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Exploring physical sciences learners’ graphical interpretation of rate and extent of reaction graphs

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Abstract

Graphs are very important in all areas of science, and they are an essential part of tertiary, high school, and primary school learning, worldwide. A solid understanding of graphical interpretation is essential for understanding today's world and becoming scientifically literate. The aim of this study was to explore grade 12 learners’ graphical interpretation of the rate and extent of reaction topic. A mixed-method methodology 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. A validated two-tier diagnostic questionnaire and semi-structured interviews were used to collect data. Quantitative data were analysed using SPSS version 25 and inductive coding was used to qualitative data. The Johnstone triangle and the Peircean semiotic modes were employed as the theoretical framework. The findings indicated that learners rely on definitions to interpret graphs. Most of the learners failed to interpret the salient features of the graphs. The findings of this study are diagnostic, and they assist module designers and educators in determining challenges learners face when interpreting graphs in chemistry. Implications for instructional approaches particular to the rate of reaction graphs are discussed. Further studies are needed on instructional practices and their effect on students’ ability to interpret rate and extent of reaction graphs.

Keywords: Graphical interpretation; rate and extent of reaction; Johnstone triangle.

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1. Introduction

Reaction rates measure how fast a reaction is progressing through monitoring of a suitable parameter that changes with time. The parameters can be volume, pressure, or concentration of the reaction system. The rates of reaction are affected by many variables, and graphs are used to summarise data sets and complex relationships between variables effectively. 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 high school chemistry curriculum. The practice of visually representing scientific data with graphs, diagrams, and tables is central to science.

The 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 chemistry, physics, and mathematics education reveal a widespread difficulty in understanding, interpretation and applying rates of change concepts among high school students. Studies on the teaching and learning of chemical kinetics have identified a variety of difficulties and misconceptions that persist after instruction (Bain & Town, 2016; Potgieter et al., 2008; Planinic et al., 2016). Seethaler et al. (2018) categorised students' challenges with rate and extent of reaction 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 challenge among grade 12 Physical Sciences high school students. The ability of a graph reader to interpret graphs created by others or themselves is known as graph interpretation. Graph interpretation is a fundamental skill that is necessary for all students to make sense of and communicate information presented in graphs, which are present in everyday life (Glazer, 2011). Graduate and high school chemistry students find it difficult to construct and interpret graphs and may suffer anxiety when faced with chemistry problems involving graphs (Potgieter et al., 2008; Secken et al., 2015).

Even when graphs provide accurate values, high school students and tertiary institution undergraduates find it difficult to interpret accurate reaction rates versus time graphs (Kolomuc & Tekin, 2011). One of the challenges in interpreting reaction rates graph was reported by Moore et al. (2014), that curved graphs involve changes in both height and slope and students find it difficult to interpret them. Furthermore, students struggle to interpret graphs where the rate has a negative sign. They commonly confuse the negative sign as the y- coordinate and they drop the negative sign (Doerr et al., 2013).

The South African Physical Sciences National Diagnostic Analytical Reports or the chief marker reports from 2016 to 2020 have revealed a decline in students' performance in rates of reaction and extent of reaction. The diagnostic report of 2016 reported that most of the matriculants lacked an application of knowledge on rates of reaction. Even simple recall questions were poorly answered. Students failed to relate the gradient to the rate of the reaction and incorrect volume values from the graph were added. The chief marker encouraged teachers to help students to interpret given data and identify variables by exposing students to more exercises which require practical skills starting from Grade 10.

In 2017, the diagnostic report revealed that students struggled to identify the reaction rate involving the change in volume per unit time. The students lacked basic skills to interpret graphs and could not draw graphs that represented the data in the table. A question that involved stoichiometric and rate calculation was a challenge to most of them. Teachers were encouraged to integrate stoichiometry with rate and extent of reaction at the Grade 12 level.

The report of 2019 showed that many students swopped the independent and the dependent variable. Many students did not know how to approach the calculation and calculate the average rate from the graph. The National Diagnostic Reports (2020) reported the persistence of challenges in answering graph related questions. Students still struggled to identify variables, give correct reasoning for their answers, and interpret, draw and analyse graphs. Learners also struggled to interpret the Maxwell-Boltzmann energy distribution curves. Despite recommendations and workshops, the topic has always been problematic. Rate and extent of reaction can now be identified as a perennial challenge in the Physical Sciences. Recent reviews recommended further research into how students interpret graphs of rate of reactions and reaction mechanisms to investigate the possible causes of students' difficulties with these concepts (Bain & Towns, 2016; Kaya & Geban, 2012).

There is a paucity of research on students' challenges with graph interpretations in reaction kinetics (Bain & Towns, 2016); it is valuable to examine how grade 12 Physical Sciences students interpret graphs on rate of reactions. Therefore, this study was guided by the following research questions:

1. How do grade 12 Physical Sciences students interpret graphs of rate of reaction?
2. What challenges, if any, do grade 12 Physical Sciences students encounter when interpreting graphs of rate and extent of reactions?

1.1 Theoretical framework

The study of graphical representation falls within Presmeg's (2008) description of science as a study of sign systems. A graphic representation consists of symbols, notation, and imagery. Mudaly and Rampersad (2010) described the connection of sign systems and meanings as semiotic activity. The present study adopted the Peirce triad semiotics as the theoretical framework. The study of signs, which refers to symbols that represent something other than themselves, is called semiotics. Peirce's triadic model (Figure 1) describes the relationship between the representamen (that which represents something else), the object (that which it stands for or represents) and the interpretant (the sense or possible meaning that the representamen might convey) (Presmeg, 2008). A sign is formed by these three parts, known as the "semiotic triad". Mudaly (2014) posited that interpretation or meaning is not directly attached to the sign; instead, it is mediated through the reciprocity among representamen, interpretant, and object.

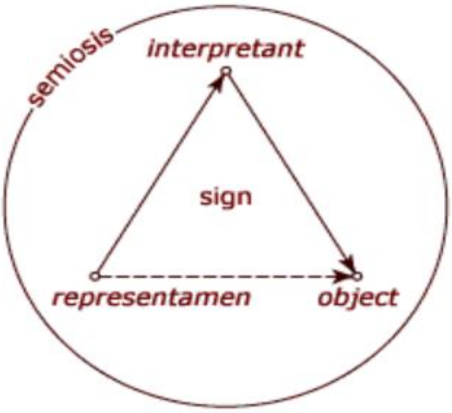


Figure 1

Peirce's Triadic Model

The Peircean semiotics can be considered a solid theoretical framework for understanding the representations of chemical knowledge, especially from the context of graph interpretation. A semiotic representation includes chemical language, symbols, chemical equations, graphs, and schemes. The idea that chemistry knowledge can be understood on three fundamental 'levels' or 'representations' was suggested by Alex Johnstone (2009) to include the macroscopic, symbolic, and sub-microscopic levels (Figure 2).

Macroscopic level describes the level of observation that uses senses to describe matter during laboratory experiments. The macroscopic level includes all learners can see, smell, and feel with their sensory organs. The sub-microscopic level consists of the atoms, molecules and ions that are dynamic in rate and extent of reaction. They are also unseen and consist of explanatory models. The representational or symbolic level makes chemical phenomena abstract. The representational level includes the symbols, equations, mathematical formulae, graphs, and diagrams. In the present study, the representational level consisted of rate and extent of reaction graphs. Although science occurs on a visible level, its explanations are often abstract or not visible.

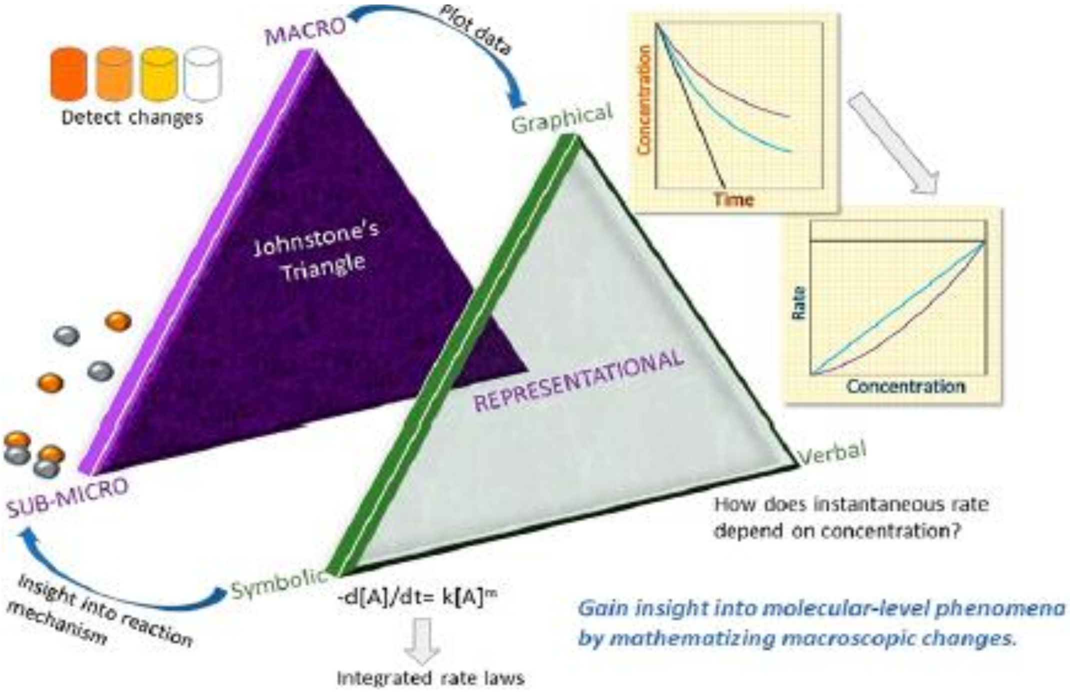


Figure 2

Johnstone's Triangle Adopted from Seethaler (2018)

The utility of the Johnstone's triangle framework is not restricted to chemistry alone. Wright et al. (2016) used the framework to study how students interpreted catalysis graphs in biology. According to Gkitzia et al., (2020), the Johnstone' triangle theory outlines a way to describe the various components found in chemistry in three levels. The use of these three levels as modes of illustration assist students' learning, makes interpretation of ideas less complicated and assemble deeper appreciation of chemical kinetics (Keiner & Graulich, 2020). Students' understanding of chemistry concepts is enhanced by the interplay between the three levels. An important skill in chemistry is translation, which is the ability to move from one level of the triangle to another (Seethaler et al., 2018). In the present study students were expected to translate among the levels when interpreting rate of reaction graphs.

1.2 Literature Review

A considerable amount of literature exists on graph interpretation (Glazer, 2011; Bowen & Ruth, 2005; Shah & Hoeffner, 2002) and much of it builds directly or indirectly on Bertin's (1983) graph interpretation theory. The graph is an essential part of any scientific study, and it is used in all disciplines in universities, secondary schools, and even primary schools worldwide. Several studies in science education studies showed that students still have many difficulties with graph interpretation at university level, as well as at earlier levels (Glazer, 2011; Planinic et al, 2013; Ivanjek et al. (2016); Araujo et al. 2008; Nguyen and Rebello 2011; Christensen and Thompson 2012; Wemyss and van Kampen, 2013; Rodriguez et al., 2020).

A variety of factors affect students' interpretation of a graph, including their background, their understanding of the context in which the graph is set, and the inferential processes required by the graph operation (Phage *et al*., 2017). Their findings on interpretation of kinematics graphs showed that students generally transferred their mathematics knowledge on coordinate reading and representations of straight-line functions to the kinematics contexts. In both the mathematics and kinematics contexts, poor performance was due to insufficient understanding of the gradient concept. Bollen et al., (2016) suggested that the barrier to learning chemistry graphs is not just the mathematical formalism, but also a missing connection between mathematics and chemistry.

Glazer (2011) argued that there is a growing emphasis on the development of scientific inquiry skills that requires display and interpretation of data. The interpretation of graphs, however, is a complex and challenging task. Competence in interpreting graphs is influenced by many factors, including aspects of the graph itself, the content of the graph and the viewer's prior knowledge of the graph (Planinic et al., 2013).

All students need to have the ability to interpret graphs in their everyday lives, since graphs are universal in the world today. Glazer (2011) identified three levels of interpretation that had been used in science education, namely elementary, intermediate, and advanced. At the elementary level, the interpretation requires the student to locate and read specific data points. Intermediate and advanced consist of finding trends and relationship and analysis of relations respectively. Christensen and Thompson (2012) reported that when all three levels are used in the same question, learners struggle. Furthermore, the complexity of the graph is an important factor in interpretation. The complexity of the number of variables represented in the graph and the domain knowledge the reader possesses influence the interpretation of the graph.

Learners often encounter interpretation challenges when the graph is viewed as a picture or as lateral pictures of a context neglecting the abstract quantitative information (Glazer, 2011). Therefore, it is important for learners to have adequate quantitative knowledge about rate and extent of reaction before interpreting a graph. In previous research, Ivenjek et al. (2016) reported that learners struggle to interpret the gradient, height of the graph and area under the graph. Glazer (2011) argued that the interpretation of graphs should be explicitly taught in schools due to their importance and complexity in chemistry education. There is a paucity of literature of graphical interpretation since most studies had been carried out in isolated instances instead of monitoring change over time (Gültepe, 2016).

2. Research Design

The present study adopted a sequential exploratory research design which included a semi-structured interviews and quantitative analytical descriptive (survey) questionnaire. Our principal focus was on how students interpreted rate of reaction graphs. The objective of the mixed-methods study is to understand phenomena in context, using both quantitative and qualitative methodologies, such as real-life settings, in which the researcher does not manipulate the phenomenon of interest (Kumar, 2019). A qualitative research study that gathers data using semi-structured interviews allows the researcher to ask questions that enable a deeper understanding of the phenomenon being studied.

2.1 Participants

The study took place at a large, Department of Basic Education district (King Cetshwayo) in KwaZulu-Natal province, South Africa. The researchers obtained approval for the study from the University Ethical Reviews Committee and Department of Basic Education before recruiting for questionnaires and interviews. Learners and parents/guardians consented prior to participating in the research study. 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. The accessible population was 146 grade 12 Physical Sciences learners. Of this population, 14 students were purposefully selected for the interviews according to gender and the range of percentage marks obtained in the questionnaire. All the interviews took place observing

COVID-19 protocols and regulations. To protect the identity of students who participated in the study, their names were replaced by letters of the alphabet.

2.2 Instrumentation

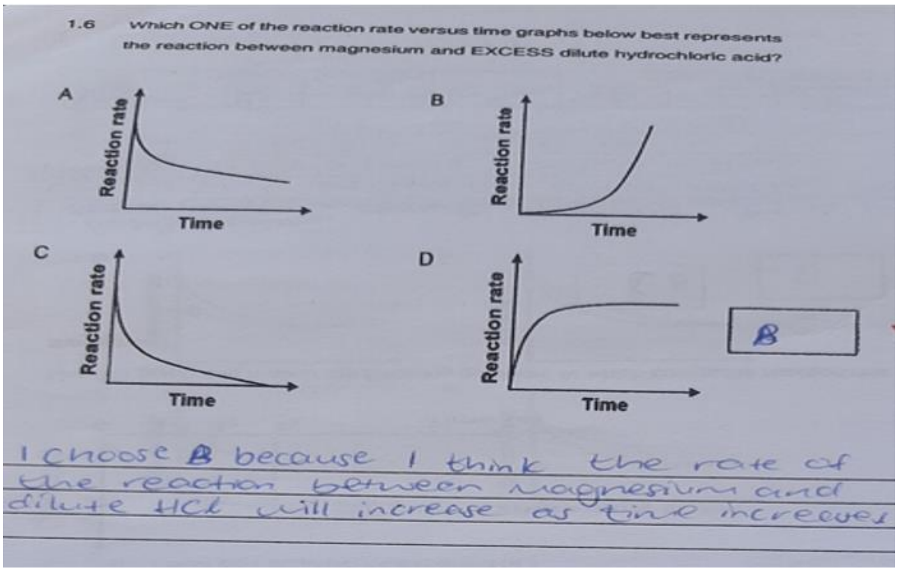
The development of the two-tier questionnaire involved defining the content boundaries of rate and extent of reaction. The South Africa's high school National Curriculum Statement (NCS) for Physical Sciences (rate and extent of the reaction) was used to define the content scope of the study, encompassing reaction rates, factors affecting rates, concentration, and temperature. Distractors in the first tier were obtained from the literature of a review of studies in chemical kinetics (Bain & Towns, 2016; Glazer, 2011; Rodriguez et al., 2020).

The questions were divided into three levels of graphical interpretation, namely elementary, intermediate, and overall, based on Glazer (2011). In the elementary level, learners find a single piece of information at one location. In the overall level, learners notice patterns from groups of graphing elements, glean information from multiple sources, and combine information into a more general statement.

To check the content validity, the questionnaire was examined by four high school Physical Sciences teachers. Content validity was established by presenting the questionnaire and objectives to teachers to ensure that the content fall within the scope. Teachers were requested to fill a check list (yes or no), followed by remarks on each question. A reliability coefficient of 0.71 was established using the Kuderson-Richardson correlation moment coefficient.

2.3 Interview protocol

The learners' responses to the five two-tier questions were used in the interviews. The interviews consisted of two stages. The first stage of the interview allowed the students to engage with their questionnaire responses (Figure 3).



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

B

I choose B because I think the rate of the reaction between magnesium and dilute HCl will increase as time increases

Figure 3

Student Questionnaire Response on Reaction Rate Versus Time

All the learners were given their questionnaire responses and asked to shed light about their responses and the justifications they had provided with respect to their graphical interpretation. Following their explanation of their choice, they were asked probing questions. Learners were not told whether they answered correctly or not by the interviewer. All the interviews were conducted by the researcher and COVID-19 regulations and protocols were observed. Each Interview lasted for about 20 minutes.

2.4 Method of Analysis

Data analysis took place in two phases in this study. Firstly, the quantitative data were analysed using the Statistical Package for the Social Science (SPSS) version 25. The learners' interviews were tape-recorded and then transcribed verbatim. The interviews were initially analysed for emergent themes using inductive coding and, in the process, the key graphical interpretations about rate of reactions were identified (Kumar, 2018). The constant comparison method was used to refine the codes and group into categories. The students' responses regarding the graphical interpretation of rates of reaction were grouped into four groups. Finally, the interpretations were eventually deductively coded.

3. Results

The analysis of the semi-structured data resulted in the identification of five themes (Table 1), according to students interpreting the graphs of rate of reactions. We calculated the inter-rater reliability by calculating the percent agreement between the two researchers' authors in coding the students' justifications. An 86% agreement was finally reached after discussions between the two researchers. Responses were coded as "term of rate of reaction" when students where probed on question 1.

Table 1. Interview Responses Codes

Code	Description
Term rate of reaction (n=8)	Change in concentration of products or reactants per unit time.
Catalyst (n=9)	Increase rate of reaction, the shape of the graph should start at the same point but end on different points.
Maximum rate of reaction (n=7)	Obtained when the volume the gas collected is also at its maximum.
Rate of reaction with excess reactants (n=6)	Magnesium a limiting reactant. Rate of reaction increases and reaches equilibrium.
Depend on variable (n=5)	The vertical axis is the depend on variable.

The codes were used to summarise the graphical interpretation made by learners using the Peirce triad semiotics. In Question 1, learners were asked to define the rate of reaction using the graph concentration versus time (Figure 4, representamen). Most of the learners (8 out of 14) stated that the rate is change in concentration of products or reactants per unit time. This probably indicated that they simply relied on the definitions that are used in their textbooks. Very few learners stated that the rate represented the gradient or slope of the graph.

In the interview excerpts for students C and F regarding their responses, student C was asked about the answer and justification:

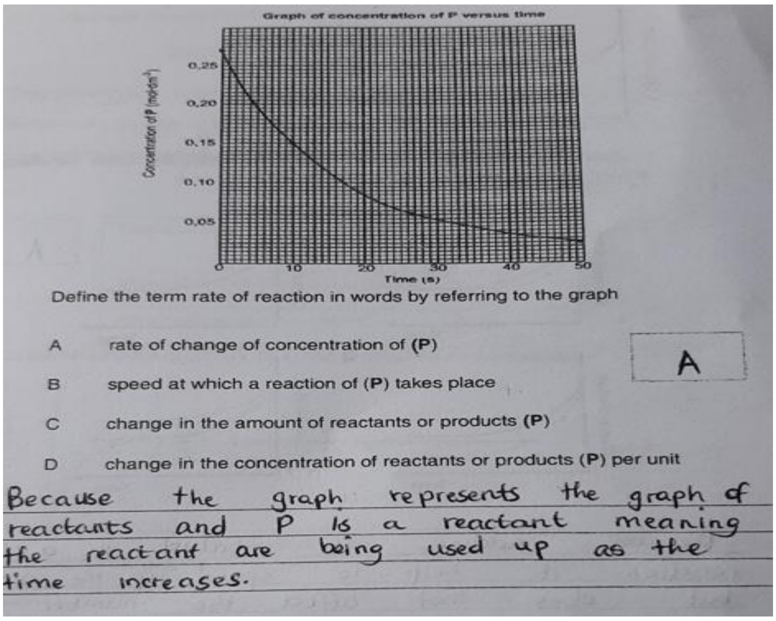
> *"Yes, the rate is the change in concentration of products or reactants over time.When the reaction starts there are no products it's the reactants only. As the the reaction progresses the concentration of products increases and that of products decreases. The rate has products and reactant whose concentrations are inversely proportional as the reaction progresses."*

Similarly, student F also failed to interpret the concentration versus time graph:

> *"I think rate involves changes in products and reactants concentration. The textbooks also define rate of reaction like that."*

Researcher: Did you check the graph or you use a graph to arrive at this interpretation?

> *"On the graph the concentration is decreasing with time which fits well with the definition of rate of reaction in the textbooks."*



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

A

Because the graph represents the graph of reactants and P is a reactant meaning the reactant are being used up as the time increases.

Figure 4

Learner's Response on Defining Rate of Reaction

Semiotic analysis of learner responses showed the representamen (graph of concentration (P) versus time), object (rate of reaction/slope of the graph) and interpretant (interpreted using textbook definitions not related to the graph, slope of the graph, speed at which reaction takes place). The graph was based on concentration of P but most of the students kept mentioning the reactants. From these interview excerpts, it shows that students rely on definitions to interpret the graph of concentration versus time graph.

The catalyst increases the rate of reaction, and the starting point and end points of the graph remains the same. In addition, it provides an alternative path with a lower activation energy and the enthalpy of the reaction remains the same. The responses (Figure 5) show that the student relied on the definition of a catalyst to interpret the graph. The total responses of the participant (64%) viewed the catalysed and non-catalysed reaction end points to be different.

Student B stated:

> *"The catalyst increases the rate of reaction and the speed the reaction, the one with the catalyst will reach equilibrium first."*

The student knew what the catalyst does and was used to interpret the graph.

In contrast, Student L stated that:

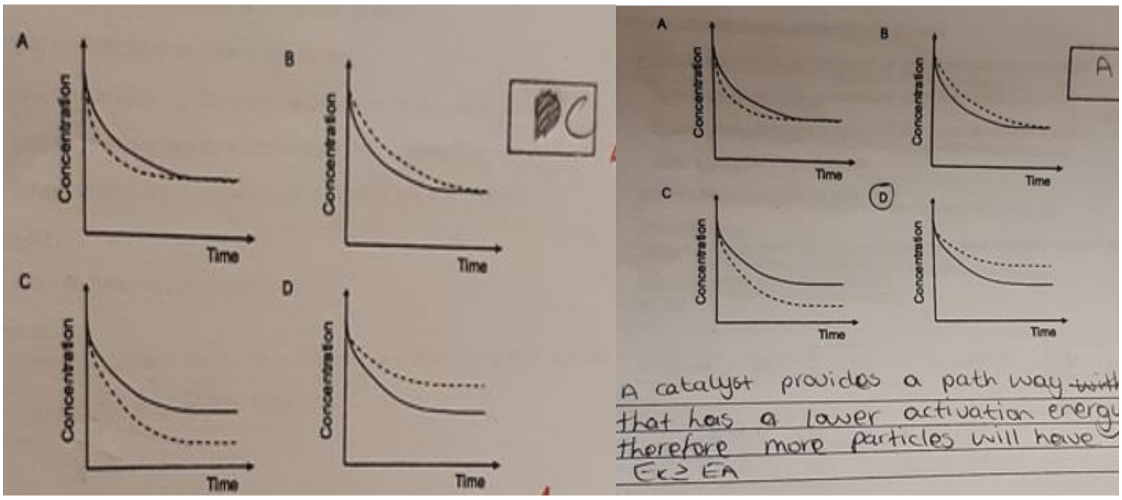
> *"The catalyst speeds the rate of the rate of the reaction and the presence of a catalyst allows a reaction to reach equilibrium more quickly, but it has no effect on the position of the equilibrium."*

Interviewer: In your response you wrote Ek ≥ E_A, can you explain?

Student L:

> *"The catalyst lowers the activation energy, and many molecules will have the required energy and it increase the rate of the reaction according to the collision theory."*

The response from student L shows a complete understanding of the catalyst which was used to interpret the graph. There was integration of catalyst and activation energy and collision theory. Thus, the interpretation of the concentration versus time graph requires a translation in the different concepts.



A catalyst provides a path way ~~with~~
that has a lower activation energ
therefore more particles will have
$E_k \geq E_A$

Figure 5

Students Response on the Effect of a Catalyst

Peirce triad semiotics of the responses showed the representamen (effect of catalyst graph), object (enthalpy remains the same/ starting points and endpoints of the graph remain the same between a catalysed and non-catalysed reaction) and interpretant (interpreted as a catalysed reaction to be faster and reach equilibrium first than a non-catalysed reaction, catalyst increase rate of reaction and the start and end point are like those of the non-catalysed). The interpretation by most learners (9 out of 14) showed that they interpretated the catalyst to be faster and that the endpoints should be different. According to the Johnstone triangle, most the learners failed to link the representation and sub-micro domains.

The rate of reaction with excess reactants graph where magnesium reacted with excess dilute hydrochloric acid produced mixed results. The interview responses showed that 43% of participants viewed the rate of reaction to increase and reach equilibrium. Student L (Figure 5) stated:

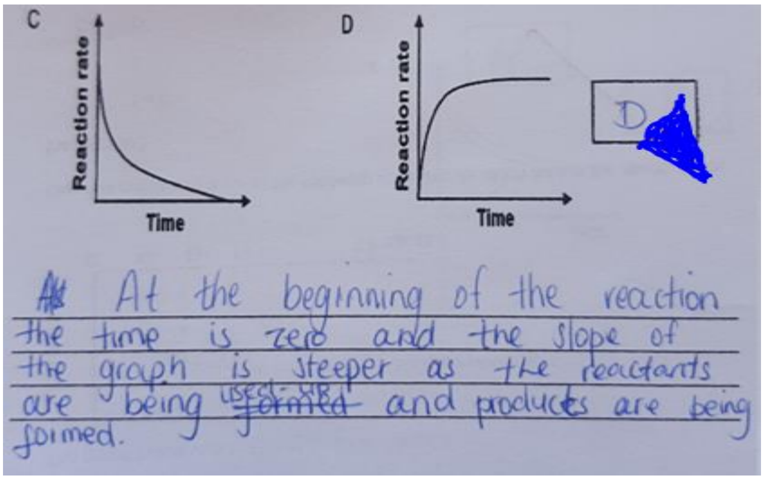
> *"In the beginning the products concentration is zero and increases as the reaction progress, the reaction reaches equilibrium, and the graph flattens when all the magnesium has reacted."*

Interviewer: In your response you mentioned slope being steeper as reactants are being used?

Student L:

> *"In the graph products are being formed and since products are being formed the rate starts high and it slows as the rate progresses."*

The response showed that there was an incomplete understanding of rate of reaction versus time graph. The reaction rate decreases with time and is inversely proportional to time.

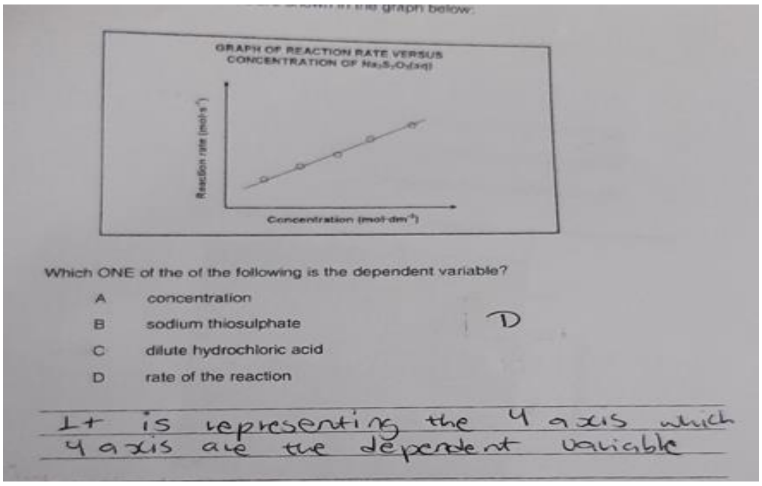


At the beginning of the reaction the time is zero and the slope of the graph is steeper as the reactants are being ~~formed~~ used up and products are being formed.

Figure 6

Student Response on Reaction Rate Versus Time

Identifying a dependent variable (Figure 7) captured the instances of students who were challenged to differentiate between the two axes and transferring mathematical graphical knowledge. Most of the students identified the dependant variable but the justification was incorrect. A total of five students were unable to differentiate between the axes. The students in this theme lacked not only coherence between the variables and demonstrated shallow understanding of experimental variables in chemistry. The question was based on graph of reaction rate versus concentration. The concentration was varied, and it represented the independent variable



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

D

It is representing the y axis which y axis are the dependent variable

Figure 7

Student K Response on Graph Variables

Student K said:

> *"I know from mathematics the y-axis is the dependent variable, the x-axis represents the independent variable."*

Interviewer: In your response you mentioned that concentration does not depend on the rate reaction?

Student K stated:

> *"In science I have forgotten how to determine variables, I had to rely on my mathematics knowledge of functions."*

The question was based on identifying the dependent variable; 35% the responses showed that students struggled with justifying the responses and literally transferred mathematical knowledge to interpret the graph. In Physical Sciences, independent variable is changed, and the dependant variable are measured.

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

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 axes was labelled concentration. 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 reach equilibrium faster. Thirdly, measuring rate of reaction, the question compared how the volume of Hydrogen gas would be produced between 0.1M HCl and 0.1M CH_3COOH versus magnesium. The magnesium powder was in excess. The challenge on this question was to interpret the shift of the graph to the right and the use of slope and height.

Table 2.0 below illustrates the semiotic analysis of learner challenges in the diagnostic questionnaire. The most encountered challenge was on the graph of concentration versus time of catalyst and non-catalysed reaction (48%) and the least was on reaction rate versus time (28%).

Table 2. Learners Challenges on Rates of Reaction

Representamen	**Object**	**Interpretant challenges**
Graph of concentration (P) versus time.	Slope or gradient of the curve.	Change in reactants or products concentration (44%).
Graph of concentration versus time (catalysed and non-catalysed reaction).	Catalysed and non-catalysed the reach the same equilibrium.	Catalyst increases the speed and reach different equilibrium with non-catalysed (48%).
Measuring rate of reaction. Graph volume of CO_2 versus time. Compare volume produced between 100ml of 0.1M HCL and 0.1M CH_3COOH with excess magnesium powder.	HCL will have a higher rate of reaction and graph is to the right of that of CH_3COOH.	The graphs are similar since they have the same concentration (36%).
Graph of reaction rate versus Concentration.	Identify the dependent variable.	Transfer of mathematical knowledge of graphs. Dependent variable is the y-axis (28%).

4. Discussion

In this study, how grade 12 Physical Sciences learners interpret rate of reaction graphs was explored. The qualitative data in the current study provided evidence for five major themes. In terms of the term rate of reaction, we found that learners relied on the definition of rate of reaction to interpret the graph. A possible explanation for this result might be that most textbooks define the rate of reaction as the change in concentration of reactants or products per unit time. The definition was selected as the answer to a graph that showed the change in concentration of reactant P over time. This finding corroborates the ideas of Secken et al. (2015), who suggested that both graduate and high school chemistry students find it difficult to interpret graphs.

With respect to the effect of the shape of the graph between catalysed and non-catalysed, most of the leaners thought the graphs would be completely different. Again, the leaners seem to have relied on the definition of a catalyst in their interpretations. A catalyst speeds up the rate of the reaction and remains unchanged at the end of the reaction. A possible explanation for this might be that learners thought that the speeding effect by the catalyst would result in different end points with a non-catalysed reaction. This finding can be explained using the Johnstone triangle where learners fail to translate between the sub-micro level and the representational.

At sub-micro a catalyst lowers the activation energy, but the enthalpy of the reaction remains the same. Thus, the starting and endpoints of the graph are the same at representational level. Furthermore, when the activation energy is lowered more particles gain the necessary kinetic energy, thereby increasing the number of collisions among the reactants. However, this result has not previously been described even though Ivanjek et al. (2016) also found that learners struggle to interpret curved graphs that involve changes in both height and slope.

The rate of reaction with excess reactants requires learners to understand how the rate of reaction progress with time. However, learners relied on the product formation versus time graph. The learners struggled with the sub-micro domain of knowing how the rate progresses. Excess reactants would mean the graph of rate of reaction versus time will touch both axes. This result has not previously been described and might be explained by the insufficient knowledge about the gradient.

In relation to measuring rates of reaction, the findings showed that most of the learners relied on their mathematical knowledge to interpret the point of maximum rate of reaction. The graph was volume (cm^3) versus time. A possible explanation might be that learners thought that the maximum volume collected represented the point when the rate of reaction was at its maximum. Surprisingly, the rate of the reaction is maximum when the slope C is steep at the beginning of the reaction. The learners struggled with the two domains the sub-micro and representational.

Sub-micro level required the learners to know how the gentleness of the slope changes as the reaction progress. Furthermore, when learners were asked to identify the dependent variable, they transferred mathematical knowledge. Most of learners struggled to justify their responses resorting to explaining using their graphical knowledge from mathematics. This finding agrees with Phage et al. (2017), that learners generally transferred their mathematics knowledge on coordinate reading and representations of straight-line functions to the kinematics contexts.

The transference was largely influenced by the insufficient understanding of the gradient concept. This finding supports previous research by Bollen et al., (2016), who suggested that the barrier to learning chemistry graphs is not just the mathematical formalism, but also a missing connection between mathematics and chemistry.

The second 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 of which four challenges were identified.

5. Conclusion and Recommendations

In this study, we explored grade 12 Physical Sciences learners' graphical interpretation in the topic rate and extent of reaction. We found that learners relied on definitions to interpret concentration versus time graphs and catalysed versus non-catalysed graphs. Furthermore, mathematical knowledge on graphs was transferred to interpret rate and extent of reaction graphs. The semiotic analysis of the learners' responses using Peirce triad semiotics revealed that the object stage was a challenge, leading learners to make incorrect interpretations. The translations within and between the three domains or levels of representation creates a relational understanding in interpreting rate and extent of reaction graphs, confirming Johnstone's triangle. The findings of this study seem to support that graphical interpretation requires learners to translate between the sub-micro and representational domains of the Johnstone triangle.

This research study did not observe how the rate and extent of reaction is taught in classrooms to characterise instructional practices about the graphs. The findings indicate that future research should focus on instructional practices and their effect on interpreting rate of reaction graphs. In terms of an overall Pierce triad perspective, teachers must also be aware of semiotics and the language they use. To achieve deep understanding, teachers need to facilitate a strong connection between the representamen, object, and interpretant. The findings of the present study seem to suggest that educators should focus on all the three translations to help students gain a deeper understanding on what they experience macroscopically and in the two other domains.

The findings reported in this study suggest that learners need additional opportunities to master the interpretation of graphs. Learners' attention needs to be directed to the fact that rate of reaction is the slope or gradient of the variables being observed versus time. There is need to make specific distinctions between the interface of graphical formalism in mathematics and chemistry. If not handled properly, it risks the translations from mathematics to chemistry when interpreting graphs. If educators would emphasise the difference between experimental and mathematical variables, the learners could correctly determine the variables.

Future research could also target high school and university students to allow for an exploration of differences when interpreting graphs in chemical kinetics. Another interesting possibility for a future investigation would be a comparison of graphical interpretation between educators and learners.

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