses were then coded into three categories namely: sound understanding (SU), partial understanding (PU), and no understanding (NO). The purposes of the interviews were three-pronged. Firstly, it was to find out how students interpret surface features of graphs. Secondly, semi-structured interviews were conducted to shed light on students' interpretations. Thirdly, the researcher sought to find out how qualitative and quantitative data corroborate. Interviews yielded interesting results in this study that could not be obtained by relying strictly on quantitative methods. Below are excerpts from the interview process, as well as some comments.

4.7 Interview Excerpts

Interviewer: Welcome to the interview session concerning the topic on rate and extend of reaction. Basically, the idea is to find out your perceptions on the topic rate and extent of reaction. The goal is to gather information on how you interpret surface features of the graphs.

Interviewer: The question below was asked in the questionnaire which you responded to last week. Can you please explain the rate of reaction at points labelled A, B, C as shown in the diagram below?

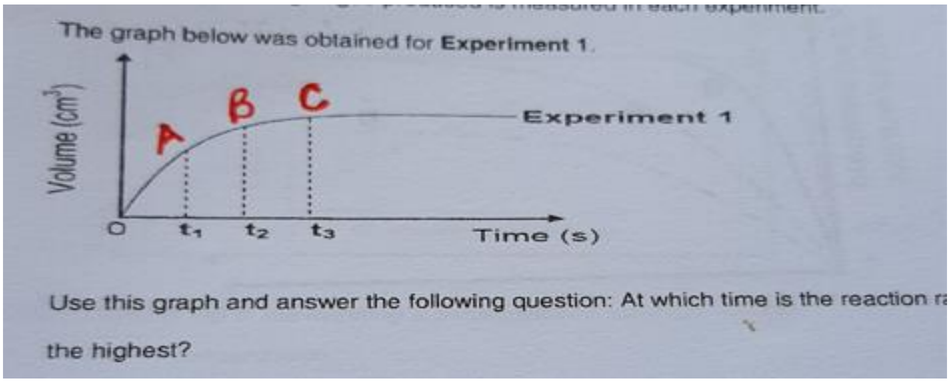


Figure 4. 7: Surface features on Volume versus time graph

Student D: The rate of reaction is high at C because more volume has been collected. The volume of A and B is lower than at C. I think when rate of reaction is high more volume is collected. At C the reaction reaches equilibrium and most of the gas has been collected.

Interpretation

The student lacked knowledge of how the rate of reaction progresses as the reaction proceeds. The graph is being interpreted mathematically where the amount of volume is being directly linked to the rate of reaction. There might be an understanding that when the reaction nears completion more gas is released. The explanation does not include the steepness of the gradient as the reaction progresses. The explanation was categorise as NO.

Student F

The rate of the reaction decreases as the reaction proceeds forward. In the question the gradient of volume versus time is the rate of the reaction. When the gradient is steep the rate of reaction is high. Therefore, the rate of reaction is high at A followed by B and lastly C.

Interpretation

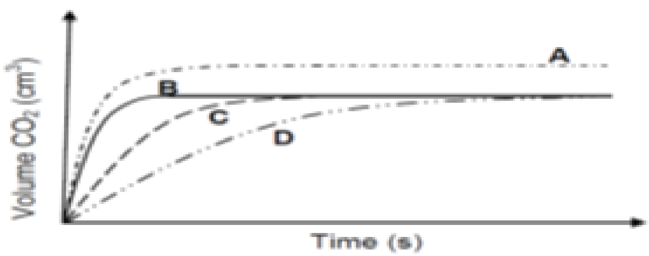
The student had a firm grasp of how the rate of reaction proceed and also the context of the graph where the gradient of volume vs time is the gradient. The response was place under SU.

Measuring rate of reaction

Interviewer: Please take a good look at the diagram below and arrange the experiments numbers accordingly from A, B, C and D.

	EXPERIMENT			
	1	2	3	4
Concentration of acid (mol·dm^{-3})	1	0,5	1	1
Mass of impure calcium carbonate (g)	15	15	15	25
Initial temperature of acid (°C)	30	30	40	40

The learners obtain graphs **A**, **B**, **C** and **D** below from their results.



Student H

The original graph for experiment 1 is B because it's a bold line. The other graph is drawn to compare the difference of graph B to other graph with different mass, concentration and temperature.

Interviewer

You still need to arrange the graphs how are they compared to B and provide justifications.

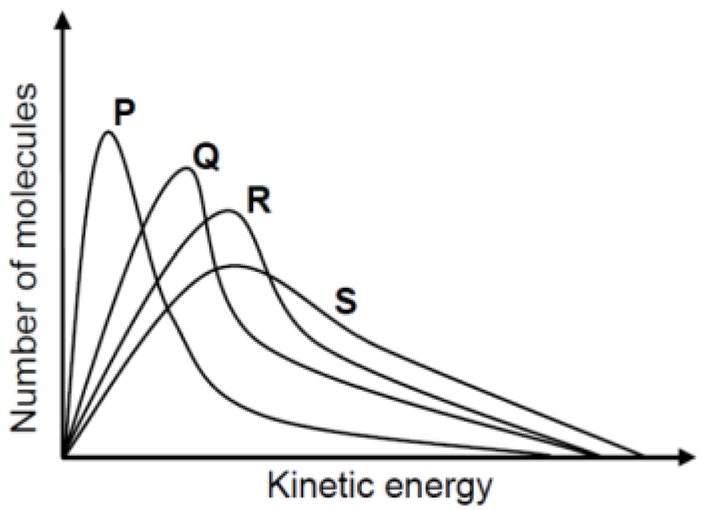
Student H

During the questionnaire I responded that just guessing on the confidence rating. I was not sure but let me guess for experiment 1 is B, experiment 2 is C experiment 3 D and the last one A.

The student could not mention the factors that were affecting the rate of reaction. Thus, the response was classified as NO.

Mechanism of the rate reaction

Interviewer: The following question represent the molecular distribution for a reaction at different temperatures. Which of the following graphs represents the reaction at the highest temperature?



Student G

When temperature increases, the reaction will be faster. The number of molecule decreases faster when temperature is higher. The appropriate answer will be S.

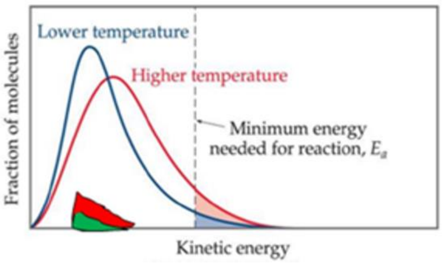
Student B

The temperature increase affects the area under the curve. The graph shifts to the right and more molecules will have the necessary energy.

Interpretation

Student G did not mention anything about the area under the graph and how it's affected by temperature change. Student B knew about the shift of graph and its area but keywords of activation energy were missing. At lower temperatures, the graph shifts to the left, and only a small percentage of the molecules have the required energy. According to the collision theory, only a small fraction of the molecules has the required activation energy.

The Maxwell-Boltzmann curve can also include the shift of the graph to left and increasing the area under the graph as shown below:



Increase in temperature does not affect the activation energy but increases the area under the graph.

The three questions of the semi-structured interviews were analysed using nomothetic and ideographic methods as shown in Figure 4.8. The sub-topic that had least sound understanding (SU) was mechanism of rate of reaction. Interview response analysis show that most students fall within the Partial understanding (PU) and No understanding (NU).

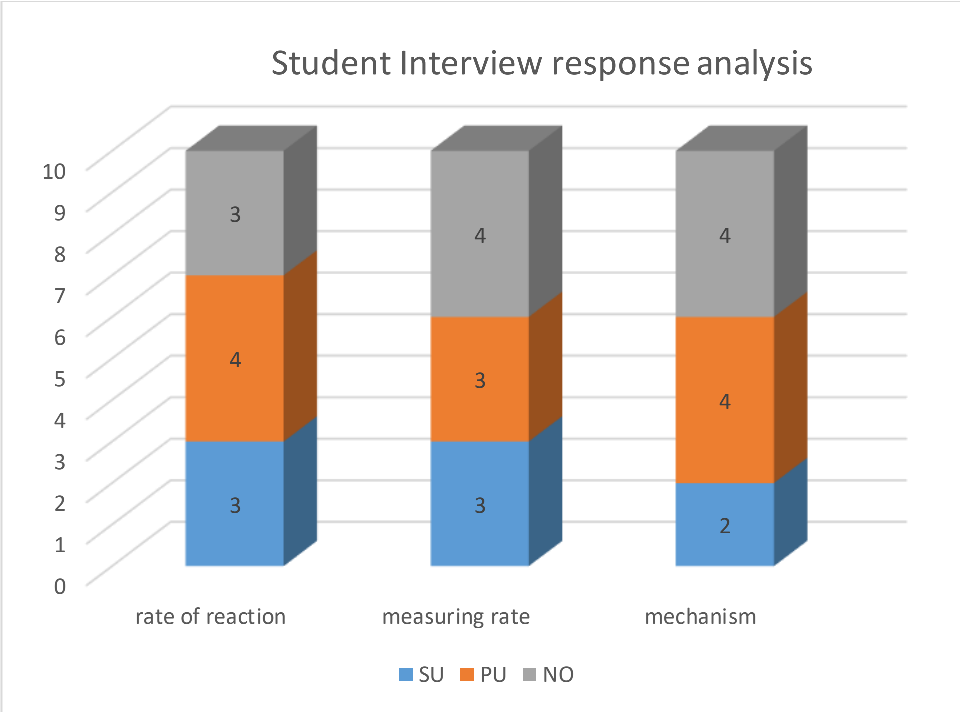


Figure 4. 8: Student interview response analysis

4.8 Specific graphical literacy levels of students on rate and extent of reaction

Table 4.4 was used as a rubric to measure the graphical literacy of the respondents on the topic of rate and extent of reaction. The external identification stage questions assessed students' understanding of the graph to associate the x-axis with the independent (causal) variable and the y-axis with the dependent (effected) variable. Question 1.8 was a graph of reaction rate versus time on the reaction of a sodium thiosulphate solution with dilute hydrochloric acid to investigate several factors that affect the rate of a chemical reaction. The question required students to identify the dependent variable on the graph.

Table 4. 4: Graph Interpretation and levels rubric

Graph Interpretation rubric	**Curcio's Levels**		
	Read the data Level 1	Read between the data Level 2	Reading beyond the data Level 3
External identification stage Associate x-axis with the independent (causal) variable	2		

and y-axis with the dependent (effected) variable Select an appropriately scaled set of axes for a set of data (correct range and interval)	2		
Elementary Level Indicators ***Reading the data*** **(locating, translating)** Read the value of a point using an axis and label Find point of given “x-y coordinates		2 2	
Intermediate Level Indicators ***Reading between the data*** **(integrating, interpreting)** Select an appropriate graph to display the data Describe a relationship expressed in a graph Calculate the comparative (quantitative) difference between data points		2 2	
Overall Level Indicators ***Reading beyond the data*** Identifies scientific knowledge about graph content that affects graph interpretation Identifies personal experience about graph content that affects graph interpretation			2 2 2
Total marks	**4**	**8**	**6**

The scores per task question were grouped and calculated according to Curcio’s levels of graph comprehension (see Table 4.4), a clearer picture emerged regarding the respondents’ graphical literacy skills. Overall scores for Curcio ’s three levels are visualised in Table 4.4 and indicate, once again, a disturbingly low response at the highest level of graphical interpretation. There was a lack of graphical literacy amongst the respondents on the topic of rate and extent of reaction. It is clear from Figure 4.9 that the percentage of graphical literacy declined in the three sub-topics. However, the mechanism of reaction tasks gave an unexpectedly high positive response on reading beyond the data. These overall scores per Curcio’s levels are relatively low.

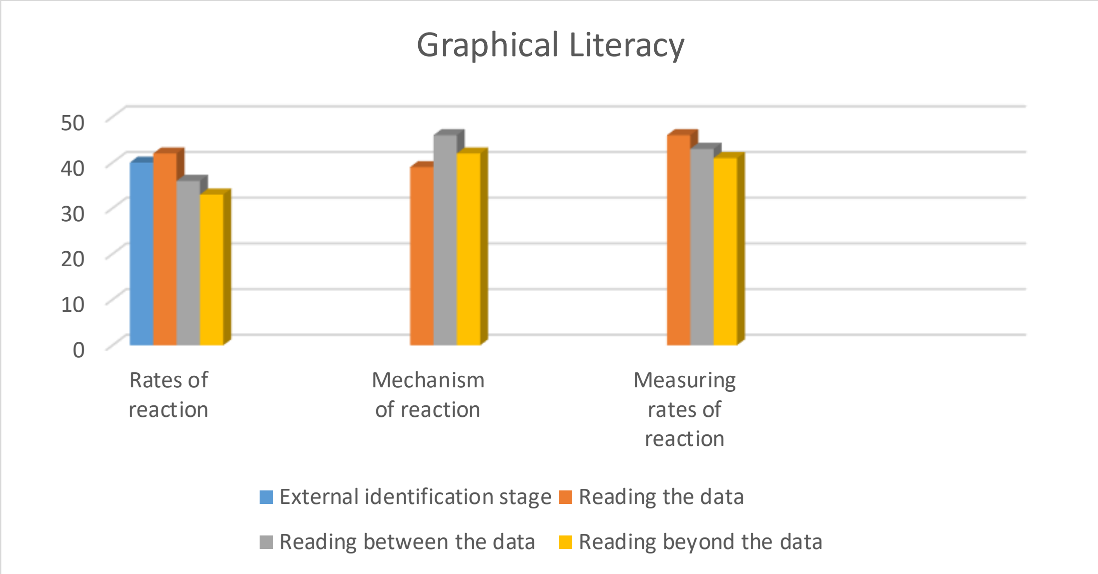


Figure 4. 9: interview analysis of responses

Figure 4.9 shows that (42%) of the students could not determine independent and dependent variables of the reaction rate versus concentration graph. The students lacked the basic understanding of dependent and independent variables in an experiment or investigation as shown in Figure 4.10. The first response shows the correct answer but the justification is wrong. Mathematical knowledge of identification of the dependent variable being the y axis and the independent x-axis might have been used to identify the reaction rate. The right concentration was identified as the dependent and the justification shows a lack of knowledge on variables in an experiment.

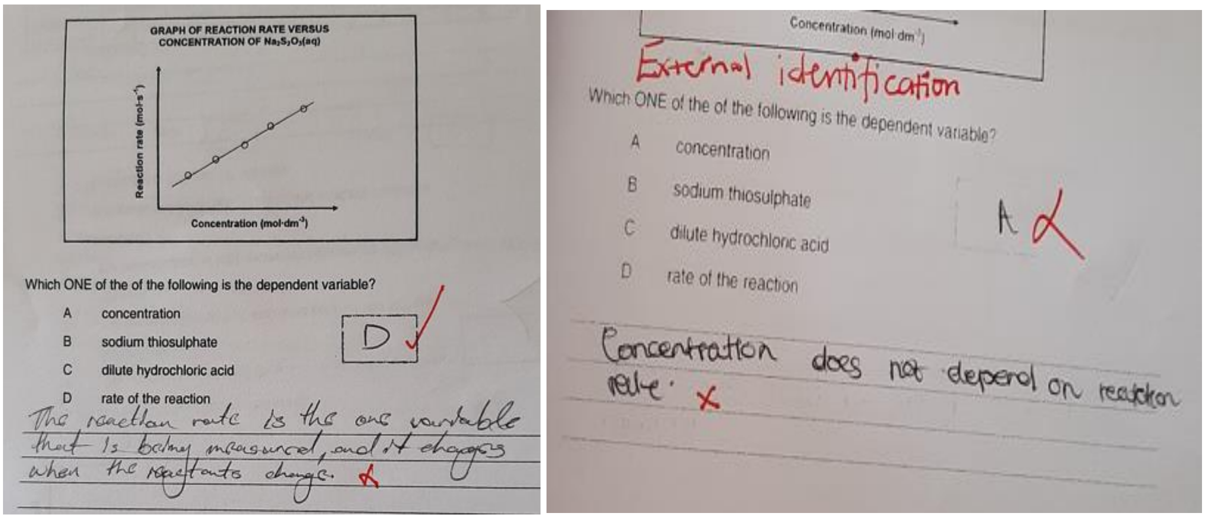


Figure 4. 10: Students Responses on identification of variables

Question 1.5 required the students to use the reaction between impure powdered calcium carbonate and excess hydrochloric acid to investigate the reaction rate. The question was categorised under reading beyond data. It required the students to use scientific knowledge about graph content that affects graph interpretation. Three factors were involved, namely; concentration, mass of impure calcium carbonate, and temperature and the dependent variable was the volume of gas produced. The concentration of acid was 1 M in the three experiments. Knowledge of the three factors that affected the rate of reaction was crucial in justifying the first-tier. The collision theory would also be integrated when interpreting the shape of the graph. The shifting of the graph to the right being affected by the temperature was also an important factor in interpreting the graph correctly.

Figure 4.11 shows that students who selected option B struggled with the justification of their responses. The reading beyond was displayed well in option C where the collision theory was integrated. Numbering the graph shows that students knew about the factors that were affecting the rate of reaction. The students were aware of the shifts and steepness of the graph. The critical factor was the temperature that was directly linked to the collision theory.

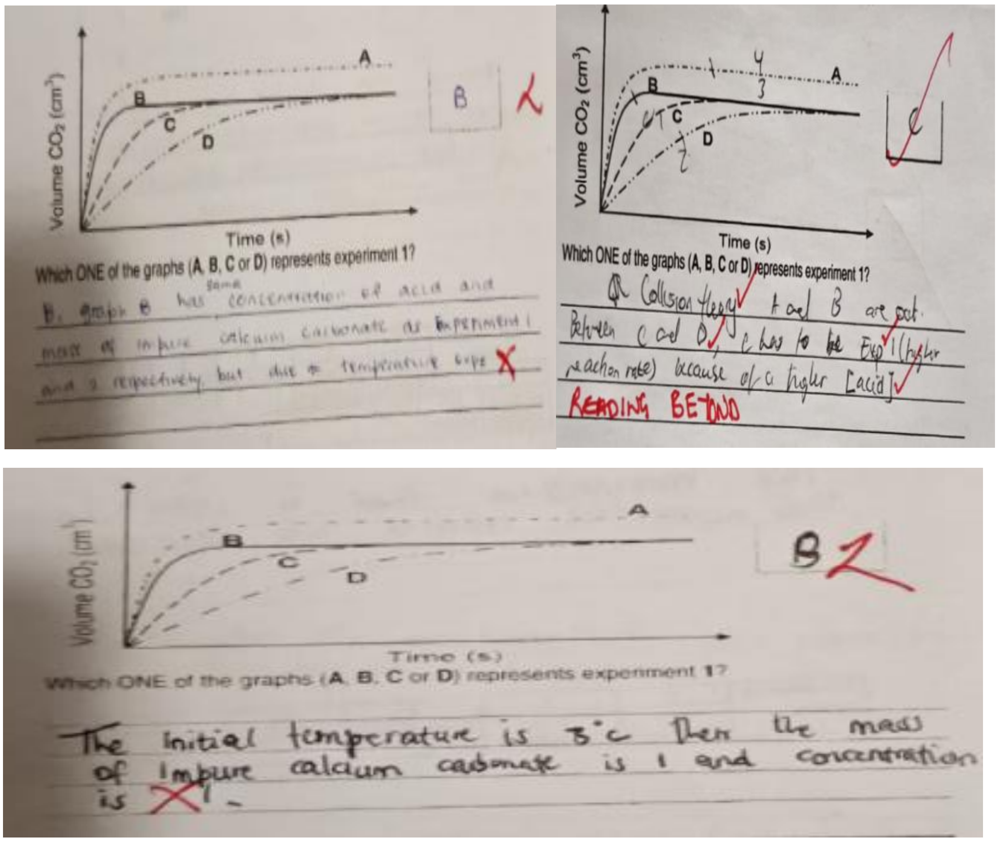


Figure 4. 11: Students responses on measuring rate of reaction

Overall, the failure by the students to translate among the graphical literacy levels is evident from the results obtained in this study. Physical sciences require a well-developed graphical literacy for students' success at a FET level. The results show that a very large number of students are struggling with external identification and beyond the data level.

4.9. Conclusion

In this chapter, the findings were presented as per research questions. The objective was to present both the quantitative as well as the qualitative data. The findings of this study revealed that most students rely on definitions to interpret graphs on rate of reaction. It was also revealed that learners struggle with graphical literacy even the lowest stage of external identification. The surface features of the rate of reaction graphs also proved difficult to most of the students.

5.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter presents the summary of the current study followed by the discussion of the main findings. The findings of the study are then supported by literature and a discussion of the study's contribution to knowledge. Suggestions for future research, practice and theory are also offered by the researcher. Finally, the limitations of the study are mentioned and the chapter is concluded.

5.2 DISCUSSION

This study intended to determine how grade 12 Physical Sciences students interpret graphs on the rate and extent of reaction among selected secondary schools in the King Cetshwayo District. To this end, the findings of the study are discussed with regard to the research objectives of the study. The findings are presented as they relate to the three research objectives namely:

i. To identify the challenges encountered by grade 12 Physical Sciences learners when interpreting graphs of the rate and extent of reactions
ii. To determine how do grade 12 Physical sciences learners interpret and describe salient features of graphs of rate and extent of reaction.
iii. To determine the specific graphical literacy levels of grade 12 Physical sciences learners on rate and extent of reaction.

5.3 To identify the challenges encountered by grade 12 Physical Sciences learners when interpreting graphs of the rate and extent of reactions

The literature reviewed in this study, supported by the findings of the study revealed that students relied on definitions when interpreting graphs under rates of reaction. The challenge was in the identification of the rate of the reaction with the gradient of the concentration versus time graph. A possible explanation for this might be that students think about the definition first before analysing the graph These findings concur with the literature which reveals that students struggle to associate the gradient with rate of reaction (Glazer, 2011). The isolation of the representational level of the Johnstone triangle explains these results (Seethaler et al., 2017)

In Figure 2.4 colour codes were used to identify the levels of graph interpretation difficulty. This result falls under the yellow code where the graph connections are not done. Taber (2013) modified Johnstone's triangle where students shift between two domains, which are the macro and sub-micro using representations of graphs does not explain the result since graphs do not use the macro domain. The other challenge identified was the role of the catalyst on the shape of the graph. The results of this study showed that students thought that the speeding of the reaction by the catalyst also affect the shape of the graph. Thus, the graphs with or without a catalyst (Figure, 4.3) would start at the same point but end at different points. It is difficult to explain this result, but it might be related to the reliance on definitions in interpreting graphs.

A catalyst is a substance that speeds the rate of reaction or any substance that increases the rate of a reaction without itself being consumed. This finding supports previous research by Moore et al., (2014) about the challenges that students face in interpreting rates graph on curved graphs that involve changes in both height and slope. According to Bertin's Theory of graph interpretation, students failed to translate between the graph context and rate and extent of reaction domains. In line with Johnstone's triangle, students might have difficulties with the sub-micro level of knowing the role of catalyst in a reaction. It provides an alternative route, that minimises the activation energy and does not affect the enthalpy of the reaction.

The challenge of the reaction rate versus time graph is an interesting finding for this study. However, this result has not previously been reported elsewhere. The reaction rate versus time is associated with the rate of reaction of product formation versus time. This result may be explained by the fact that students' knowledge mainly centres on what they read in textbooks and they rarely apply their minds to the question. Lack of knowledge on the representational level of the Johnstone triangle explains this result. The researcher agrees with the previous researchers that there are graphical challenges encountered by students when learning rates of reaction. Most of the difficulties emanate from the lack of understanding of the rate of reaction. Lack of such understanding of the basic concepts affects learners' competency in describing various forms of the rate of reaction graphs.

In measuring the rates of reaction, the main challenge was the shifting of graphs to match the experiments. The learners had difficulties matching how the factors of the reaction affect the shape of the graph. These results are consistent with those of other studies, like Bain and Town, (2016); Potgieter *et al.*, (2008); Planini *et al.*, (2013) on the teaching and learning of chemical kinetics. The researchers identified a variety of difficulties that persist after instruction. There are, however, other possible explanations that may suggest the lack of knowledge when it comes to the integration of the three concepts factors, which include the rate of reaction and shape of the graph. The framework of the Johnstone triangle views the results as a failure to translate between the macro and sub-micro levels towards the representational level. Measuring rates of reaction requires students who move with ease in all three domains. Furthermore, the Taber model of the Johnstone triangle posits that the shifting of levels between the macro and sub-micro may be used to explain why students failed to translate between the domains.

The mechanism of the rate of reaction which includes the Maxwell-Boltzmann curve had similar results with measuring the rate of reactions. The shifting to the right of the curve when the temperature was raised was a challenge. These findings further support the ideas of Glazer, (2011) and Moore et al., (2014) who suggested that students struggle with interpreting curves in graphs. The results could be due to failure on part of the learners to comprehend how the increase in temperature works in the collision theory. Thus, translating between the graph and Maxwell-Boltzmann space was a challenge to learners. The shifting of the graph and the increase in the area of the particles with the required activation energy was the knowledge required between the representational and sub-micro domains.

The findings of this study have an impact on the modified Johnstone triangle by Taber (2013). Graphical interpretation may shift between representational and sub-microscopic levels or domains. The findings on the rate of reaction confirmed the existence of some graphical interpretation difficulties affecting learners' understanding of the rate of reaction and chemistry at large. The graphical interpretation difficulties impact negatively in students' constructing knowledge about rates of reaction.

5.4 To determine how do grade 12 Physical sciences learners interpret and describe salient features of graphs of the rate and extent of reaction.

Multiple learners in these interviews were confused about how the rate of reaction progressed with time, even though they could recite definitions for these concepts. Despite the definitions knowledge, learners still had difficulties explaining how the gradient changes as the reaction progressed. Furthermore, students focused almost entirely on the structure of the graph. Most students were categorised in the NO and few in the PU. However, this result on the progression of the rate of the reaction has not previously been described where students link mathematical knowledge to the rate of reaction. It seems possible that these results are due to interpreting the rate of reaction being higher when the volume is at its highest yet the slope is steeper when the reaction starts and slows as the reaction progress. Although, these results are different from some published studies like that of Planinic et al,. (2012, 2013) who confirm that the interpretation of graphs in physics questions is more difficult than the same task in mathematics. The current study findings show the translation by the learners from the mathematics knowledge domain to the graph interpretation context. The present findings seem to be consistent with those of Michelsen (2005), that mathematical formalism presents a barrier in learning chemistry and physics. It is clear that there is a missing link when learners translate between mathematics and chemistry rate of reaction graphs.

The learners interviewed were often uncertain about the arrangement of the graphs based on the concentration, the mass of powdered calcium carbonate, and temperature. The skill of deriving the shape of the graph using the three factors was complex to most of the learners. Lack of knowledge and conceptual understanding hindered students from identifying the correct shapes of the graph. Based on such findings, it is important to note that the integration of factors on the rate of reaction can be an effective strategy when teaching learners how to interpret graphs. The Johnstone triangle guiding reforms in chemical education suggest a shift from rote and procedural learning to authentic. learning. Students must move with ease among the three domains of representation. Insufficient content knowledge may be a barrier to graphical interpretation.

The area under a graph of the Maxwell-Boltzmann curve seems to be very difficult for students to interpret. As much as most of the students interviewed knew the shifts of the curve but the increase of the area under the curve and the activation were rarely mentioned by them. Learners seemed to understand how the graph shifts to the right. However, it seems like the sub-microscopic involving activation energy remained elusive for them. This finding is in accordance with the findings of high school and undergraduate students having difficulties in sketching and interpreting graphs despite being provided with accurate verbal explanations (Kolomuc and Tekin, 2011)

5.4 To determine the specific graphical literacy levels of grade 12 Physical sciences learners on rate and extent of reaction

The findings of this study revealed that the graphic literacy levels of the learners were very low. The external identification which is the lowest level of graphical literacy proved complex for most of the learners. Identifying variables in chemistry depend on the experiment variable that is being changed to get the results. The present findings seem to be consistent with the study by Doerr et al., (2013) who concur that learners who struggle with external identification do not have the mental models to engage in high-level construction or interpretation of graphs. The current study found that mathematical formalism and procedures on graphs were applied by most students to identify the independent variable which was concentration. This finding concurs with Planinic et al, (2013) that when learners are confronted with a question similar to a mathematics question, they are obliged to answer it in a standard “mathematical” way.

The results of the study also reveal some difficulties students experience in the reading beyond level. The findings indicated that students can’t apply their prior knowledge to interpret the graph thereby reducing the graphic literacy level. This finding corroborates the ideas of (Potgieter *et al*, (2008) and Secken *et al., (*2015), who observe that students take a long time to master the graphical literacy levels. The fundamental concepts and skills of science should be practiced over multiple years. The difficulties with graphical literacy span across the school system starting with primary schools (Shah & Hoeffner, 2002) and high school students (Tairab & Khalaf Al-Naqbi, 2004).

5.5 A summary of the research

The main focus of the study was to determine the graphical interpretation challenges and graphic literacy levels among grade 12 Physical Sciences learners in King Cetshwayo District in KwaZulu-Natal province. The study was framed within the mixed-methods (pragmatic) research paradigm. This study involved one hundred and forty-six (n = 146) grade 12 Physical Sciences learners and utilised a quantitative analytical descriptive (survey) and qualitative (interviews). The rate and extent of reaction concepts involved were rate of reaction, mechanism of the reaction and measuring rate of reaction. A three-tier rate and extent of reaction (RER) diagnostic questionnaire, which consisted of ten multiple-choice questions, was used to measure graphic literacy levels and to identify interpretation challenges.

The data collected through the RER questionnaires were analysed using descriptive statistics and interviews were analysed using scientifically completed response (nomothetic) and classification of explanations (ideographic). A conceptual framework for analysing the graphical interpretation challenges encountered by students integrated the Johnstone triangle and Bertin's graphical interpretation. The framework helped to define the constructs or variables investigated and their relationship within a given context. Both theoretical frameworks espouse an integrated approach to the interpretation of graphs.

This study has attempted to identify the graphic literacy levels and the challenges grade 12 Physical Sciences learners encounter when interpreting graphs. The main results were as follows:

1The identified problems with regards to graph interpretation identified included, identifying dependent and independent variables; interpreting slope and height changes on a Maxwell-Boltzmann curve.

2. The learners relied heavily / solely on definitions when interpreting graphs rate of reaction.

3. The learners usually transfer mathematical knowledge when interpreting variables on measuring rate of reaction graph.

4. The lack of knowledge hampered learners' understanding of mechanism of rate of reaction (Maxwell-Boltzmann equation).

5. The Physical Sciences learners displayed notable deficits in graphical literacy capabilities.
6. The Physical Sciences learners struggled to operate at even the most basic level of graphical literacy especially external identification.

5.6 LIMITATIONS

This study had the following limitations which might have affected the outcome of this study:

1. There were fifteen students who did not respond to the questionnaire. The reason could be that, the questionnaire was administered towards the end of the 2nd term and some learners were preparing for the mid-year exams and questionnaires were not adding to their School Based Assessment.

2. The study was restricted to only grade 12 Physical Sciences students in rural province in South Africa. The sample size was small and might not have been large enough to be representative of the entire population of Physical Sciences students in South Africa.

4. The rate of reaction concepts taught were limited to reaction rates, mechanisms of rate of reaction and measuring rate of reaction. There is need to study the whole spectrum of rate and extent of reaction.

5. The interview sample size of ten students drawn for this study might had been too small. A larger sample could have given a clearer picture of the challenges and graphical literacy levels held by grade 12 students. Interviews were used for triangulation and shedding light on the identified challenges.

5.7 RECOMMENDATIONS FOR FURTHURE RESEARCH

There is need to study the whole spectrum of rate and extent of reaction, as this study only focused on reaction rates, mechanisms of rate of reaction and measuring rate of reaction as part of the rate of reaction concepts. Additionally, only identifying the challenges that students are faced with such as having difficulty in interpreting graphs and having low levels of graphical literacy is not enough. The results of this study points to further the exploration of graphic literacy levels using the Kimura‘s seven levels. The Kimura levels can give a clear picture of the students’ graphical interpretation. However, it should be noted that the results of this study have highlighted problem areas that have implications for the teaching of rates of reaction in the FET phase.

5.7.1 Recommendations for instruction

Based on the findings of this study, the following steps may be recommended in the teaching rate of reactions:

- Translating among three representations. Educators should design activities that allow students to translate among the three representation in an effort to link visual feature information to relevant quantitative information.
- Emphasis should be placed on both the rate of a reaction as the slope of the graph and the change of the slope as the reaction progresses.
- Prospective teachers and in-service teachers must be mindful of the challenges students encounter when interpreting graphs. Increasing graphical literacy is a long time goal each grade must strive achieve.
- During teaching of rate of reaction graphs instructors should focus on related prior-knowledge and correspondences between mathematics and rates of reaction graphs.

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APPENDICES

APPENDIX A: PARENT AND GUARDIAN'S INFORMED CONSENT DECLARATION

(Parent or Guardian)

Project Title: ANNEXURE D: PARENT AND GUARDIAN'S INFORMED CONSENT DECLARATION

INFORMED CONSENT DECLARATION

(Parent or Guardian)

Project Title: **Exploring learners' graphical interpretation of rate and extent of reaction: a case study of King Cetshwayo District grade 12 learners**.

Ms Zanele Maryjane Qwabe from the Department of Mathematics, Science and Technology Education (MSTE) University of Zululand has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project, and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project exploring students' graphical interpretation of rate and extent of reaction: a case study of King Cetshwayo District grade 12 learners.
2. The University of Zululand has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate.
3. By participating in this research project my child/ward will be contributing towards improving 'Assessment for Learning' which necessitates that learners are given opportunities to reflect and to be informed about their learning, while the teachers persistently assess learners' task and adjust instruction to meet their needs.

4. My child/ward will participate in the project by interview, test and questionnaire administration

5. My child's/ward's participation is entirely voluntary and if my child/ward is older than seven (7) years, s/he must also agree to participate.

6. Should I or my child/ward at any stage wish to withdraw my child/ward from participating further, we may do so without any negative consequences.

7. My child/ward may be asked to withdraw from the research before it has finished if the researcher or any other appropriate person feels it is in my child's/ward's best interests, or if my child/ward does not follow instructions.

8. Neither my child/ward nor I will be compensated for participating in the research.

9. There may be risks associated with my child's/ward's participation in the project. I am aware that:

a. the following risks are associated with my participation: there are no known risks at the moment

b. the following steps have been taken to prevent the risks: N/A

c. there is a 0 % chance of the risk materialising: N/A

10. The researcher intends publishing the research results in the form of an article. However, confidentiality and anonymity of records will be maintained and that my or my child's/ward's name and identity will not be revealed to anyone who has not been involved in the conduct of the research.

11. I will not receive feedback/will receive feedback in the form of statistics regarding the results obtained during the study.

12. Any further questions that I might have concerning the research or my participation will be answered by Zanele Maryjane Qwabe (Ms)

13. By signing this informed consent declaration I am not waiving any legal claims, rights or remedies that I or my child/ward may have.

14. A copy of this informed consent declaration will be given to me, and the original will be kept on record.

I, ………………………………………………………….. have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of my child/ward during the research.

I have not been pressurised in any way to let my child/ward take part. By signing below, I voluntarily agree that my child/ward…………………………………………………………., who is …………….. years old, may participate in the above-mentioned research project.

…………………………………. …………………………………

Parent/Guardian's signature Date

APPENDIX B: PARTICIPANT INFORMED CONSENT DECLARATION
INFORMED CONSENT DECLARATION

(Participant)

Project Title:

from the Department of Mathematics, Science and Technology Education (MSTE) University of Zululand has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project, and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to explore students graphical interpretation of rate and extent of reaction: a case study of King Cetshwayo District grade 12 learners from the following six schools: **Empangeni High, Khombindlela Secondary, Ngono Secondary.**
2. The University of Zululand has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate.
3. By participating in this research project I will be contributing towards improving graphical interpretation.
4. I will participate in the project by completing the research questionnaire.
5. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.
6. I will not be compensated for participating in the research, but my out-of-pocket expenses will be reimbursed.
7. There may be risks associated with my participation in the project. I am aware that

a. the following risks are associated with my participation: there are no known risks at the moment

b. the following steps have been taken to prevent the risks: N/A

c. there is a 0 % chance of the risk materialising: N/A

8. The researcher intends publishing the research results in the form of an article. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone who has not been involved in the conduct of the research.

9. I will not receive feedback/will receive feedback in the form of statistics regarding the results obtained during the study.

10. Any further questions that I might have concerning the research or my participation will be answered by

11. By signing this informed consent declaration I am not waiving any legal claims, rights or remedies.

12. A copy of this informed consent declaration will be given to me, and the original will be kept on record.

I, ……………………………………………………………………….. have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

Participant's signature

Date……………………………………………..

APPENDIX C: ETHICAL CLEARANCE CERTIFICATE

UNIVERSITY OF ZULULAND
RESEARCH ETHICS COMMITTEE
(Reg No: UZREC 171110-030)

RESEARCH & INNOVATION
Website: http://www.unizulu.ac.za
Private Bag X1001
KwaDlangezwa 3886
Tel: 035 902 6273
Email: ViljoenD@unizulu.ac.za

ETHICAL CLEARANCE CERTIFICATE

<table>
<tr><td>Certificate Number</td><td colspan="7">UZREC 171110-030 PGM 2021/104</td></tr>
<tr><td>Project Title</td><td colspan="7">Exploring students' graphical interpretation of rate and extent of reaction: A Case Study of King Cetshwayo District grade 12 learners</td></tr>
<tr><td>Principal Researcher/ Investigator</td><td colspan="7">Z.M Qwabe</td></tr>
<tr><td>Supervisor and Co-supervisor</td><td colspan="4">Dr T.W Chinaka</td><td colspan="3"></td></tr>
<tr><td>Department</td><td colspan="7">Mathematics, Science and Technology Education</td></tr>
<tr><td>Faculty</td><td colspan="7">Education</td></tr>
<tr><td>Type of Risk</td><td colspan="7">Medium Risk – Data collection from people</td></tr>
<tr><td>Nature of Project</td><td>Honours/4th Year</td><td></td><td>Master's</td><td>x</td><td>Doctoral</td><td></td><td>Departmental</td></tr>
</table>

The University of Zululand's Research Ethics Committee (UZREC) hereby gives ethical approval in respect of the undertakings contained in the above-mentioned project. The Researcher may therefore commence with data collection as from the date of this Certificate, using the certificate number indicated above.

Special conditions:

(1) This certificate is valid for 2 Months from the date of issue.
(2) Principal researcher must provide acceptance letters of where they will do their research and submit to UZREC to acquire a 1-year certificate [due date-27 September 2021]
(3) Principal researcher must submit a report at the end of project in respect of ethical compliance.
(4) The UZREC must be informed immediately of any material change in the conditions or undertakings mentioned in the documents that were presented to the meeting.

The UZREC wishes the researcher well in conducting research.

Professor Nokuthula Kunene
Chairperson: University Research Ethics Committee
Deputy Vice-Chancellor: Research & Innovation

26 July 2021

CHAIRPERSON
UNIVERSITY OF ZULULAND RESEARCH
ETHICS COMMITTEE (UZREC)
REG NO: UZREC 171110-30
26 -07- 2021
RESEARCH & INNOVATION OFFICE

APPENDIX D: PERMISSION TO CONDUCT RESEARCH IN THE KZN DoE INSTITUTIONS

KWAZULU-NATAL PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

OFFICE OF THE HEAD OF DEPARTMENT

Private Bag X9137, PIETERMARITZBURG, 3200
Anton Lembede Building, 247 Burger Street, Pietermaritzburg, 3201
Tel: 033 392 1051
Email: buyi.ntuli@kzndoe.gov.za

Enquiries: Buyi Ntuli **Ref.**:2/4/8/7137

Ms Zanele Maryjane Qwabe
P.O. Box 579
Steenbok Crescent
Nyala Park
EMPANGENI
3880

Dear Ms Qwabe

PERMISSION TO CONDUCT RESEARCH IN THE KZN DoE INSTITUTIONS

Your application to conduct research entitled: **"EXPLORING STUDENTS GRAPHICAL INTERPRETATION OF RATE AND EXTENT OF REACTION: A CASE STUDY OF KING CETSHWAYO DISTRICT GRADE 12 LEARNERS:"** in the Kwazulu-Natal Department of Education Institutions has been approved. The conditions of the approval are as follows:

1. The researcher will make all the arrangements concerning the research and interviews.
2. The researcher must ensure that Educator and learning programmes are not interrupted.
3. Interviews are not conducted during the time of writing examinations in schools.
4. Learners, Educators, Schools and Institutions are not identifiable in any way from the results of the research.
5. A copy of this letter is submitted to District Managers, Principals and Heads of Institutions where the Intended research and interviews are to be conducted.
6. The period of investigation is limited to the period from 29 July 2021 to 31 August 2023.
7. Your research and interviews will be limited to the schools you have proposed and approved by the Head of Department. Please note that Principals, Educators, Departmental Officials and Learners are under no obligation to participate or assist you in your investigation.
8. Should you wish to extend the period of your survey at the school(s), please contact Miss Phindile Duma at the contact numbers above.
9. Upon completion of the research, a brief summary of the findings, recommendations or a full report/dissertation/thesis must be submitted to the research office of the Department. Please address it to The Office of the HOD, Private Bag X9137, Pietermaritzburg, 3200.
10. Please note that your research and interviews will be limited to schools and institutions in KwaZulu-Natal Department of Education.

Dr. EV Nzama
Head of Department: Education
Date: 29 July 2021

GROWING KWAZULU-NATAL TOGETHER

APPENDIX E: QUESTIONNAIRE
University of Zululand

Faculty of Education

Department of Mathematics and Science Education

Researcher: Qwabe Z. M.

Rates of Chemical Reactions Alternative Conceptions Test

PRE-TEST

Biographical information:

1. Student assigned No: ____

2. Gender: Male ☐ Female ☐

3. Age ______________________________

INSTRUCTIONS AND INFORMATION

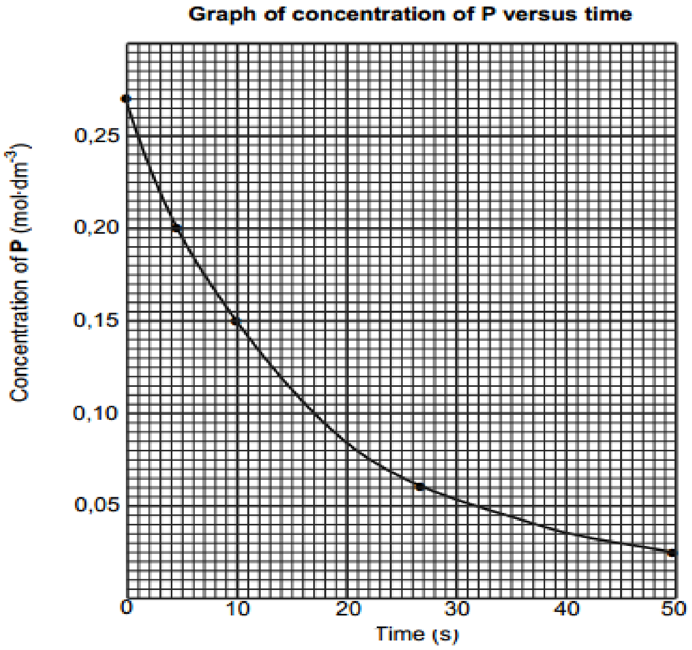
1. This question paper consists of 10 multiple choice questions. Answer **ALL** the questions.
2. Each question consists of **three** parts.

   Part 1-multiple choice question

   Part 2-space provided to justify or give a reason for answer in Part 1

   Part 3-deals with how confident you are in your choice of answers.
3. Motivate the choice of your answer in the space provided and be brief.
4. Non-programmable calculators may be used.
5. Appropriate mathematical instruments may be used.
6. Wherever motivations, discussions, etc. are required, be brief.
7. Round off your final numerical answers to a minimum of TWO decimal places.

1.1 The graph below shows the decomposition of a gas P according to the following equation: $P(g) \rightarrow 2Q(g) + R(g)$ **ΔH < 0**



Define the term rate of reaction in words by referring to the graph

A rate of change of concentration of **(P)**

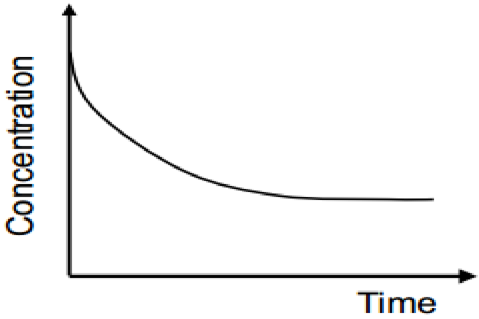
B speed at which a reaction of (**P**) takes place

C change in the amount of reactants or products **(P)**

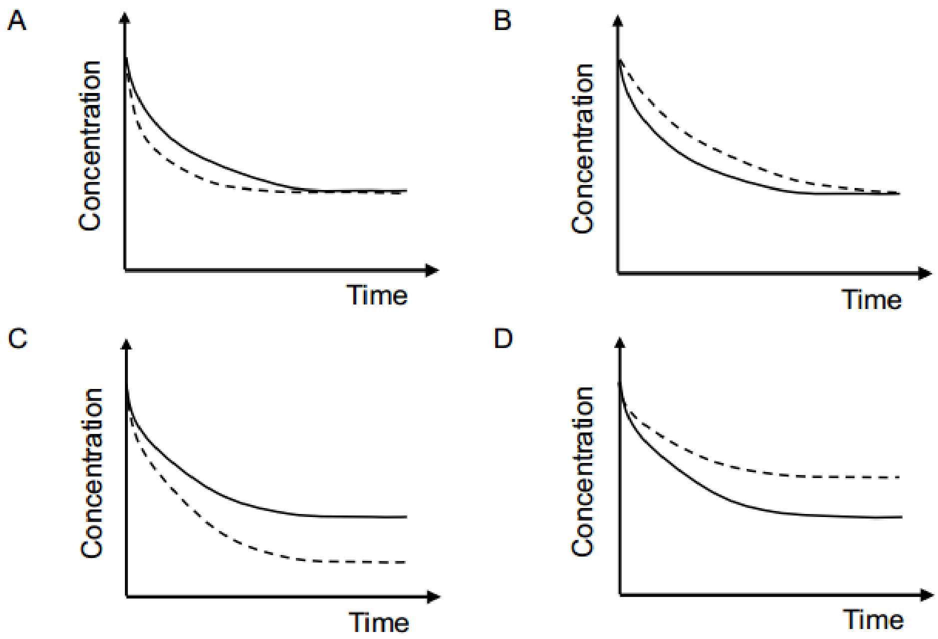
D change in the concentration of reactants or products (**P**) per unit

Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

1.2 The graph below represents the change in concentration of a reactant against time for a chemical reaction

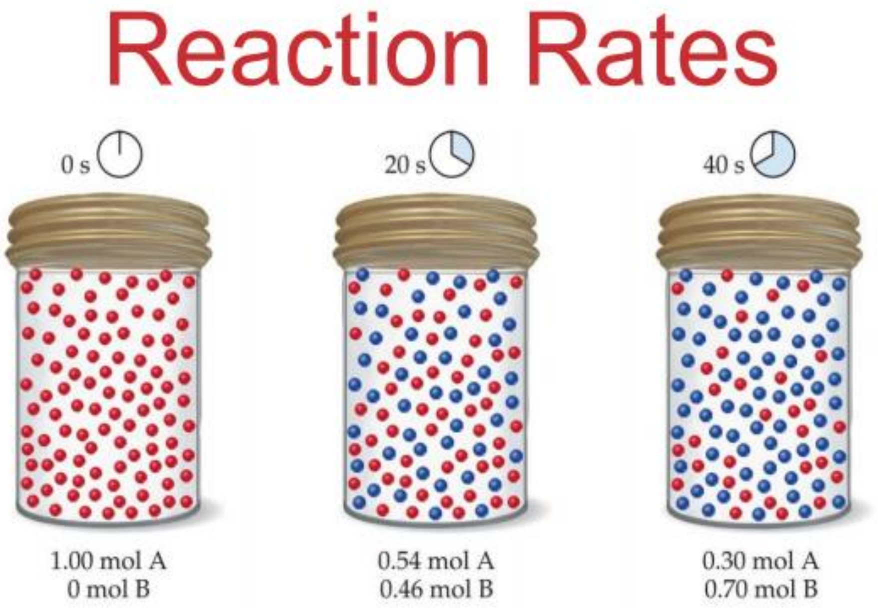


In which ONE of the following graphs does the dotted line show the effect of a catalyst on this reactant?



Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

1.3 Rates of reactions can be determined by monitoring the change in concentration of either reactants or products as a function of time.



Calculate the average rate of appearance of B over the time interval from 0 to 40 s.

A 0.70

B 0.0175

C 2.33

D 28

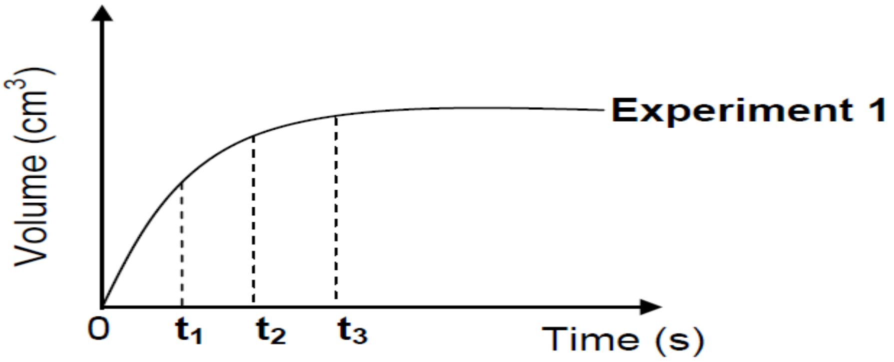
Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

1.4 Dilute acids, indicated in the table below, react with EXCESS zinc in each of the three experiments to produce hydrogen gas. The zinc is completely covered with the acid in each experiment.

EXPERIMENT	DILUTE ACID
1	100 cm^3 of 0,1 $mol·dm^{-3}$ H_2SO_4
2	50 cm^3 of 0,2 $mol·dm^{-3}$ H_2SO_4
3	100 cm^3 of 0,1 $mol·dm^{-3}$ HCℓ

The volume of hydrogen gas produced is measured in each experiment.

The graph below was obtained for **Experiment 1**.



Use this graph and answer the following question: At which time is the reaction rate the highest?

A t = 0

B t_1

C t_2

D t_3

Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

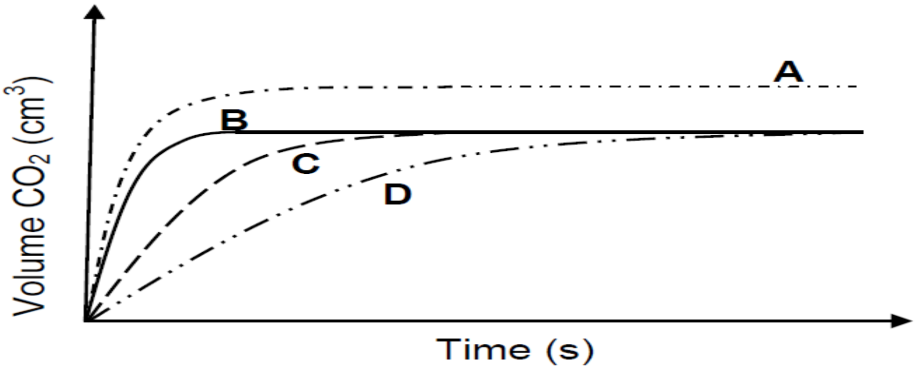
1.5 Learners use the reaction between IMPURE POWDERED calcium carbonate and excess hydrochloric acid to investigate reaction rate. The balanced equation for the reaction is:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

They perform four experiments under different conditions of concentration, mass and temperature as shown in the table below. They use identical apparatus in the four experiments and measure the volume of gas released in each experiment.

	EXPERIMENT 1	2	3	4
Concentration of acid ($mol\cdot dm^{-3}$)	1	0,5	1	1
Mass of impure calcium carbonate (g)	15	15	15	25
Initial temperature of acid (°C)	30	30	40	40

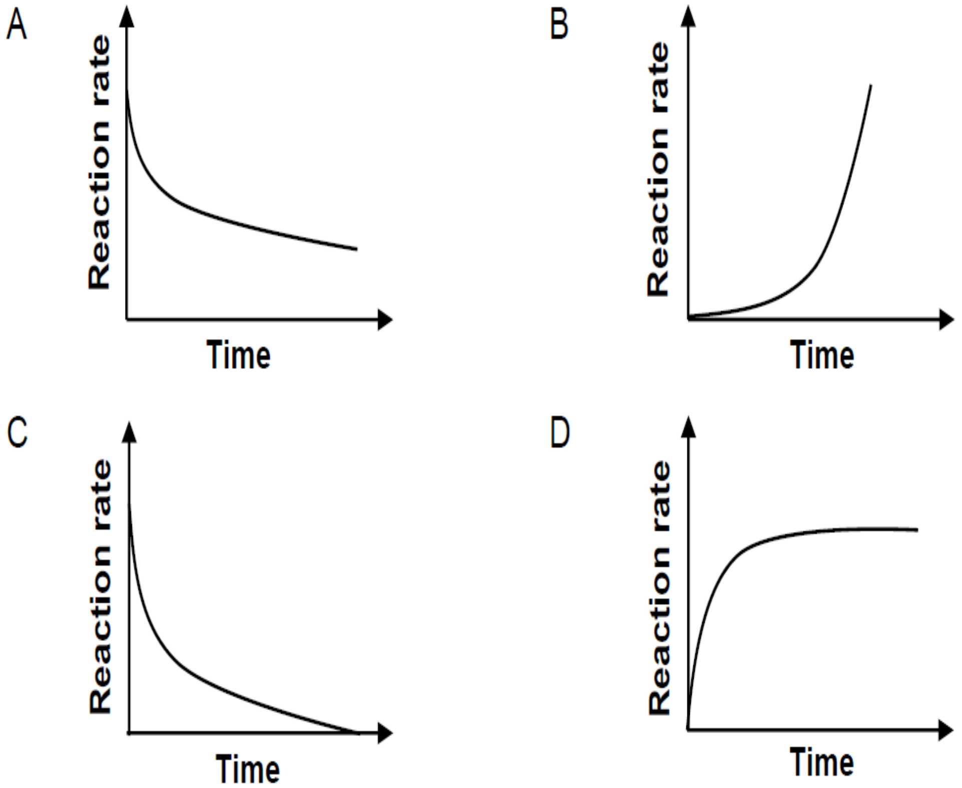
The learners obtain graphs **A**, **B**, **C** and **D** below from their results.



Which ONE of the graphs (**A**, **B**, **C** or **D**) represents experiment **1**?

Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

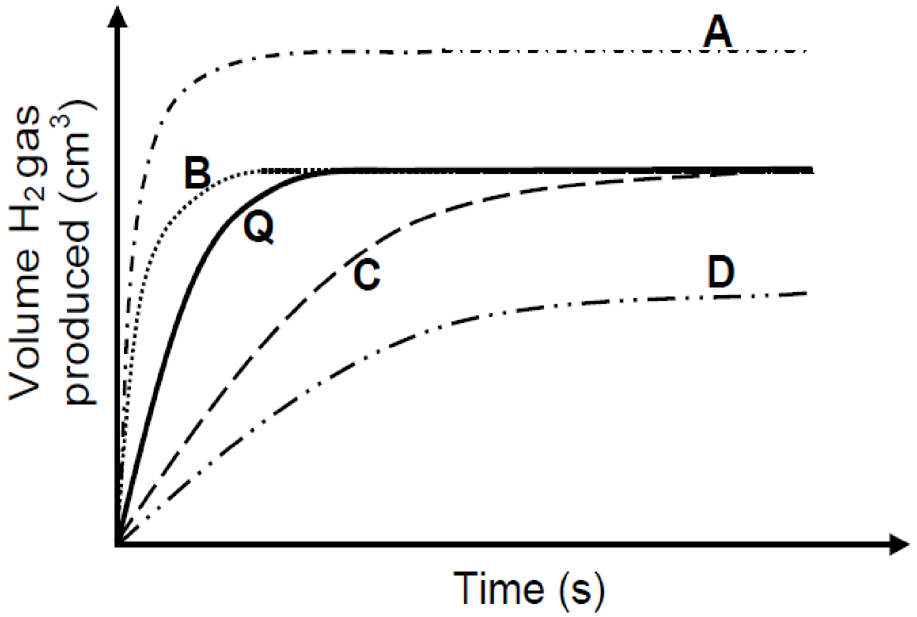
1.6 Which ONE of the reaction rate versus time graphs below best represents the reaction between magnesium and EXCESS dilute hydrochloric acid?



Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

1.7 Graph **Q** (the solid line) below was obtained for the reaction of 100 cm^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 100 cm^3 of a 0,1 mol·dm^{-3} CH_3COOH solution with excess magnesium powder?

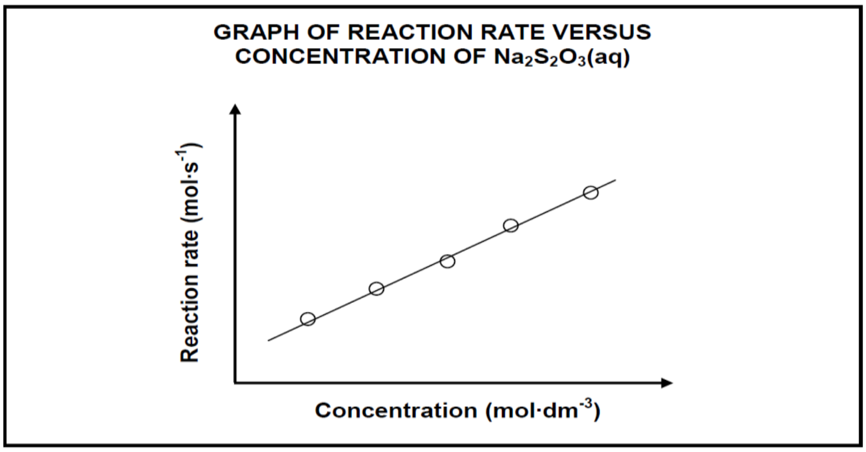


Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

1.8 Learners use the reaction of a sodium thiosulphate solution with dilute hydrochloric acid to investigate several factors that affect the rate of a chemical reaction. The balanced equation for the reaction is:

$Na2S2O3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + SO2(g) + S(s) + H2O(\ell)$

The results obtained are shown in the graph below:



Which ONE of the of the following is the dependent variable?

A concentration

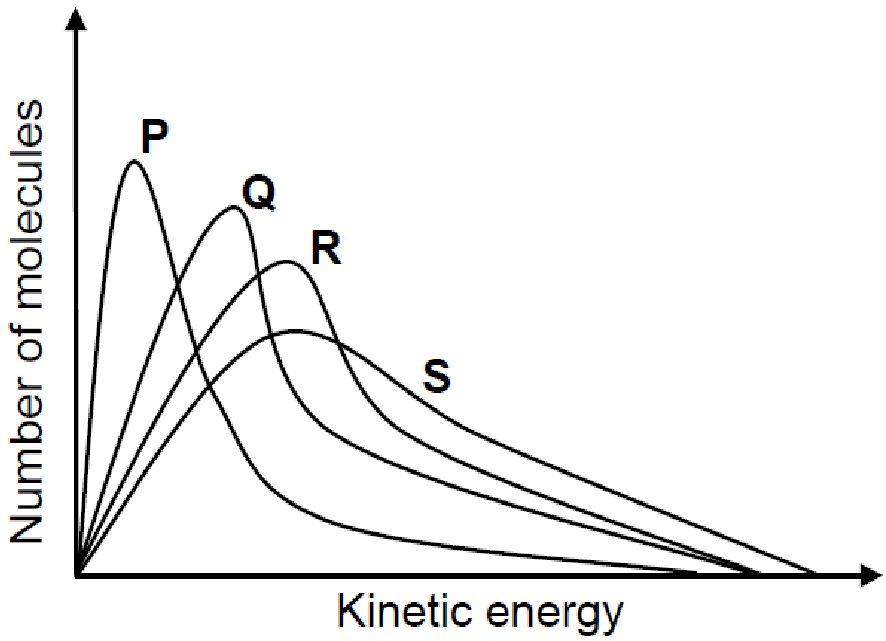
B sodium thiosulphate

C dilute hydrochloric acid

D rate of the reaction

Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

1.9 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**

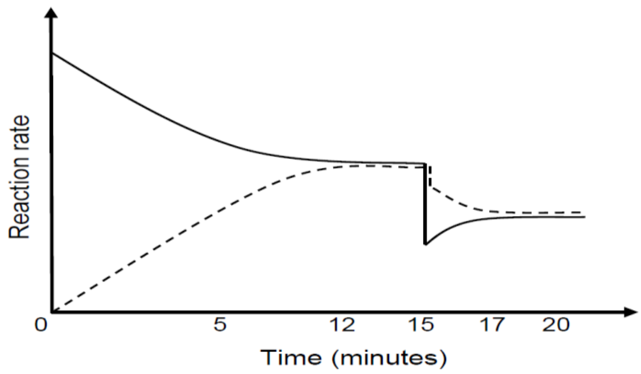
D **S**

Confidence Rating	**1** Just Guessing	**2** Very Unconfident	**3** Unconfident	**4** Confident	**5** Very Confident	**6** Absolutely Confident

1.10 Pure hydrogen iodide, sealed in a 2 dm^3 container at 721 K, Decomposes according to the following balanced equation:

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g) \quad \Delta H = +26\ kJ{\cdot}mol^{-1}$$

The graph below shows how reaction rate changes with time for this reversible reaction.



Choose the correct statement from the following:

A the concentration of HI(g) does not change between the 12^{th} an minutes.

B the concentration of $H_2(g)$ increases between the 12^{th} and 15^{th} minutes

C the concentration of $I_2(g)$ decreases between the 12^{th} to 15^{th} minutes

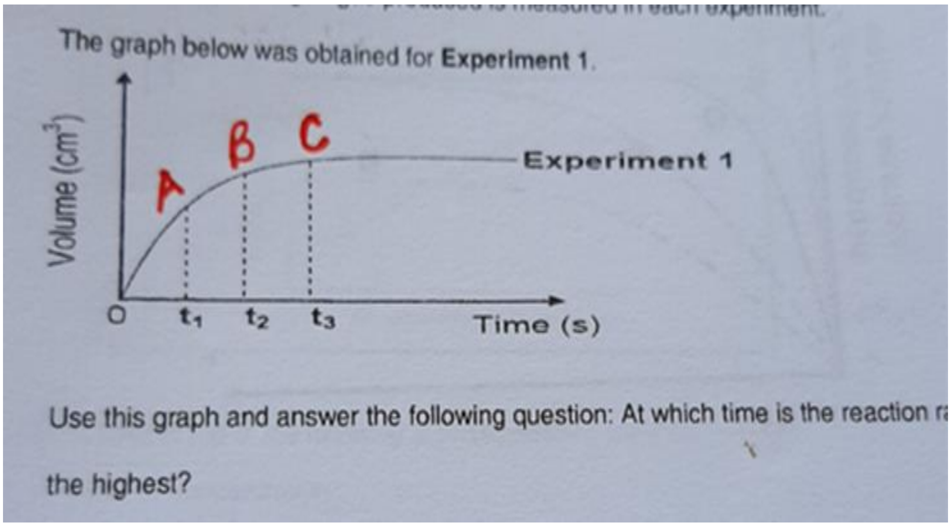
D the concentration of both reactant and products increases between the 12^{th} and 15^{th} minutes

Confidence Rating	1	2	3	4	5	6
	Just Guessing	Very Unconfident	Unconfident	Confident	Very Confident	Absolutely Confident

<u>APPENDIX F</u>: INTERVIEW SCHEDULE

QUESTIONNAIRE SCHEDULE FOR INTERVIEWS

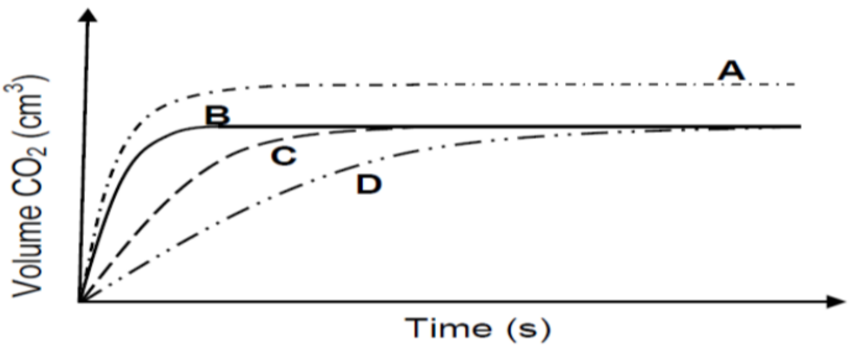
Question 1



QUESTION 2

	EXPERIMENT			
	1	**2**	**3**	**4**
Concentration of acid ($mol \cdot dm^{-3}$)	1	0,5	1	1
Mass of impure calcium carbonate (g)	15	15	15	25
Initial temperature of acid (°C)	30	30	40	40

The learners obtain graphs **A**, **B**, **C** and **D** below from their results.

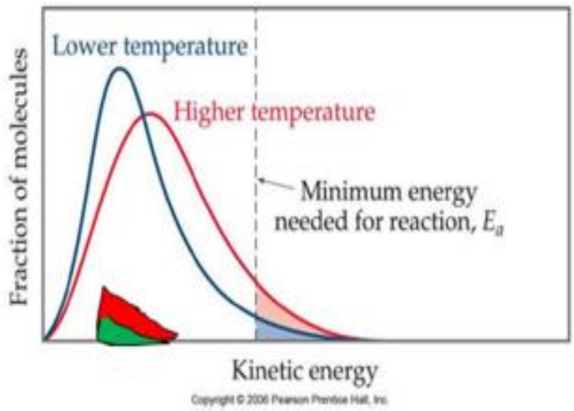


Which ONE of the graphs (**A**, **B**, **C** or **D**) represents experiment **1**?

3. Using the Maxwell-Boltzmann distribution below explain how the graph is affected by:

- increasing temperature
- using a catalyst

Maxwell-Boltzmann Distribution



APPENDIX H: Physical Sciences CAPS Document

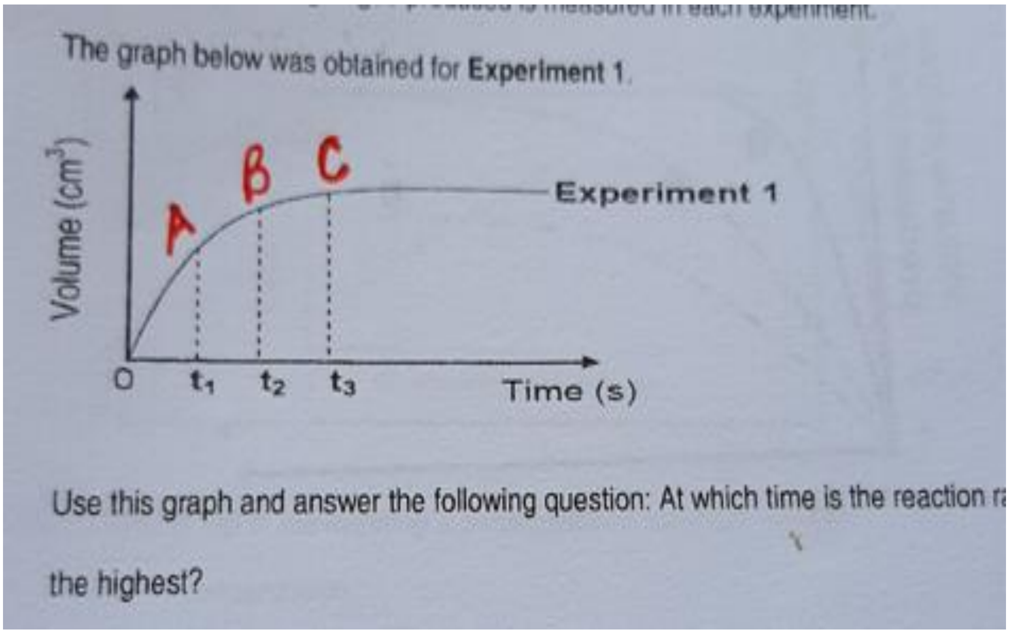
GRADE 12 CHEMISTRY *(CHEMICAL CHANGE)* TERM 2

Time	Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
4 HOURS	**Rate and Extent of Reaction:**				
2 hours	Rates of reaction and factors affecting rate (nature of reacting substances, concentration [pressure for gases], temperature and presence of a catalyst);	• Explain what is meant by reaction rate • List the factors which affect the rate of chemical reactions. (Surface area (solid), concentration (solution), pressure (gas), temperature, and catalyst) • Explain in terms of collision theory how the various factors affect the rate of chemical reactions	**Experiments:** Determine the: (1) Effect of different concentrations of- vinegar and baking soda (2) Effect of temperature - vinegar and baking soda; Alka Seltzer or Cal-C-Vita (3) Effect of temperature and concentration - potassium iodate (0.01 M), soluble starch, $Na_2S_2O_3$ and H_2SO_4 (iodine clock reaction) (4) Effect of catalyst - hydrogen peroxide and manganese dioxide; burning a sugar cube with and without dipping in activated carbon. Also adding a piece of copper to the reaction between zinc and HCl will accelerate the rate	**Materials:**	This section must be done very well; deep understanding of this section gives the foundation for incisive knowledge later. Link chemical systems grade 12 to industrial processes. Very useful PHET simulations of reaction rate are available. Also others like Greenbowe simulations for redox reactions
1 hour	Measuring rates of reaction;	• Suggest suitable experimental techniques for measuring the rate of a given reaction including the measuring of gas volumes, turbidity (e.g. precipitate formation), change of colour and the change of the mass of the reaction vessel	**Experiment** (1) Determine the reaction rate and the influence of all the rate factors in the reaction of Zn and HCl **Recommended experiment for informal assessment** (2) Determine the quantitative reaction rate and drawing graphs in the reaction between $Na_2S_2O_3$ and HCl. Turbidity is seldom quantitatively accurate, but it is useful	**Materials:** Sodium sulphite, dilute hydrochloric acid, 5 test tubes, glass beaker, propette, 2,5 ml syringe, white paper, pencil, stop watch or cell phone with stop watch function, ice, burner, spatula, graph paper.	This is an important section for illustrating and assessing understanding of investigative process, the relationship between theory and experiment, the importance of empirical data and mathematical modelling of relationships. Teaching about practical investigations should form part of this section

APPENDIX I: TRANSCRIPTS OF STUDENT INTERVIEWS

<u>A: Interview with student A (8 00 – 8 20am)</u>

Researcher: Thank you very much for coming. It will take us 20 minutes. Once again thank you for your time. Umm let's start. Explain what happens at the following terms (A, B and C) and the use the graph to explain where the reaction is the highest?



Student A: The rate of reaction is determined by monitoring volume as a function of time. The average rate of reaction decreases as the reaction proceeds. As the reaction proceeds there are fewer collisions between reactant molecules. The rate of reaction is higher at A as compared at B. At C the reaction has reached completion. All this can be explained using the Collision theory. At A more collisions leading to a high frequency of effective collision turning reactants into products. If we use a more concentrated acid the shape of the graph shifts to the left, the staring and end point

Researcher: Can you explain the term rate?

Student A: To me rate is just the gradient when you have two variables a dependent and independent. A clear explanation of the rate can be described graphically. I understand it better when I use graphs. Rates of reaction is all about the rate the gradient how it moves as the reaction progresses.

Researcher: Question 3 and 4 is about the Maxwell-Boltzmann Distribution curve how does temperature, catalyst and concentration affect the rate of reaction?

Student A: Temperature deals with the average kinetic energy of the particles. If the temperature increases the kinetic energy of the particles also increases. There will be a high frequency of collisions and effective collisions and the rate increases. Activation energy remains the same though. The Maxwell- Boltzmann distribution is all about statistics. In any reaction very few molecules have the sufficient energy to form products. If temperature increases the small part of the graph after the point of the activation energy increases.

Researcher: Thank you very much (Researcher switches off tape recorder)

APPENDIX H: TRANSCRIPTS OF STUDENT INTERVIEWS

EXPLORING STUDENTS GRAPHICAL INTERPRETATION OF RATE AND EXTENT OF REACTION: A CASE STUDY OF KING CETSHWAYO DISTRICT GRADE 12 LEARNERS

ORIGINALITY REPORT

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1	Maia Popova, Stacey Lowery Bretz. "Organic chemistry students' interpretations of the surface features of reaction coordinate diagrams", Chemistry Education Research and Practice, 2018 Publication	2%
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