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PREDICTION OF THE CORRELATION BETWEEN PROBLEM-SOLVING SKILLS AND CONCEPTUAL REASONING IN STOICHIOMETRY

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Abstract. *Learners underperform in stoichiometry as they lack conceptual reasoning of the underlying concepts and the ability to solve stoichiometric problems. Therefore, it was necessary to determine if there is a statistical correlation between problem-solving skills and conceptual reasoning in stoichiometry and if so, whether one can significantly predict the other. The theoretical framework is the cognitive load theory (CLT). This theory expects teachers to know where to focus their teaching and how to assess their learners' work to avoid unnecessary overloading of the working memory, which might affect their performance. The explanatory sequential mixed-method research design was employed with 410 grade 11 Physical Science learners in their intact classes. The participants wrote the learner achievement test (LAT) and responded to a semi-structured interview. The learners' test scores were then used to run a statistical test. The Pearson correlation and regression showed that the justifications given by learners for choosing correct or incorrect multiple-choice options were not due to chance, and the results of the learner interviews supported the learners' performance in the test. Moreover, the findings indicated that there was a positive correlation between problem-solving skills and conceptual reasoning where statistically, conceptual reasoning predicted learners' problem-solving skills using regression analysis.*

Keywords: *conceptual reasoning, cognitive load theory, explanatory sequential research design, stoichiometry, problem-solving skills*

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Introduction

This study differs from previous studies because the focus is to explore if there is a statistical correlation between problem-solving skills and conceptual reasoning in stoichiometry and if one significantly can predict the other. Research on learners' misconceptions involving chemical phenomena has been conducted widely (Bowen & Bunce, 1997; Bridges, 2015; Gabel & Bunce, 1994; Gultepe et al., 2013; Nakhleh, 1992), and some studies focused on problem-solving and conceptual understanding in Chemistry (Carson, 2007; Chiu, 2001; Gultepe et al., 2013; Mandina & Ochonogor, 2017; Sanger, 2005). Other studies looked at the problem-solving and conceptual understanding of the topic of stoichiometry (Dahsah & Coll, 2007; Hanson, 2016; Mandina & Ochonogor, 2017; Mashamba, 2018; Schmidt & Jignéus, 2003). If the research shows that conceptual reasoning can predict learners' problem-solving skills in a statistically significant way, it will then presume that teachers should focus more on conceptual understanding and solving problems in a sequential manner, showing as many details as possible. This is supported by (Chirinda, 2013) who stated that teachers use systematic approaches to teaching problem-solving skills to create scientifically literate citizens.

Stoichiometry is a section of Chemistry as part of Physical science which cut across the Further Education Training (FET) phase which include grade 10 – 12 in the South African curriculum. The sections on stoichiometry-related concepts are in line with the South African high school syllabus known as the Curriculum and Assessment Policy Statement (CAPS). This study focused on grade 11 learners because stoichiometry is more pronounced in this grade and in grade 12, where more complex calculations are required than in grade 10. The grade 12 class is an examination class hence could not be used.

Research Problem

According to the National Senior Certificate (NSC) diagnostic report (DoBE, 2020), learners in the final year grade (grade 12s) are not performing well in the topics that have a direct bearing on stoichiometry, namely

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Reaction Rate and Stoichiometry; Chemical Equilibrium, and Acids and Bases. Therefore, learners need to master stoichiometry in the preceding grades before entering their final year, which is grade 12 (Bridges, 2015).

Table 1 shows the summary of the average learner's performance (marks per question) expressed as a percentage in seven years according to the National School Certificate diagnostic reports (DoBE, 2014–2020). The sections in Chemistry that are of concern for this paper are those highlighted in the table. In the highlighted portion of the column for 2014, learners are not doing well – they had an average mark of 36, 43, and 48, respectively. Similarly, in 2016 the percentages were 39, 33, and 29 (see Table 1).

Table 1
A summary of Average Marks per Question in Percentage from 2014-2020

Question Number	Title of the Section in Chemistry paper two	Percentage per year						
		2014	2015	2016	2017	2018	2019	2020
1	Multiple Choice Question	52	45	50	46	54	48	62
2	Organic Nomenclature	65	64	66	62	48	57	57
3	Physical Properties of Organic Compounds	47	55	48	28	53	50	50
4	Organic Reactions	61	36	41	51	49	46	50
5	Reaction Rate and Stoichiometry	36	35	39	35	48	40	52
6	Chemical Equilibrium	43	40	33	50	43	45	37
7	Acids and Bases	48	34	29	43	44	37	45
8	Galvanic Cell	45	46	47	53	46	46	56
9	Electrolytic Cell	33	35	35	35	45	39	23
10	Fertilizers	58	50	34	49	39	44	49

Research Focus

Teaching stoichiometry is aimed at developing learners' conceptual reasoning of the underlying concepts and their ability to solve stoichiometric problems (Kimberlin & Yezierski, 2016)"ISSN":"19381328","abstract":"Students' inaccurate ideas about what is represented by chemical equations and concepts underlying stoichiometry are well documented; however, there are few classroom-ready instructional solutions to help students build scientifically accurate ideas about these topics central to learning chemistry. An intervention (two inquiry-based activities. This study looked at conceptual reasoning as the process of applying logical thinking to a situation (a question) to achieve the correct result (reasoning and words used to describe the process). Accordingly, problem-solving will be explored as the strategy applied to a given question; using the strategy to bring about a solution that can be algorithmic in nature. As a result, the outcome of this study would highlight the necessity of conceptual reasoning and efficient and meaningful problem-solving skills for achieving success in solving problems in Chemistry.

Theoretical Framework

Problem-solving is described in the context of the cognitive load theory (CLT) because this theory views problem-solving as a process that includes reflection, observation, and experiential development. The basic notion of the cognitive load theory is that cognitive capacity in the working memory is limited (Paas et al., 2016) – thus, if a learning activity requires too much capacity, learning will be hindered. There simply may not be enough working memory capacity available for learning entirely new tasks. Therefore, teachers should design instructional activities that will optimize the use of working memory capacity and avoid cognitive overload (Sweller, 1988) – until fundamental skills have been developed. It is worth noting that some information may impose a high working memory load, while other information may impose a low working memory load (Sweller, 2016). Hence it is believed that the findings from this study could influence teachers to ensure that they do not overload learners' working

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memory – to enable learners to demonstrate their problem-solving skills, for example, when performing stoichiometric calculations. This implies that teachers must ensure that their learners are proficient in understanding and performing stoichiometric calculations.

Research Aim and Questions

As noted by Surif et al. (2012), a gap exists between learners' conceptual reasoning and their problem-solving ability in Chemistry. Stoichiometry calculation capability tends to be particularly poor in the developing world, even among teachers (Stott, 2021). Thus, the study aimed to explore if conceptual reasoning can predict the problem-solving skills of grade 11 Physical Science learners and if one can significantly predict the other. Therefore, this study was designed to answer the following research questions:

1. Is there a statistical correlation between problem-solving skills and conceptual reasoning in stoichiometry?
2. Can one significantly predict the other?

Research Methodology

Research Design

An explanatory sequential research design was used with a mixed-method approach where both quantitative and qualitative methods were utilized to collect and analyze data. The mixed-method approach was adopted because the research outcomes could not be achieved by quantitative or qualitative methods alone (Creswell, 2012). No single viewpoint can present the entire picture and there may be multiple realities. Therefore, different approaches can be complementary and used.

Research Sample

A convenient sample technique was chosen due to the availability and willingness of the participating schools to partake in the study (Creswell, 2012); and also because the researchers reside in the province and the schools were easily accessible. The research population are high schools in the Tshwane North District. The researchers focused on schools in circuit 4 of this district and the selection of the sample were 11 intact classes. The sampled schools are found within the same geographical location. They have similar socio-economic status, where the learners are amongst others, part of a school feeding scheme and are referred to as quintile one schools. These schools form a group of schools catering to the poorest 20% of learners – in other words, a group representing 20% of a population with the lowest income (Nordstrum, 2012). The teachers of the sampled learners were from similar academic backgrounds (Dilnot, 2016). The research time was approximately 4 weeks.

The participants were all grade 11 learners (n = 410) from eleven selected public schools in a District of the Gauteng Province, in South Africa. The average age of the learners is seventeen. Gender was not considered in the data analysis due to an unbalanced distribution of gender. The learners participated in a two-phase exercise which comprised writing a test and taking part in a semi-structured interview.

All participants gave consent and written letters were given to assure them of full confidentiality as well as anonymity. In addition, the learners were informed of their right to withdraw from the research at any time during the study, if they so deem it necessary (Kotoka, 2020). Letters were also written to all other stakeholders such as the Gauteng Department of Education, principals and teachers at the schools, and parents of the participating learners. Ethical clearance was granted by Unisa's research ethics review committee (2015_CGS/ISTE_009).

Instruments

Two research instruments were used namely a learner achievement test (LAT) and a semi-structured learner interview schedule (LIS). The learner achievement test consisted of two sections – section A with five multiple-choice items, and section B with five short-answered written questions. The mark allocations for the first section of the test are three marks per question and that of the second section is five marks per question. The questions in

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the test were adapted and slightly modified from sources such as the South African matriculation past examination papers for Physical science (Chemistry) (*Parent24*, 2014) and commonly used South African Physical science textbooks (de Vos, du Plessis, Nel, Spies & van Wyk, 2015).

The learner interview schedule consisted of five questions that were posed to selected learners. The interview was done to confirm how the learners understood the learner achievement test they wrote. The questions on the learner interview schedule are stated below.

Q1; Were the problems on the learner achievement test difficult or easy?

Q2; How did you balance the chemical equations in questions one and five in section B?

Q3; How did you relate mass, molar mass, and moles of substances?

Q4; Regarding question three, in section B, how did you apply the concept of mole ratio?

Q5; How do you understand limiting reactants?

Validity

Validity demands that an item describes what it is meant to describe (Bulsara, 2014). Therefore, the LAT and LIS were given to three experts in Physical science in the Tshwane North District in the Gauteng province of South Africa to read and make corrections and suggestions. This was done to ensure both face and content validity. These experts included a cluster leader, a district subject advisor, and a seasoned senior teacher of reputable standing in content and curriculum in the field of science education. Their criticism and comments were to ensure a high level of validity. For example, they suggested rephrasing the questions. There was a suggestion that open-ended questions that require learner thinking, be incorporated into the test since conceptual reasoning and problem-solving skills are being tested.

Reliability

Reliability tells test users about the consistency of the scores produced in a test and it is therefore important for judging the suitability of a test or measuring instruments (Golafshani, 2003). The marks obtained from the learners who wrote the learner achievement test twice on pilot bases were used to calculate the Spearman correlation coefficient using SPSS version 23 (Siegle, 2013). The Spearman correlation coefficient obtained was .924 which showed a high correlation and indicated high reliability of the test. Fourteen learners from another district in Gauteng province were interviewed using the prepared learner interview schedule to test its reliability. The learners' responses were consistent, indicating that the learner interview instrument was reliable. This means that while the absolute responses of what learners report may differ somewhat from one another, the effect is consistent across all learners so that the effect does not appear to advantage or disadvantage one learner group compared with another (Bostic & Sondergeld, 2015).

Procedures and Data Collection

Eleven classes of learners (n = 410) took the test in one session. Their chemistry teachers supervised the test. The learners were required to answer all the questions (10 items in the two sections). Learners were to provide both the answer and an argument for their answers in the first section. The test required the learners to write down their chosen answers to the conceptual questions and to provide reasons for their answers using their conceptual knowledge about the topic. To gain a deeper understanding of the learners' problem-solving skills, the second part of the test involved algorithmic questions. The question required the learners to work through a procedure to find a numerical solution to a chemical problem. These types of questions were considered problem-solving questions where the learners were expected to show reasonable solutions. See the appendix for the test item and its marking memorandum.

Section A of the test aimed to obtain data on learners' conceptual reasoning whereas section B was to gather data on learners' problem-solving skills. Therefore, section A contained multiple-choice (A-D) questions, and spaces were provided for the learners to state their reasoning behind each choice they made. The learners who took part in the interviews were selected based on their performance according to the test results. With the assistance of the subject teachers and based on the first term test, learners were classified as good, average, or weak. There were six

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learners sampled from each of the eleven schools that participated in the interview. Due to technical problems, however, two audiotapes out of the eleven schools could not be used for analysis. Therefore, the total number of learners was those from nine schools. The data from the interview transcripts were used to substantiate and authenticate the results of the analysis of the test.

Data Analysis

The learner achievement test was analyzed quantitatively and qualitatively. These tests were marked, and the scores were recorded in Excel and later exported to SPSS version 23 for statistical analysis. Pearson correlation was used to do a statistical correlation to determine the association between learners' problem-solving skills and their conceptual reasoning. Furthermore, a regression analysis was conducted to see if learners' problem-solving skills depended on their conceptual reasoning. In other words, can learners' conceptual reasoning predict their problem-solving skills? Even though the study aims to explore the correlation between conceptual reasoning and problem-solving skills, Pearson correlation and regression were conducted on the multiple-choice responses alone and the reasoning behind the choices made. This was done to ascertain whether the learners' choice out of the multiple choices was merely due to chance.

Apart from the quantitative analysis, the multiple-choice responses with their accompanying learner reasoning were also analyzed qualitatively. Both quantitative and qualitative analysis were used as the qualitative results were used to shape the quantitative results based on the views and opinions of the participants. Conceptual reasoning refers to the learners' ways of thinking – these include analyzing a problem, developing new ideas, and reflecting on them (Rahman, 2019). Problem-solving signifies how an individual uses previously acquired knowledge, skills, and understanding to satisfy the demands of an unfamiliar situation (Carson, 2007). Conceptual reasoning per this study means that when a learner reasons through the concepts in each problem and then applies adequate problem-solving skills to resolve it, then it is assumed that the learner understands the problem. The multiple items were analysed qualitatively using descriptive method (see Figure 1, Table 9 and Appendix B). The learners' conceptual reasoning was categorised into No conceptual reasoning (NCR), Partial conceptual reasoning (PCR), and Good conceptual reasoning (GCR) where different marks were allocated to each (see Appendix B).

In section A of the learner achievement test (conceptual reasoning questions) learners were asked to justify the reason for choosing the correct multiple-choice answer in all five test items. This is to show the conceptual reasoning of the learner regarding the concept being tested. The justification had been categorized into 'no conceptual reasoning' (NCR), 'partial conceptual reasoning' (PCR), and 'good conceptual reasoning' (GCR). The connotation of NCR was that the learner gave an incorrect reason or no reason at all for his/her choice of an answer. PCR means that the learner gave a vague or a partially valid reason, an incomplete reason, and/or an imprecise answer. GCR would mean that the learner stated sound conceptual reasoning; a completely valid reason and/or a precise answer for his/her multiple-choice. The correct multiple-choice was awarded one mark, no conceptual reasoning was awarded a zero-mark, partial conceptual reasoning was awarded one mark, and good conceptual reasoning was awarded two marks. In section B of the learner achievement test, the learners were tested for their problem-solving skills. There were five questions in total, and each question was allocated five marks, which made it easier for the researchers to award a mark to the different steps shown by the learners in their solutions. Hence, on the memorandum of the learner achievement test, marks were awarded for each step of thinking required.

The learners' interviews were audiotaped and transcribed word by word for analysis. Document analyses were used to find themes in the responses. The responses were grouped under three themes that related to the main questions that were asked during the interview sessions (Saldana, 2015). The prominent themes that arose for each response were colour-coded and titled.

- ■ Most favourable responses
- ▲ Fair (to neutral) responses
- ● Unfavourable responses

Therefore, the transcribed interviews were classified according to the themes (Saldana, 2015).

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Research Results

Quantitative Results on Learner Achievement Test

Statistical tests were run for the multiple-choice questions versus their conceptual reasoning. Table 2 represents all the Pearson correlation coefficients and shows values between 0.3 and 0.6 demonstrating a strong correlation at $p = .001$. For example, objective Q1 (question 1) is significant, [Pearson $r = .367$, $n = 410$, $p < .001$]. From table 2, objective Q4 (question 4) showed the strongest correlation. The Pearson correlation gave a significance p of .001 which is less than .01 and .05 and since the .001 is less than the chosen significance levels. Therefore, the correlation showed statistically significant relationship between the variables (conceptual reasoning and problem-solving skills). The results showed that the justifications given by learners for choosing correct or incorrect multiple-choice options were not due to chance. This suggested that a learner choosing the right multiple-choice option has the right conceptual reasoning as far as the findings of this study are concerned.

Table 2
Correlations between the Objective Question Scores and their Conceptual Reasoning

	Objective	Objective	Objective	Objective	Objective
	Q1	Q2	Q3	Q4	Q5
Pearson Correlation	.367**	.472**	.467**	.615**	.426**
p	.001	.001	.001	.001	.001
n	410	410	410	410	410

**Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

Regression goes beyond correlation by adding prediction capabilities (Gerber, 2013; Pérez & de Los Campos, 2014). Therefore, regression analysis was done for the same objective questions versus their conceptual reasoning to establish the strength of the significance of the two variables on each other (see Tables 3 and 4). Table 3 presents the model summary for the five questions where most of the adjusted R square values show a modest variation. The average adjusted R square (for the 5 questions) was .225 and the predictor (conceptual reasoning) varies from the dependent variable (objective questions) by an average of .367. The standard error of the estimate of .367, is a measure of how much R (the conceptual reasoning) is predicted to vary (about 37% variation).

Table 3
Model Summary for the Questions

Model	*R*	*R Square*	*Adjusted R Square*	*SE*
1	.367[a]	.134	.132	.277
2	.472[a]	.223	.221	.360
3	.467[a]	.218	.216	.441
4	.615[a]	.378	.376	.391
5	.426[a]	.182	.180	.366

[a]. Predictors: (Constant), Conceptual Reasoning Q1-Q5

The table of coefficients (Table 4) for the five questions indicates that the regression for Q1 is significant, (b =.367, $t = 7.960$; $p < .001$). The average (all question) standardized coefficient b value of .4694 at the significant level of .001, shows a significant difference. Considering that the standardized coefficients b values are greater than .001,

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there is a statistically significant correlation between the dependent (objective questions) and the independent (Conceptual Reasoning) variables at that significant level.

Table 4
Coefficients[a] for Questions

Model	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*
	B	*SE*	*Beta*		
1 (Constant)	.791	.021		36.921	.001
Conceptual Reasoning Q1	.101	.013	.367	7.960	.001
1 (Constant)	.561	.028		20.307	.001
Conceptual Reasoning Q2	.197	.018	.472	10.826	.001
1 (Constant)	.224	.030		7.417	.001
Conceptual Reasoning Q3	.235	.022	.467	10.660	.001
1 (Constant)	.330	.025		13.276	.001
Conceptual Reasoning Q4	.316	.020	.615	15.738	.001
1 (Constant)	.634	.025		25.606	.001
Conceptual Reasoning Q5	.174	.018	.426	9.522	.001

[a]. Dependent Variable: Objective Q1-Q5

Conceptual Reasoning vs. Problem-solving Skills

The Pearson correlation illustrates the correlation conducted between learners' conceptual reasoning (CR) and their problem-solving skills (PSS) (see Table 5). The results show the descriptive statistics indicating the means, the standard deviation, and the number of learners. The mean score for the 410 learners' CR was 8.81 ($SD = 3.59$) and the mean score of learners' PSS is 8.08 ($SD = 5.89$). The Standard Deviation of problem-solving skills of 5.89 indicates a widespread PSS attained by learners.

Table 5
Descriptive Statistics for Conceptual Reasoning and Problem-solving Skills

	M	*SD*	*N*
CR	8.81	3.59	410
PSS	8.08	5.89	410

The correlation to show the connection between conceptual reasoning and problem-solving skills is illustrated in table 6 below. The Pearson correlation between conceptual reasoning and problem-solving skills (see Table 6) is [$r = .48$, $n = 410$, $p < .001$]. This correlation revealed a positive connection between the two variables. Thus, there is a positive correlation between conceptual reasoning and problem-solving skills. However, this positive correlation is a moderate correlation because is less than .5.

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Table 6
Correlations for Conceptual Reasoning and Problem-Solving Skills

		CR	PSS
CR	Pearson Correlation	1	.483**
	p		.001
	n	410	410
PSS	Pearson Correlation	.48**	1
	p	.001	
	n	410	410

**. Correlation is significant at the .01 level (2-tailed).

A few outliers of the data set may have resulted in the value of .483 (p at .001 < 0.05). The outliers might have caused the moderate correlation between the conceptual reasoning and problem-solving skills otherwise a stronger correlation may have resulted.

Conceptual Reasoning Predicting Problem-solving Skills

To determine if conceptual reasoning can predict problem-solving skills, regression analysis was used. The model summary for the conceptual reasoning and the problem-solving skills which gave an adjusted R square of .23 is presented in table 7. The variation of .23 (23%) between the predictor and the dependent variables indicated a modest fit between them comparing it to the rule of thumb as a guide (Muijs, 2010).

Table 7
Model summary for Conceptual Reasoning and Problem-solving Skills

Model	R	R Square	Adjusted R Square	Standard Error of the Estimate
1	.48[a]	.23	.23	5.17

[a]. Predictors: (Constant), CR
[b]. Dependent variable: PSS

The coefficients for conceptual reasoning (CR) and Problem-solving skills (PSS) are presented in table 8. The regression is significant (b = .483; t = 11.14, p < .001) because the b value, .483 is greater than p < .001. This indicates that the independent variable can significantly predict the dependent variable. Therefore, there is a statistically significant prediction between CR and PSS.

Table 8
Table of Coefficients for Conceptual Reasoning and Problem-Solving Skills

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	*SE*	*Beta*	*t*	*p*
1	(Constant)	1.08	.68		1.60	.001
	CR	.79	.07	.48	11.14	.001

a. Dependent Variable: PSS

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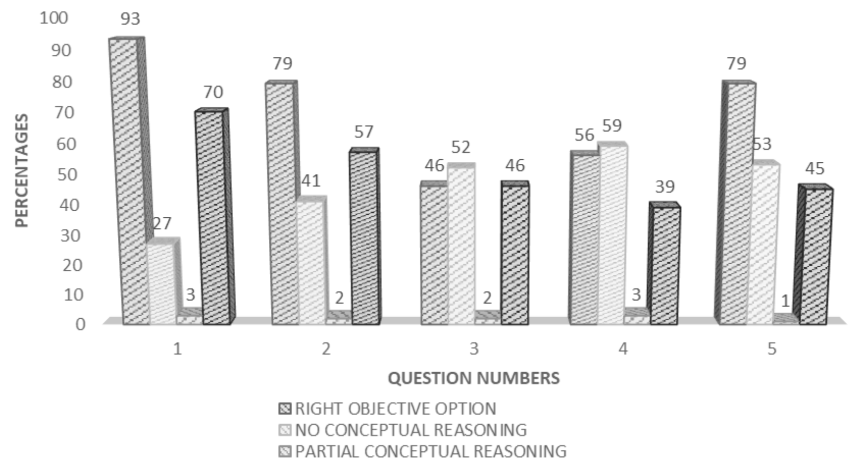
Qualitative presentation of the Result of the Learner Achievement Test

Section A

The summary of the analysis of the conceptual reasoning questions (section A) of the LAT is presented in Figure 1. To make the interpretation visually clearer, the data was used to draw a multi-bar graph which showed the Right multiple-choice, No conceptual reasoning (NCR), Partial conceptual reasoning (PCR), and Good conceptual reasoning (GCR) in different colours. The number of learners was expressed in percentages (see Figure 1 below).

Figure 1
Learners' Right Objective Answer and its Justification in Percentages.



Questions one, two, and five were the best answered in terms of making the best objective choices and giving the reasons for the choices made in section A. For questions three and four the highest percentages were recorded for no conceptual reasoning (NCR) which means learners could not give reasons for their choices. The extracts of how the learners' scripts were marked in terms of the different categories (NCR, PCR, GCR) is presented in appendix B.

Section B

Table 9 shows problem-solving questions (section B) where the question numbers were split into the expected demonstrated skills by the learners, the number of learners who showed right method and wrong method expressed in percentages. In the table, learners demonstrated more wrong methods in their problem-solving process compared to the right method. As far as problem-solving questions in section B are concerned, question four was the best-answered question among the problem-solving questions and question three was the most poorly answered (LAT section B).

Table 9
Problem Solving Skills Demonstrated by the Learners in each Question

Question number	Skills Learners are Expected to Demonstrate	Wrong method	Percentage (%)	Right method	Percentage (%)
	Balance equation	185	45.1	225	54.9
	Calculate molar mass	291	70.9	119	29.1
1	Calculate moles	320	78.0	90	22.0
	Use mole ratio	228	55.6	182	44.4
	Calculate mass	343	83.7	67	12.3

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Question number	Skills Learners are Expected to Demonstrate	Wrong method	Percentage (%)	Right method	Percentage (%)
2	Use a balanced equation	203	49.5	207	50.5
	Calculate molar mass	322	78.5	88	21.5
	Calculate moles	323	78.9	87	21.1
	Use mole ratio	190	46.3	220	53.7
	Calculate mass	346	84.4	64	15.6
3	Calculate moles	266	64.9	144	35.1
	Determine the mole ratio	357	87.1	53	12.9
	Compare quantities	378	92.2	32	7.8
	Determine limiting reactant	369	90.0	41	10.0
4	Calculate volume using molar volume	151	36.8	259	63.2
	Change subject formula/use ratios	155	37.8	255	62.2
	Convert units	190	46.3	220	53.7
5	Balance equation	187	45.6	223	54.4
	Calculate molar mass	286	69.8	124	30.2
	Calculate moles	288	70.2	122	29.8
	Use mole ratio	307	74.9	103	25.1
	Calculate mass	317	77.3	93	22.7
	Calculate percentage yield	320	78.0	90	22.0

Qualitative presentation of the result of the Learner Interview Schedule

Below are the tabulated results from the interview sessions expressed in percentages.

Table 10
Number of Responses given by the Learners and its Percentages

Most favourable responses			Fair (to neutral) responses		Unfavourable responses	
Responses		%	Responses	%	Responses	%
1.	18	33.3	30	53.7	6	13.0
2.	33	61.1	6	11.1	15	27.8
3.	47	87.0	7	13.0	0	-
4.	13	24.0	0	-	41	76.0
5.	33	61.1	0	-	21	38.9
Average		**53.30**		**15.56**		**31.14**

The learners belonging to the different themes identified earlier in this section were compared (see Table 10). Learners belonging to the 'most favourable responses' theme constitute the highest percentage at 53.30%. This group represented the learners with much insight into the concept of stoichiometry. The learners belonging to the theme of 'fair to neutral responses', constitute the least percentage; and learners belonging to the 'unfavourable responses' theme (31.14%) were those who seem to have no insight into stoichiometry. The above results imply that learners have knowledge about concepts taught in stoichiometry (see Figure 1).

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Discussion

With regard to the research questions, quantitatively, the data in table 2 indicates "If a learner gets a multiple-choice question right it means the learner has the right conceptual reasoning" and vice versa. These findings are in agreement with other studies that verified the above correlation (Chiu, 2001; Cracolice et al., 2008; Hanson, 2016). To further respond to the research questions, the statistical test showed a positive correlation between the learners' conceptual reasoning and their problem-solving skills (from Table 4). The above results are consistent with the findings of other researchers in this field. For example, according to a study done at a local high school in Taiwan, most learners were considered both good problem solvers and good conceptual thinkers (Chiu, 2001). The current result also supports the findings by Gultepe et al. (2013), where increased conceptual problem-solving ability improved algorithmic problem-solving skills in their study. The conceptual reasoning had statistical significance for learners' problem-solving skills. The current findings, which indicate a positive correlation between conceptual reasoning and problem-solving skills, are in agreement with a study that found that there is a significantly positive correlation between algorithmic problem-solving skills and conceptual understanding and mathematical processing skills (Al-Mutawah et al., 2019).

To deal with the research questions qualitatively, looking at conceptual reasoning, question 1, when the learner chooses the right multiple-choice answer, he/she scores one mark out of the three marks allocated – and this applies to all five multiple-choice questions in the section. If a learner justifies his/her answer by saying he/she used the knowledge of how the mole is related to the mass and molar mass of oxygen, for example, 1 mol O = 16g/mol = molar mass, and mass of O given = 35.2g and did the calculation shown below to obtain the moles; n = m/M ∴ ∴ O = 35.2g/16 = 2.2 mol, the learner is awarded two marks for GCR due to the correct and complete conceptual reasoning provided. Another example: if the learner shows the formula n = m/M and uses the formula to explain the associations among the variables, he/she will be awarded two marks. A learner is awarded one mark, which is PCR, when he/she gives a partially valid reason – like just writing n = m/M – with no explanation. When a wrong formula or reason is given or noting is written for the justification, 0 is awarded, which is NCR.

For conceptual reasoning question 2, where the learners were asked to calculate the mass of a substance. They must show or explain the formula, calculate molar mass, and use it to find the mass. It is only then they obtain the 2 marks for GCR. The molar mass of $C_8H_9O_4$ = 169g/mol, and n = m/M so, m = n x M = 0.432mol x 169g/mol = 73g. If they only provide formula and could not find the molar mass to calculate the mass, it is partial work done and deserves 1 mark. No mark would be awarded if the mass is incorrect or no reason at all is provided.

With the third conceptual reasoning question, the justification is being able to identify the reactant and the product and their coefficient. Also, they must know the mole ratio between O_2 and CO_2 produced for the two marks, thus, O_2: $2CO_2$ = 1:2. Therefore, if the learner mentioned mole ratio in his/her explanation but did not get the right coefficients and in their correct order, it is given a mark – PCR. The wrong mole ratio such as 2:2, 2:1, or 1:1 is NCR (0 mark).

Conceptual reasoning question 4 was testing the knowledge of the amount of substance (Moles) from the other terminologies such as grams, litres, and particles. Therefore, all the multiple-choice options provided were the same in terms of the number of reactants and the number of products. Here the learners were expected to justify their multiple-choice answers based on total moles (amount of substance) for reactants and products and the difference between moles, mass, volume, and atoms. ∴∴ 1 + 8 = 5 + 6 thus, 9:11 gives a learner the two marks for good conceptual reasoning. Any other justification will not be awarded a mark.

The final question requested the definition of Limiting reagent, which requires knowing the concept of limiting reagent and being able to define it as the substance that is totally used up when the chemical reaction is complete. This determines how many moles of a product should be formed for the two marks. A partial or incomplete definition was awarded one mark and no definition was 0 mark for the justification of one's choice.

Five marks were allocated to each of the five questions in section B of the learner achievement test where problem-solving skills were being tested. A mark is awarded for a correct step shown in the problem-solving process, as stated previously above. For example, when a leaner was able to balance the given chemical equation, calculate the moles of one molecule and use mole ratio to find the moles of the required molecule and, continue to calculate mass where necessary, providing the right formula, methodology, and appropriate unit. This learner would have demonstrated acceptable problem-solving skills. The same applies to those questions that required the learners to calculate the molar volume and the percentage yield of a compound as well as the limiting reagent of a substance.

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Concerning interview question two, 61.1% of the learners knew how to balance the chemical equation. However, 55% were able to balance chemical equations for questions one and five in the test (section B). From interview question three on mass, mole, and molar mass, 87% of the learners were able to mention the formula that connects the three concepts (see table 10 for interview response). From marking the learners' scripts, particularly section B, the test results revealed that an average of 70% of the learners could not calculate moles and mass of substances using the molar mass correctly (see table 9 for test outcome). The researchers suspect that the reason why some of the learners were not able to calculate moles and mass of substances using the molar mass correctly could be due to the multiple steps involved in this type of calculation. The learners had to first calculate the molar mass of the substance to be able to calculate the moles and/or mass of the substance. In situations where the chemical equation given is not balanced, the learners had to balance the chemical equation before commencing with the calculations, hence they had difficulties.

Interview question four indicated that 24% (see table 10) of learners used mole ratio correctly in solving stoichiometric problem 3 in section B. From the test results, however, only 12.9% (table 9) of the learners were able to apply the mole ratio correctly to solve the given problem (question 3, in section B). Indeed, only 16 learners out of 410 (4%) were able to solve question 3 completely right. Lastly, the fifth interview item, attested that the learners could define limiting reactants (61.1%), but the outcome of the test showed that merely 10% of the learners could work through the calculations of limiting reactants using the right method as required in the question 3 of section B of the test.

The cognitive load theory (CLT) provides guidelines that assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance (Jalani & Sern, 2015). With an understanding of the CLT and its instructional implications, educators will be in a better position to design and develop instructional materials that align with human cognitive architecture (Sithole, 2019). In the end, instructional materials that employ CLT guidelines can enhance learning effectiveness and efficiency for learners in a variety of educational contexts (Artino, 2008).

This study has found that learners' conceptual reasoning determined their problem-solving skills. So according to CLT, to reduce the overloading of learners' working memory, teachers should explain complex phenomena to learners; provide learners with relevant previous knowledge before expecting them to use new knowledge, and encourage learners to apply available resources to advanced cognitive processes (Chang & Karpudewan, 2020).

The qualitative findings were consistent with quantitative results. It was discovered through statistics that learners' conceptual reasoning informed their choices of answers to the multiple-choice options. The existence of a positive correlation between learners' conceptual reasoning and their problem-solving skills means that learners' problem-solving skills reflect their conceptual reasoning. This means that one variable predicted the other. Thus, in line with the CLT standpoint, teaching methods need to provide learners with guidance and support to maintain learner focus and avoid cognitive overload during a task that has the potential to become overwhelming for learners due to its complexity.

Limitations

The findings cannot be generalized as the data presented was from a single district and should therefore be regarded as illustrative rather than exhaustive. This limits the transferability of the study to other contexts since it is not representative of other contexts (Vasileiou, et al., 2018).

Conclusion and Implications

Literature showed that stoichiometry is regarded as one of the more challenging topics to teach. We explored how grade 11 Physical Science learners' problem-solving skills can be predicted by conceptual reasoning in stoichiometry in the South African context. It has been established that there is a positive correlation between learners' conceptual reasoning and their problem-solving skills. The results revealed that conceptual reasoning indeed reflects how learners approach questions and indicated that learners with good reasoning skills solve problems much better. Therefore, it was shown that the one can predict the other.

Stoichiometry should be taught in such a way to enhance learners' conceptual understanding, thereby leading to good problem-solving skills. During instruction, teachers should pay attention to all concepts of stoichiometry such as the mole concept, molar gas volume, concentration of solutions, percentage composition, empirical

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and molecular formula, stoichiometric calculations, and so forth, to promote learners' conceptual reasoning and problem-solving skills.

The implication of this study is that teachers during instructional activities should be mindful not to overload the working memory of learners in an attempt to enhance their problem-solving skills of the learners. Teachers need to ensure that all aspects of curriculum needs are met and that all levels of the curriculum would align properly.

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Appendix A

Learner Achievement Test (LAT)

Learner Code _______________ School Code ___________ Date ___________ Class_____
Total: 40 Marks **Time: 1 Hour 30 Minutes**

Instructions and information
1. This question paper consists of **TWO** sections.
2. Answer **ALL** the questions.
3. Keep the question numbers correctly as used in this question paper.
4. Non-programmable and non-graphical calculators may be used.
5. All calculations must be clearly shown.
6. Write neatly and legibly.

SECTIONS A (15 Mark)
Stoichiometry multiple choices test on Conceptual Reasoning.
Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Only circle boldly the letter (A–D) next to the question number. Give reason(s) for the option you chose. Three marks will be awarded for each question, one mark for choosing a correct option, and two marks for the justification.

1. Calculate the number of moles of oxygen atoms in 35.2 grams of oxygen.
A. 2.20 moles
B. 4.42 moles
C. 0.54 moles
D. 2.57 moles **(1)**

Give reason for your answer (justify) ____
____
____ **(2)**

2. What is the mass of 0.432 moles of $C_8H_9O_4$?
A. 86.9g
B. 391g
C. 113.8g
D. 73.0g **(1)**

Give reason for your answer (justify) ____
____
____ **(2)**

3. In the reaction $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, what is the ratio of moles of oxygen used to moles of CO_2 produced?
A. 1:1
B. 2:1
C. 1:2
D. 2:2 **(1)**

Give reason for your answer (justify) ____
____
____ **(2)**

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ISSN 2538–7138 /Online/

4. Which of the following is true about the total number of reactants and the total number of products in the reaction shown below?

$C_5H_{12}(\ell) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(g)$

A. 9 moles of reactants chemically change into 11 moles of product.
B. 9 grams of reactants chemically change into 11 grams of the product.
C. 9 litres of reactants chemically change into 11 litres of product.
D. 9 atoms of reactants chemically change into 11 atoms of product. **(1)**

Give reason for your answer (justify) ____

____

____ **(2)**

5. When two substances react to form products, the reactant which is used up is called the ____.

A. determining reactant
B. limiting reactant
C. excess reactant
D. catalytic reactant **(1)**

Give reason for your answer (justify) ____

____

____**(2)**

[15]

SECTIONS B

Problem Solving Skills Questions on Stoichiometry. Five marks each, a total of 25 marks.

Instructions:

1. Show all the steps in your calculations of the following problems.
2. Don't round off until the very last answer.
3. Do not forget to write the units. Answer the questions on the lines provided below.
4. Make sure you are working with a properly balanced equation where necessary.

Question 1

Hydrogen sulfide reacts with sulfur dioxide to give H_2O and S, balancing the equation;
$H_2S(g) + SO_2(g) \rightarrow H_2O(\ell) + S(s)$.
If Hydrogen sulfide contains 125 g, how much S(s) is produced? **(5)**

Question 2

How many grams of Na are required to react completely with 75.0 grams of Chlorine using this reaction: $2\ Na + C\ell_2 \rightarrow 2\ NaC\ell$. **(5)**

Question 3

If 50 cm^3 of silver nitrate solution with a concentration of 0.2 mol/dm^3 is added to 100 cm^3 of a sodium chloride solution with a concentration of 0.5 mol/dm^3. How many moles of silver nitrate and sodium chloride were present in the solutions? What is the limiting reactant?
$AgNO_3(aq) + NaC\ell(aq) \rightarrow AgC\ell + NaNO_3(aq)$ **(5)**

Question 4

How many liters do 3.8 moles of O_2 occupy at STP (standard temperature and pressure)?
NOTE: At STP, for 1 mole of any gas, molar volume = 22.4ℓ. temperature = 273K (0^{o}C) and pressure = 1 atm (1.013×10^5). **(5)**

https://doi.org/10.33225/jbse/22.21.615

Question 5

When 12.8g Cu is allowed to burn in oxygen, 15.2g copper (II) oxide is produced. Balance the chemical equation for the reaction that occurs; $Cu(s) + O_2(g) \rightarrow CuO(s)$.

Determine the percentage yield using the formula below;

Percentage yield = $\frac{actual\ yield}{theoretical\ yield}$ x 100%

(5)

[25]

Marking Guidelines for Learner Achievement Test (LAT)

Learner Code________________ School Code__________ Date_________ Class______

Total: 40 Marks **Time: 1 Hour 30 Minutes**

SECTIONS A (15 Mark)

Stoichiometry multiple choices test on Conceptual Reasoning.

1. A

Justification: Using the knowledge of mole relating it to the mass and molar mass of Oxygen (1mol = 16g/mol,).
n = m/M ∴ O = 35.2g/16 = 2.2 mol

2. D

Justification: Know calculation of molar mass, use relation between mass & moles n = m/M
so, m = n x M = 0.432 x 169 = 73g because $C_8H_9O_4$ = 169g/mol

3. C

Justification: Know the mole ratio between O_2 and CO_2 produced. Also, be able to identify the reactant and the product and their coefficient. ∴ $O_2 : 2CO_2 = 1:2$

4. A

Justification: Know total moles (amount of substance) for reactants and products and the difference between moles, mass, volume, and atoms. ∴ 1 + 8 = 5 + 6 thus 9:11

5. B

Justification: Know the concept of limiting reagent and being able to define it as the substance that is totally used up when the chemical reaction is complete. And that it determines how many moles of a product should be formed.

Marking criteria for SECTION A: 3 MARKS EACH

Question	Concepts tested	Objective choice	Conceptual reasoning		
		1 mark	NCR = 0	PCR = 1	GCR = 2
1	Mole Calculation				
2	Mole Calculation				
3	Mole Ratio				
4	Distinguish between Moles, Atoms, Mass, Volume, etc.				
5	Limiting Reagent				

NCR- No Conceptual Reasoning, PCR- Partial Conceptual Reasoning and
GCR- Good Conceptual Reasoning.

NCR	PCR	GCR
No reason at all	Partially valid reason	Sound conceptual reasoning
Incorrect reason	Incomplete reason	Complete valid reason
	Imprecise reason	Precise reason

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SECTION B (25 marks) Problem Solving Questions on Stoichiometry

Criateria:	Formula/ Equation	(1)
	Substitution	(1)
	Method/Evaluation	(2)
	Correct Answer	(1)

Q1. Solution:

Balanced reaction: $2\ H_2S + SO_2 \rightarrow 2\ H_2O + 3\ S$ (solid). ✓

$n(H_2S) = \frac{m}{M} = \frac{125g}{34\ gmol{-}1} \times 2$✓ $= \frac{125g}{68\ gmol{-}1} = 1.8382mol$ ✓

$n(S) = 3 \times 1.8382 = 5.5146mol$ ✓

$mass(S) = 5.5146 \times 32 = 176.47g$ ✓

OR

$2\ H_2S + SO_2 \rightarrow 2\ H_2O + 3\ S$ (solid). ✓

$n(H_2S) = \frac{m}{M} = \frac{125g}{34\ gmol{-}1} = 3.676mol$✓

mole ratio is 2:3✓

$n(S) = 3/2 \times 3.676 = 5.5146mol$ ✓

$mass(S) = 5.5146 \times 32 = 176.47g$ ✓

OR

$2\ H_2S + SO_2 \rightarrow 2\ H_2O + 3\ S$ (solid). ✓

125g x

68g/mol 96g/mol

$X = \frac{125 \times 96}{68} = 176.47g$

OR

$2\ H_2S + SO_2 \rightarrow 2\ H_2O + 3\ S$ (solid). ✓

$n(H_2S) = \frac{m}{M} = \frac{125g}{34\ gmol{-}1} = 3.676\ mol$✓

mole ratio is 2:3✓

$n(S) = 3:2 = X:3.676$

$\therefore\ 2X = 3.676 \times 3$

$n(S) = 5.5146\ mol$ ✓

$mass(S) = Nm$

$= 5.5146 \times 32$

$= 176.47g$ ✓

Q2. Solution:

$Moles(C\ell_2) = \frac{m}{M} = \frac{75.0g}{70.906\ gmol{-}1}$ ✓ $=1.06\ mol$✓

From mole ratio: 2 : 1✓

So, 2 x 1.06mol = 2.12 mol of Na✓

$\therefore$ 2.12 mol × 22.99 g/mol = 48.7 g✓

OR

2Na(g) $C\ell_2$ ✓

46g/mol 71g/molü

X 75g✓

$X = \frac{46 \times 75}{71}$ ✓ $= 48.6g$✓

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***Q3. Solution*:**

n = cv = 0.2(50 ÷ 1000) = 0.01 mol $AgNO_3$ ✓

n(NaCℓ) = 0.5(100 ÷ 1000) = 0.05 mol. ✓

From mole ratio; 1mole of $AgNO_3$: 1mole NaCℓ

So, 0.01mole of $AgNO_3$: 0.01mole of NaCℓ

Therefore, if all the $AgNO_3$ is used up, there is still 0.05 – 0.01 = 0.04mol NaCℓ left. ✓

Hence, $AgNO_3$ is the limiting reagent. ✓

Q4. Solution:

Volume = n × V_m ✓

= 3.8 molü × 22.4L ✓

= 85.12 litres of O_2 üü

OR

pV =nRT✓

1.013 x 10^5 x Vü = 3.8 x 8.31 x 273 ✓

$V = \frac{8620.794}{101300} = 0.085m^3$ ✓

∴ 0,085 x 1000 = 85L✓

At STP, 1 mol of any gas = 22.4dm^3 or 22.4L, T = 273K (0°C) and 1 atm

Q5. Solution;

2Cu(s) + O_2 (g) ⟶ 2CuO(s). ✓

M(CuO) = 63.5 + 16 = 79.5 g/mol

M(Cu) = 63.5 g/mol

$n = \frac{m}{M} = \frac{12.8}{63.5}$ = 0.2 mol Cu ✓

mole ratio = 2 : 2 ü

∴ 0.2 mol Cu : 0.2 mol CuO

So, m = nM = 0.2(79.5) = 15.9g CuO should theoretically be formed. ✓

Percentage yield = $\frac{actual\ yield}{theoretical\ yield}$ x 100%

= $\frac{15.2}{15.9}$ x 100% = 95.59% ü

OR

m(2Cu) = 127g/mol

$n = \frac{m}{M}$ = 12.8/127 = 0.1mol✓

m(2CuO) = 79.5 x 2 = 159g/mol✓

n(Cu) = n(CuO) ✓

∴ $n = \frac{m}{M}$ = 0.1 x 159 = 15.9✓

Percentage yield = $\frac{actual\ yield}{theoretical\ yield}$ x 100%

= $\frac{15.2}{15.9}$ x 100% = 95.59% ✓

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ISSN 2538–7138 /Online/

Appendix B

Extracts of Marked Learner Test Script

SECTIONS A (20 Mark)

Stoichiometry multiple choices test on Conceptual Reasoning.
Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Only circle boldly the letter (A–D) next to the question number. Give reason(s) for the option you chose. Four marks will be awarded for each question, one mark for choosing a correct option and three marks for the justification/ reason.

1. Calculate the number of moles of oxygen atoms in 35.2 grams of oxygen.
   A. 2.20 moles
   B. 4.42 moles
   C. 0.54 moles
   D. 2.57 moles (1)

   $n = \frac{m}{M}$

   Give reason for your answer (justify) number of mole is the grams divided by the molar mass (3)

2. What is the mass of 0.432 moles of $C_8H_9O_4$?
   A. 86.9g
   B. 391g
   C. 113.8g
   D. 73.0g (1)

   $m = n \times M$

   Give reason for your answer (justify) to get the mass you say the number of mole times the molar mass (3)

3. In the reaction $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, what is the ratio of moles of oxygen used to moles of CO produced?
   A. 1:1
   B. 2:1
   C. 1:2
   D. 2:2 (1)

   Give reason for your answer (justify) $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$ 1:2 1 mole of O to produce 2 moles of CO (3)

4. Which of the following is true about the total number of reactants and the total number of products in the reaction shown below?
   $CH(\ell) + 8O(g) \rightarrow 5CO(g) + 6HO(g)$
   A. 9 moles of reactants chemically change into 11 moles of product.
   B. 9 grams of reactants chemically change into 11 grams of product.
   C. 9 litres of reactants chemically change into 11 litres of product.
   D. 9 atoms of reactants chemically change into 11 atoms of product. (1)

   Give reason for your answer (justify) $CH(\ell) + 8O(g) \rightarrow 5CO(g) + 6HO(g)$ 1 mole + 8 mole = 5 moles + 6 moles (3)

5. When two substances react to form products, the reactant which is used up is called the ____.
   A. determining reagent
   B. limiting reagent
   C. excess reagent
   D. catalytic reagent (1)

   Give reason for your answer (justify) when reaction goes forward (3)

[20]

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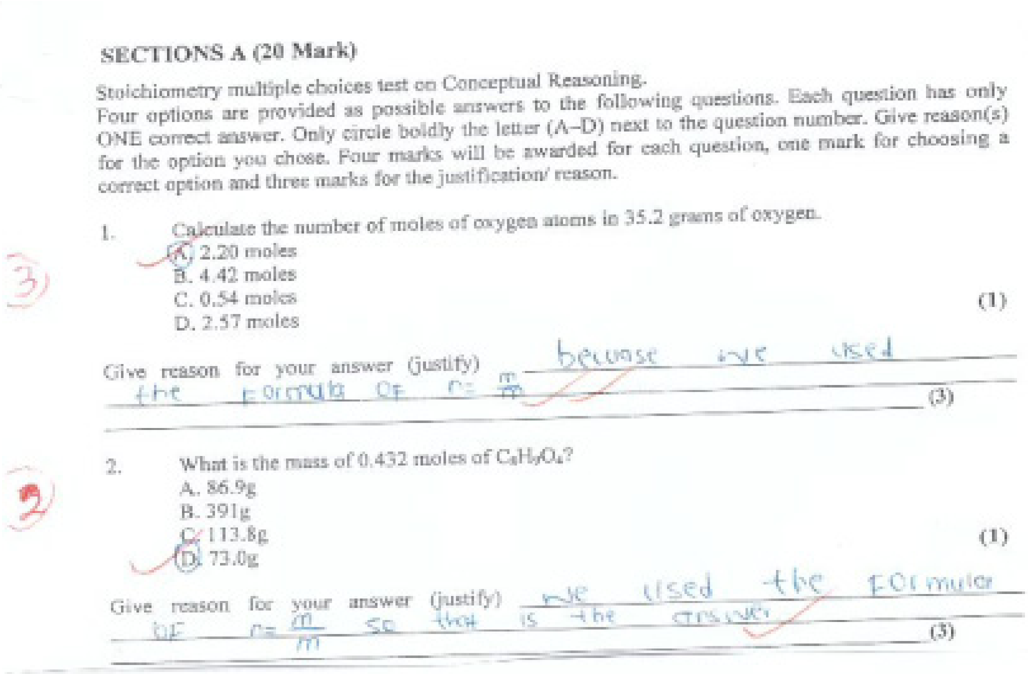


SECTIONS A (20 Mark)

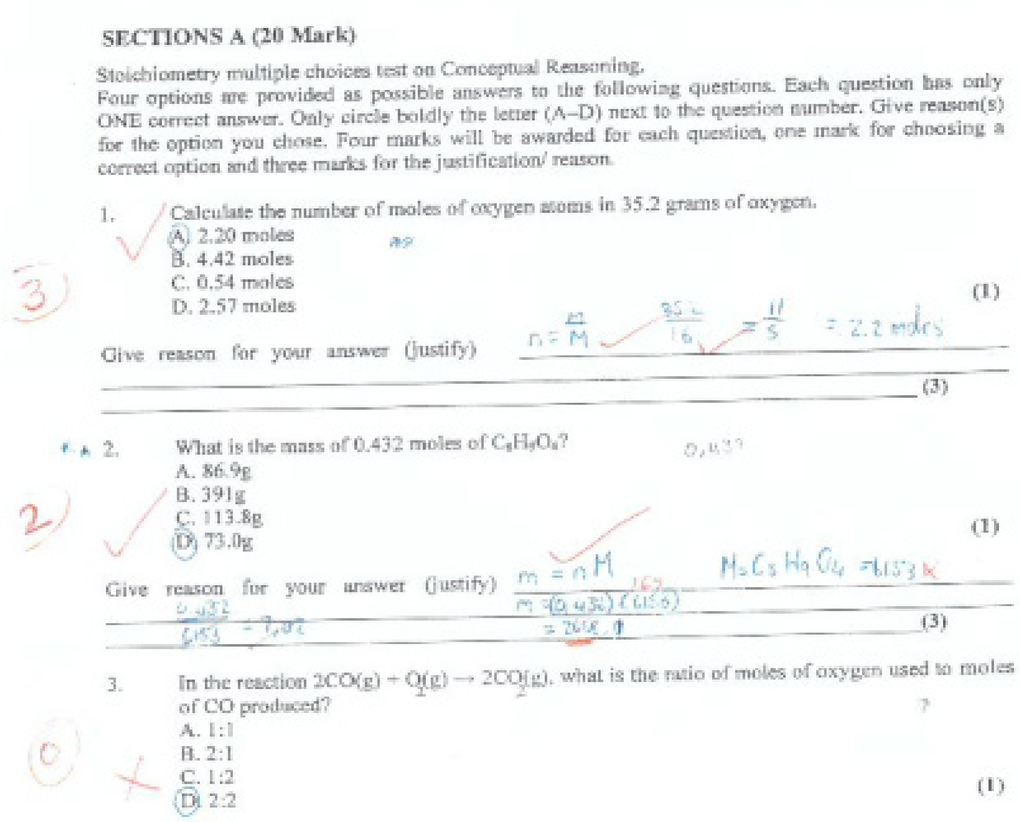
Stoichiometry multiple choices test on Conceptual Reasoning.
Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Only circle boldly the letter (A–D) next to the question number. Give reason(s) for the option you chose. Four marks will be awarded for each question, one mark for choosing a correct option and three marks for the justification/ reason.

1. Calculate the number of moles of oxygen atoms in 35.2 grams of oxygen.
   A. 2.20 moles
   B. 4.42 moles
   C. 0.54 moles
   D. 2.57 moles (1)

Give reason for your answer (justify) because we used the formula of $n = \frac{m}{M}$ (3)

2. What is the mass of 0.432 moles of $C_6H_9O_4$?
   A. 86.9g
   B. 391g
   C. 113.8g
   D. 73.0g (1)

Give reason for your answer (justify) we used the formular of $n = \frac{m}{M}$ so that is the answer (3)



SECTIONS A (20 Mark)

Stoichiometry multiple choices test on Conceptual Reasoning.
Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Only circle boldly the letter (A–D) next to the question number. Give reason(s) for the option you chose. Four marks will be awarded for each question, one mark for choosing a correct option and three marks for the justification/ reason.

1. Calculate the number of moles of oxygen atoms in 35.2 grams of oxygen.
   A. 2.20 moles
   B. 4.42 moles
   C. 0.54 moles
   D. 2.57 moles (1)

Give reason for your answer (justify) $n = \frac{m}{M}$ $\frac{35.2}{16}$ $= \frac{11}{5}$ = 2.2 moles (3)

2. What is the mass of 0.432 moles of $C_6H_9O_4$?
   A. 86.9g
   B. 391g
   C. 113.8g
   D. 73.0g (1)

Give reason for your answer (justify) $m = nM$ (3)

3. In the reaction $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, what is the ratio of moles of oxygen used to moles of CO produced?
   A. 1:1
   B. 2:1
   C. 1:2
   D. 2:2 (1)

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. Calculate the number of moles of oxygen atoms in 35.2 grams of oxygen.

A. 2.20 moles
B. 4.42 moles
C. 0.54 moles
D. 2.57 moles (1)

Give reason for your answer (justify) ____ (3)

. What is the mass of 0.432 moles of $C_8H_9O_4$?

A. 86.9g
B. 391g
C. 113.8g
D. 73.0g (1)

Give reason for your answer (justify) ____ (3)

3. In the reaction 2CO(g) + O(g) → 2CO(g), what is the ratio of moles of oxygen used to moles of CO produced?

A. 1:1
B. 2:1
C. 1:2
D. 2:2 (1)

Give reason for your answer (justify) 2CO + O → 2CO 2:1 (3)

4. Which of the following is true about the total number of reactants and the total number of products in the reaction shown below?

CH(ℓ) + 8O(g) → 5CO(g) + 6HO(g)

A. 9 moles of reactants chemically change into 11 moles of product.
B. 9 grams of reactants chemically change into 11 grams of product.
C. 9 litres of reactants chemically change into 11 litres of product.
D. 9 atoms of reactants chemically change into 11 atoms of product. (1)

Give reason for your answer (justify) 8g of Oxygen and 1 grams of methane chemically changes into 11 grams (3)

5. When two substances react to form products, the reactant which is used up is called the ____.

A. determining reagent
B. limiting reagent
C. excess reagent
D. catalytic reagent (1)

Give reason for your answer (justify) limiting reagent is a reagent that is completely used up during reaction (3)

[20]

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