An intervention on supporting teachers' understanding of and mediation of learning of stoichiometry in selected schools in the Zambezi Region

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By

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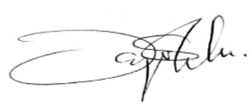
Declaration of Originality

I, Denuga, Desalu Dedayo the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree. All ideas and citations used in this study derived from other people are acknowledged and indicated in the list of references.



27 December 2018

Signature Date

Abstract

This study has been triggered by the results on stoichiometry questions in the Directorate of Namibian Examination Assessment's (DNEA) scripts. As highlighted in the examiners' reports, stoichiometry is an ongoing annual problem for most students in Namibia. It is against this background that I decided to explore the possibility of an intervention in the form of continuing professional development (CPD) and collaboration workshops to improve the understanding and the mediation of learning of stoichiometry by Physical Science teachers in the Zambezi Region of Namibia.

The study was underpinned by an interpretive paradigm and within this paradigm a qualitative case study approach was adopted. Since this study was in a form of an intervention, a participatory action research (PAR) approach was employed within the community of practice (CoP). I used document analysis, workshop discussions, observations and videotaped lessons, interviews (semi-structured and stimulated recall interviews) and reflections to gather data. The study was carried out at three senior secondary schools and six Physical Science teachers were involved. The study drew on the theory of constructivism as a theoretical framework, namely, Piaget's cognitive constructivism and Vygotsky‘s social constructivism as well as Shulman's pedagogical content knowledge (PCK). Within PCK, Mavhunga and Rollnick's Topic Specific Pedagogical Content Knowledge (TSPCK) was used as an analytical lens (Appendix L) in this study.

The findings reveal that the use of a diagnostic test on learners made the Physical Science teachers aware of the learners' challenges and what was difficult for them to understand in stoichiometry. It also helped in their understanding of the use of prior knowledge, one of the tenets of TSPCK, to access what learners knew about stoichiometry. Further findings of the study illuminate that the Physical Science teachers' subject matter knowledge, pedagogical content knowledge and skills had shifted as a result of their participation in the intervention workshops. The findings of this study indicate that the CoP members acquired the professional transformations which were important breakthroughs in their careers.

The study thus recommends that teachers should develop effective teacher professional development activities such as study teams, exemplary lessons, cluster teaching, and peer coaching where teachers are expected to examine their assumptions and practices continuously. The implication of my study is that the developed exemplary lesson during the intervention workshops by CoP members could be useful to other Physical Science teachers in the teaching of stoichiometry in all the schools in the Zambezi Region.

Keywords: Chemistry, stoichiometry, intervention programme, interpretivist paradigm, participatory action research, constructivism, pedagogical content knowledge

Dedication

This thesis is dedicated to my parents of blessed memories, Late Mr. Samuel Adetola Adenuga and Mrs Sariyu Anipele Adenuga for the contribution you made to see me going to school. May your souls rest in peace. Daddy your words keep on ringing in my ears whenever l am travelling to a foreign land, *“Ranti omo eniti iwo ise*” meaning “Remember the child of who you are”. A warning proverb for a child not to misbehave. Thanks very much. May your soul rest in perfect peace.

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Acronyms and/or abbreviations

BETD	Basic Education Teacher's Diploma
CCK	Curricular Content Knowledge
CK	Curricular Knowledge
CoP	Community of Practice
CPD	Continual Professional Development
DACE	Directorate of Adult Continuing Education
DAST	Draw-A-Scientist Test
DEEB	Directorate of Distance Education and Educational Broadcasting
ECP	Education Certificate Primary
EHDC	Education Higher Degree Committee
GRN	Government of Republic of Namibia
HOD	Head of Department
JSC	Junior Secondary Certificate
LTSMs	Learning and Teaching Support materials
MASTEP	Mathematics and Science Teachers Extension Programme
MoE	Ministry of Education
NAMCOL	Namibian College of Open Learning
Namibia. MoE	Namibia Ministry of Education
NANTU	Namibia National Teachers' Union
NIED	National Institute of Educational Development

NMEC	Namibia Ministry of Education, Sport and Culture
NSSCH	Namibia Secondary School Certificate Higher
NSSCO	Namibia Secondary School Certificate Ordinary
PAR	Participatory Action Research
PCK	Pedagogical Content Knowledge
PLC	Professional learning community
SAT	Standard Achievement Test
SEP	Science Education Program
STP	Standard Temperature and Pressure
SMK	Subject Matter Knowledge
TIMSS	Trends in International Mathematics and Science Study
TSPCK	Topic Specific Pedagogical Content Knowledge
UNAM	University of Namibia
UNICEF	United Nations International Children Educational Fund
ZFM	Zone of Free Movement
ZPA	Zone of Promoted Action
ZPD	Zone of Proximal Development

CHAPTER ONE: SITUATING THE STUDY

At a PCK summit in 2012, a definition of pedagogical content knowledge was devised by a workgroup led by Gess-Newsome, Carlson and Gardner. They defined pedagogical content knowledge as the knowledge of, reasoning behind, planning for, and enactment of teaching a particular topic in a particular reason to particular student outcomes. (Gess-Newsome, 2013, p. 3)

1.1 Introduction

The primary focus of this study was to explore and investigate the mediating effect of teachers' pedagogical content knowledge (PCK) and subject matter knowledge (SMK) in the teaching and learning of stoichiometry, in senior secondary schools in the Zambezi region. The rationale was to understand and support Physical Science teachers' mediating effect on the learning of stoichiometry. As stated in the epigraph, PCK is the knowledge of reasoning behind the planning for and enactment of teaching a particular topic (Gess-Newsome, 2013). This study focused on the PCK of the science teachers, in the teaching and mediating of the learning of stoichiometry, for effective teaching delivery.

All the Physical Science teachers who participated in this study were within schools located in the Katima Mulilo urban constituency in the Zambezi geographical location. Essentially, this study was located within the paradigm of the Namibian educational context. The study was anchored in Namibian contextual, social and historical background factors in relation to the current and the past educational systems.

1.2 Background and purpose of the study

For years, learners have been performing poorly in science and mathematics in Namibia (DNEA, 2009). One of the causes could be attributed in part to inadequate training of teachers in these subjects. Lack of imparting adequate scientific skills and proper use of PCK, and SMK by teachers, might contribute to the failure rate of Science and Mathematics learners. For instance, understanding of stoichiometry concepts allows one to calculate the concentration of solutions in moles and other Mathematical Chemistry concepts, an important aspect in Chemistry. For this study the research goal and research questions guiding the study are stated below.

Research goal:

The main goal of the study was to explore an intervention that might support teachers' understanding and the mediation of learning of stoichiometry concepts, guided by the research questions below.

Research questions:

1. What are Grade 11 Physical Science teachers' understandings of teaching stoichiometry prior to the intervention?
2. How do the interventions in the form of workshops support Grade 11 Physical Science teachers in developing exemplary lessons for teaching stoichiometry? and
3. How do Grade 11 Physical Science teachers mediate learning of the developed exemplary lessons?

Stoichiometry is a fundamental concept which deals with the calculation of the number of products and reactants in any chemical reaction. Learners tend to find stoichiometry very difficult and confusing. The examiners' reports issued by the Directorate of Namibia Examination Assessment (DNEA), reflect that stoichiometry is an ongoing annual problem for learners in Namibia. It is against this background that I investigated an intervention in the mediation of the learning of stoichiometry by Physical Science teachers in Namibia, using the research questions above. This prompted me to investigate the Namibian educational system.

1.2.1 The Namibian Educational System

Namibia was a former German and South African colony up to 1990. Schooling under the German colony was introduced by European missionaries to civilise the indigenous people (Smith, 2003, 2009), to enable the Namibians to read and write. Learners were taught how to read religious literature so that they could facilitate the spread of the Gospel and be very active in the church programmes (Shilongo, 2004). Also, Germans wanted the Namibian to suppress Namibian culture and allow German culture to flourish. This is evident from what they wanted Namibians to learn. That type of education consisted of three Rs, namely, *Reading*, *wRiting* and *aRithmetic*, which Curtis (2008) states are the basis of education. This type of education was used by the German colonisers, who conquered the territory in 1884, as a means of colonisation and racial segregation.

The indigenous people were provided with well-calculated, limiting skills to ensure that they could only work as labourers. The German colonial government paid no attention to the establishment of adequate schools for the indigenous people and science subjects were never taught.

According to Shilongo (2004), schools served as educational institutes designed for reproducing the privilege of the ruling government, in accordance with the skills and attitudes that enhanced the stability of the government, therefore serving as instruments of oppression. In addition, different educational systems and administrations were developed based on race. Whites, blacks and coloureds all had separate schools that were administered by racially based Education Departments. Whites received a superior education, while blacks received the most inferior and unproductive education. This created the governance of the South African apartheid ideology in Namibia.

The apartheid school structure in Namibia was organised into four levels, namely, lower primary level which lasts for four years, higher primary lasting for three years, junior secondary lasting for three years and higher secondary lasting for two years (Lilemba, 1990). That was the structure for Namibian schools prior to 1975 and before independence, resulting in a 12-year schooling cycle. This type of education system focused only on theoretical academic education, which did not encourage learners to use their talents to discover, investigate, criticise and implement a change in their life or society at large.

In summary, the education system of Namibia – before independence in 1990 – was designed to reinforce apartheid, rather than provide the necessary human resource base to promote equitable social and economic development. It was fragmented along racial and ethnic lines, with vast disparities in both the allocation of resources and the quality of education offered.

The new Government of the Republic of Namibia (GRN) led by the South West African People's Organisation party, set about creating one unified structure for education administration, leading to a new educational system after independence.

1.2.2 Namibian Education System after Independence

After gaining independence in 1990, the Ministry of Education in Namibia had a variety of obstacles to overcome. The first challenge was the apartheid ideology from South African rule that led to dramatic inequalities and disparities in the quality of education between ethnic groups in

Namibia. Another challenge was the content, pedagogy, and assessment practices of the pre-independence system which did not meet the needs and goals of the Namibian people (Shilongo, 2004). Thus, the Namibian Ministry of Basic Education and Culture (NMBEC) (2010) undertook a comprehensive reform process focused on access, equity, quality, democracy, and lifelong learning. A national development agenda was created by the government, in response to the needs of the education sector and called for an "innovative, knowledge-based society, supported by a dynamic, responsive and highly effective education and training system" (Namibia. NMBEC, p. 7). To date, Namibia strives to continue to work towards better quality education for all through highly trained graduates.

Education is associated with developmental change. This implies that the development of education has noticeable effects on ideas, levels of knowledge, values and ways of life. This change resulted in the development of the new educational system. The new organogram of the Namibian Education system, which was developed for better education and quality for Namibians after independence, is shown in Figure 1.2.2.1 below.

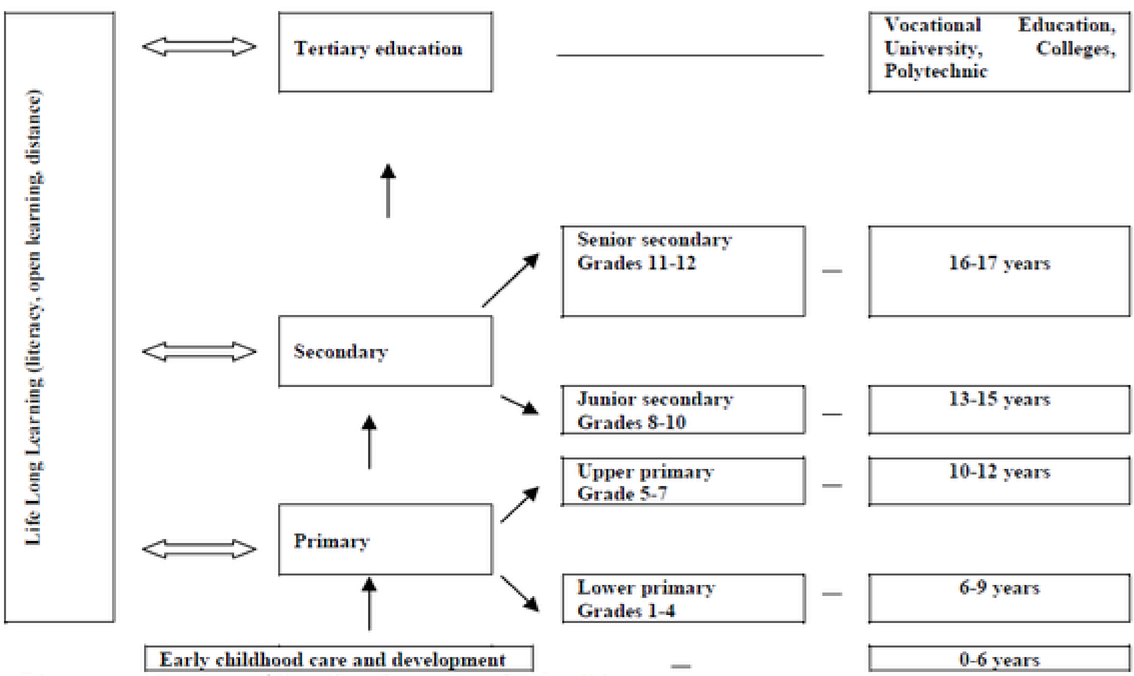


Figure 1.2.2.1: Structure of the education system in Namibia (Adapted from UNESCO-IBE, p. 7)

The organogram above reflects the Namibian education system. As illustrated in this organogram, any educational programme is expected to perform many functions so as to be constructive and fulfil the nation's manpower needs. Namibia as a nation, for effective change, needs to develop human resources and social forces. The tertiary education, as seen in the organogram, is the gateway to institutions of higher learning both at the local and international level.

1.2.3 International and local views on teaching progress

The evaluation of progress made in science subjects is a perpetual activity and done internationally. For example, in South Africa, Reddy et al. (2015) write that the Trends in International Mathematics and Science Study (TIMSS) is an example of a study which focused on tracking progress in Science and Mathematics. TIMSS is a large comparative study conducted internationally at the end of Grade Four and Grade Eight (Reddy et al., 2015). The first international assessment among 41 international systems around the world was done in 1995. TIMSS uses diagnostic tests to come up with data that reveal progress. The TIMSS assessment focuses on two dimensions, a content dimension specifying the SMK and a cognitive dimension specifying the cognitive or thinking processes (aptitude).

Reddy et al. (2015) in TIMSS (2015) also highlighted the poor performance of learners scoring 20 per cent in chemistry tests on content domain, administered in other countries globally. Provasnik et al. (2012) in the TIMSS (2011) publication of international results in science, revealed better performance in the factual recall questions than in reasoning and its applications.

Sadly, Namibia has not taken part in the TIMSS, but instead took part in the Standard Achievement Tests (SATS) (Shaakumeni, 2014). The SATs are annual assessments administered mainly to provide information regarding learners' achievement of key learning competencies in the curriculum at Grade Five and Seven. The SAT assessment for Grade Five focused on English Second Language and Mathematics, while at Grade Seven it centred on English Second Language, Mathematics and Natural Science (Namibia. Ministry of Education, 2015).

The SAT results at both grade levels showed drastic improvement when compared with previous years. For example, the Grade Five learners of 2015 obtained an average score of 54% in English Second Language, as compared to an average of 44% in 2014. Also, in Mathematics, the average improved by 19%, from 44% in 2014 to 63% in 2015. This improved performance encouraged the learning and teaching of English Second Language, Mathematics and Natural Science. Also, the Directorate of Namibia Examination Assessment (DNEA) released examiners' reports on areas where learners performed well or badly (Namibia. Ministry of Education, 2000-2015). One of the areas of science where learners performed badly was stoichiometry in Chemistry. Learners also performed poorly in other concepts of Chemistry since they depend on the understanding of stoichiometry concepts which act as the foundation for other important concepts. Despite data from examiners' reports from the DNEA, no study has been done on an intervention in the teaching and learning of stoichiometry. This is something that triggered this study.

At the beginning of this study, a stoichiometry diagnostic test (see Appendix N), validated and marked by Physical Science teachers, was administered to learners in the Zambezi Region. Below are the results. In the table below are School A, School B and School C. These were the participating schools in this study.

Table 1.2.3.1: Number of learners and marks (in %) obtained in the stoichiometry diagnostic

Percentage mark obtained	Number of learners per school		
	School A	School B	School C
0	1	0	1
5	11	4	11
10	7	3	14
15	9	8	9
20	4	1	7
25	3	1	5
30	1	0	1

The poor performance concurred with examiners' annual reports about performance in stoichiometry in the examinations. No single student in each of the three schools got above 40%; the highest was 30% as seen in Table 1.2.3.1, above. This stimulated the need to investigate the

PCK and SMK of the Physical Science teachers and develop an intervention to end learners' poor achievement in science.

1.2.4 Namibian learners' poor achievement in science

In Namibia the first commitment by the government is to provide universal basic education, with adequate monitoring to enhance quality. This quality etiquette led to a diagnostic test (Appendix N) being administered regularly to learners. In Namibia, standardised testing is done by primary schools each year with Grade Seven students. Stoichiometry diagnostic tests (Appendix N) are used to test the performance of the schools, as well as the learners. Experts have found that the majority of learners perform below average to average, with a small fraction of Namibian learners showing excellent performances in the three subjects. The core subjects being examined are English, Mathematics and Natural Science. This assessment was done in 2011 with 48 000 Grade Seven learners, in 1086 schools, by the Directorate of National Examinations and Assessment (DNEA) and the American Institutes Research. The outcome of the assessment was as follows: the national average in English was 45%, with over 58% getting an average of 45% or less, and 80% getting a score of 60% or less. The national average for Mathematics was 42 %. Over 59% of the learners got average or below average scores. 80% got a score of 54% or less (Sasman, 2011).

In Natural Science, the national average was 51%, with over 59% getting below average or average scores. Again, about 80% obtained a score of 54% or less. Only three percent of the schools tested, showed excellent results in English and Mathematics, and six percent in Natural Science. On average, the urban schools performed better by 10 to 18 % compared to rural schools, while private schools obtained about 20 to 25% higher scores than public schools.

Comparing regional performances, it was found that the Khomas and Erongo regions showed consistently better performances in all three subjects. The weakest performing regions were the Ohangwena and Zambezi regions. It could be inferred that secondary school learners' performances were affected by reasons outlined in this study.

The test data provided evidence for learners' level of mastery of basic skills and competencies for improved learning, and the results were thus to be used to develop appropriate teaching materials and appropriate teaching methodologies.

The feeder schools for the secondary schools are the primary schools where performance in English, Mathematics and Natural Science are below average. This might have a negative effect on the teaching of science in the secondary schools. The outcome of this poor performance radiates within the field of science, and this has contributed to this study in terms of how the teaching of stoichiometry can be mediated with an appropriate intervention.

My view is that, in Namibia, TIMSS is highly unpopular. There is no data or information on Namibian performance at international level with reference to Science and Mathematics. TIMSS has been carrying out educational achievement tests in Science and Mathematics throughout the world. The TIMSS report is a good measure of student performance in Mathematics and Science education in countries around the world. Namibia has not taken part in a TIMSS evaluation or diagnostic test since its inception.

The International Association for the Evaluation of Educational Achievement the international body that administers TIMSS, may be contacted in future for the development of Mathematics and Science in Namibia. South Africa acknowledges the recommendation of TIMSS, agreeing with the fact that several countries with previously low performances participated with Grade Nine learners so that the test would be more appropriate. This TIMSS evaluation test can be embarked upon by Namibia as one of the strategies to motivate and mediate the teaching of Science and Mathematics in the country.

It should be noted though, that both TIMSS and SATs do not solve poor performance, but show how learners perform in the field of Science and Mathematics. Failure of learners in Mathematics and Science is a problem that reflects the need for intervention. The impact of this problem can be curtailed by an intervention in the form of continuing professional development (CPD) for Physical Science teachers, teaching stoichiometry.

1.3 Continuing Professional Development

According to Kohl (2005), CPD is regarded as engaging teachers in activities that enhance their teaching performance, resulting in improved learner achievement. Ladson-Billings and Gomez (2001) view professional development as the cornerstone of school reform, aimed at raising academic performance. They argue that no amount of "standards, benchmarks, and high-stake testing can bring about school improvement without giving attention to teacher quality" (p. 680).

Whitehouse (2011) reports that the under-performance observed in Science affects teaching methods. Poor performance may lead to teachers having to check on their methods of teaching. This can demotivate them from innovative pedagogies that could increase learner performance. In his study, a three-year CPD programme intervention called Proficiency and Success in Science was initiated to improve the teaching skills of teachers. The CPD focused on teachers' content knowledge and developing teaching and learning practices. The findings of the study showed that the learners whose teachers participated in the programme subsequently outperformed those learners whose teachers had not taken part in the programme. Similarly, a study conducted in Malaysia by Mukundan, Hajimohammadi and Nimehchisalem (2011) probed the professional development interest of Mathematics and Science teachers. The study revealed that female teachers were more interested in participating in CPD activities compared to male teachers. Additionally, Mathematics teachers showed more interest than Science teachers and less experienced teachers were more eager to participate than experienced teachers were. A study of the current status of CPD programme implementation and its trials in government secondary schools of Dire Dawa in Ethiopia (Tisasu, 2014), showed that teachers had a positive attitude towards CPD. Collaborative engagement, strategies of planning and execution of topic concepts might encourage teachers to develop positive attitudes towards CPD. CPD engagement differs from country to country.

Internationally, approaches to teachers' CPD come in different forms. For example, the United Kingdom and Germany require teachers to participate in CPD activities (Borko, 2004). On the other hand, in Poland, Portugal, Slovakia, Slovenia, and Spain, it is optional but connected to career advancement and salary benefits (De Vries, Jansen, & Van de Grift, 2013). In France, Greece, Iceland, Denmark, Norway, Sweden, and the Netherlands, CPD is seen as a professional duty without salary benefits; participation is enforced (De Vries et al., 2013). According to Borko (2004), in the United States of America (USA), the operational CPD is inadequate and does not address how the teachers learn.

In developing countries where CPD is necessary, budgetary constraints and lack of resources are a challenge, as observed by Ono and Ferreira (2010). As a developing country, Namibia is not spared, as highlighted by Asheela (2017), and needs CPD. The noticeable evidence of CPD in the afore-mentioned developed countries might have motivated the Namibian government to introduce CPD.

According to Nyambe, Kasanda and Iipinge (2016), Namibia's CPD intervention consists of two components, namely: CPD for updating and CPD for upgrading. CPD for updating is intended to provide educators with on-going learning opportunities to update their knowledge and skills, in order to enhance their effectiveness and productivity. CPD for upgrading, on the other hand, consists of planned, structured courses which are undertaken over a period of time and have specific, designated and verifiable learning outcomes that are formally assessed by an accredited provider.

Nyambe et al. (2016) enumerate problems with CPD in Namibia as follows: uncoordinated CPD activities; lack of CPD policy from the Ministry of Education; episodic nature; no coherence and connection between activities; no follow-up and support of implementation; no monitoring of the impact of CPD activities or to inform future CPD activities, and attendance of workshops is often off site.

In this study, I started a CPD initiative in the form of an intervention for stoichiometry teaching and learning. The CPD initiative took the format of participatory action research (PAR) (MacDonald, 2012; Mertler, 2012). Physical Science teachers came together and identified problems they had with teaching stoichiometry concepts. These problems were addressed during organised workshops. The physical science teachers co-developed lesson plans and learning and teaching support materials (LTSMs), in a community of practice (CoP) (Lave & Wenger, 1991) which they then used during the class teaching of stoichiometry concepts. During teaching, Physical Science teachers were observed, video-taped, and reflections on the success and challenges of teaching stoichiometry concepts were done. Teachers interacted during reflection, learning from each other for the betterment of the teaching of stoichiometry. The CPD initiative might enrich Science teaching in Namibia as the schedule is bottom-up, coming from teachers having the same problems and interacting with each other to improve their teaching skills.

1.4 Science enrichment programmes in Namibia

In Namibia many enrichment programmes have been engaged in by the Ministry of Education and other private organisations. The enrichment programmes were the Namibian College of Open Learning (NAMCOL), Education and Training Sector Improvement Programme (ETSIP) and In-Service Training and Assistance for Namibian Teachers. These enrichment programmes are discussed below.

1.4.1 History of Namibian College of Open Learning

The Namibian College of Open Learning (NAMCOL), a formal intervention strategy by the Ministry of Education aims to help learners in their studies. NAMCOL has its roots in the education programmes provided by the Namibian Extension Unit to exiles in Zambia and other frontline states, prior to 1990. During the process of transforming and restructuring the national education system in the years following independence, these programmes were taken over by two directorates within the Ministry's Department of Culture and Lifelong Learning, each using a different mode of delivery. The Directorate of Adult Continuing Education (DACE) organised afternoon and evening classes for large numbers of young people who needed to re-sit their examinations or who could not be accommodated in conventional schools. The Directorate of Distance Education and Educational Broadcasting (DEEB) offered correspondence courses for those who wished to upgrade their qualifications but who could not attend regular classes.

Shortly after Namibia achieved its independence, the then Minister of Education, the Right Honourable Nahas Angula, set up a working group to investigate the feasibility of establishing a dedicated distance education institution for the nation. This group recommended the creation of a college that could provide a high-quality alternative to the conventional schooling system, as well as addressing the nation's human resource development needs through a number of professional training programmes. It was intended that the new body would use innovative methods of open and distance learning to bring education to people in all parts of the country.

SAIDE (2011) opines that an Interim Development Board was appointed and the process of drafting legislation to establish the college on a statutory footing was begun. In 1996, DACE and DEEB were amalgamated into a single directorate of the Ministry in order to facilitate the transfer of staff and assets to the new institution. In 1997 the Namibian College of Open Learning Act was passed by Parliament [Act No. 1 of 1997] and was promulgated in the *Government Gazette* later that same year. However, the College only became fully operational at the beginning of the following financial year (April 1998), when it assumed full responsibility for out-of-school secondary education programmes previously provided by the Ministry. NAMCOL developed as an intervention to improve learners' achievement and interest in education. The Ministry of Education and Culture's (MEC) five-year plan also assigned a significant role to distance education. "Taking Education to the People" (this statement became a famous NAMCOL slogan) was a report written that recommended the establishment of a semi-autonomous Distance Education College. The establishment of this College gained the approval of the MEC in 1993. (Namibia. Ministry of Basic Education and Culture, 1993).

In 1994, the Interim Development Board was appointed by the Minister to assist in planning for the establishment of the College through an act of Parliament. The new structure was to be named the Namibian College of Open Learning (NAMCOL), with a remit for both distance education and face-to-face components of the Ministry's continuing education programme. NAMCOL covers learners meant to upgrade Grade 10 and Grade 12 in the education programme.

An analysis of the current situation indicates that NAMCOL has been given a broad mandate to provide a range of educational programmes and courses for those who cannot or do not wish to study through conventional means. Since 1998, when NAMCOL took over responsibility for programmes formerly provided by units in the Ministry of Education, enrolments have increased by 61% and a range of new courses have been introduced, though the Secondary Education Programme still accounts for 95% of all learners. The College has moved away from its origins as a dual-mode institution and now delivers the majority of its courses through a blended-learning approach. Learners receive printed self-instructional materials, supplemented by multi-media and e-learning resources, and take part in face-to-face tutorials, either on a weekly basis or during vacation workshops. NAMCOL's management has also taken steps to address areas for improvement that were identified in a similar review of the College's roles and functions undertaken in 2005.

According to SAIDE (2011), consultations with stakeholders revealed a number of positive impressions of the College. NAMCOL's role in providing a safety net for learners who fail their junior or senior secondary examinations, or who cannot be accommodated in conventional schools, is much appreciated. Stakeholders also acknowledge the quality of the study materials developed by NAMCOL and the College's nation-wide presence through approximately 100 tutorial centres around the country. Positive comments have also been made about the Pre-Entry to Tertiary Education Programme and the professional development courses offered by the College. Over the last 13 years, NAMCOL has proved itself to be a trustworthy institution through the efficient delivery of services.

According to SAIDE (2011), one of NAMCOL's main weaknesses – in the minds of respondents – is the poor examination results achieved by Science Education Programme (SEP) learners. SEP is a special programme meant for learners who want to improve their grades. Despite the fact that the pass rates for both Junior Secondary Certificate (JSC) and Namibia Senior Secondary Certificate Ordinary (NSSCO) learners with NAMCOL have improved significantly over the last 12 years, they still lag behind those for learners in conventional schools. While many stakeholders acknowledge that the College takes in those who have not performed well in the formal system, the possibility that these learners may achieve greater learning gains than their school-based counterparts, is not widely appreciated.

SAIDE (2011) argue that NAMCOL is also faulted for admitting large numbers of second-chance learners who are preparing to re-sit examinations for subjects in which they performed poorly, even though the majority of these re-sit candidates come from conventional schools. Stakeholders also use the amount of learner-tutor/teacher contact, to assess the quality of educational services and place a lower value on NAMCOL programmes, even though SEP learners spend approximately the same number of hours per week in class as those in mainstream education.

The NAMCOL programmes are focused on how to assist those who failed Grade 10 or Grade 12 to acquire the desired grade points. For better quality and sustainability of education, another promising approach, the Education and Training Sector Improvement Programme (ETSIP), was developed.

1.4.2 ETSIP and the teaching of science

In response to the challenges identified in *Namibia Vision 2030* and the World Bank (2012) report, the government devised a comprehensive framework, the Education and Training Sector Improvement Programme (ETSIP), to strengthen strategic planning and monitoring of outcomes (National Planning Commission, 2004). The strategic plan for the first five-year phase of ETSIP focused on improving the quality and effectiveness of the education system, enhancing its internal efficiency, redressing persistent inequities and ensuring that what young people learnt was relevant to the world outside the school walls.

The ETSIP plan for 2005-2010 recognised the potential of open and distance learning to expand access to senior secondary education. It also acknowledged NAMCOL's contribution to the nation's development by offering a complementary system of education for out-of-school youth and hard-to-reach groups. The ETSIP Strategic Plan also envisaged a role for NAMCOL in creating and supporting a system of lifelong learning outside the conventional classroom. ETSIP has been supported by the adoption of a Medium-Term Expenditure Framework for budgeting and a Performance and Efficiency Management Programme, which link the provision of resources with concrete performance targets for all ministries. Various mechanisms have also been put in place to facilitate consultation between GRN and its international development partners on progress by the sector in meeting the ETSIP goals and targets. Among the goals of ETSIP embedded in the finance of Science activities in the country, are events such as Science fairs, Science expos and Science excursions. The CPD never featured in the enrichment programmes discussed in this section. This further supported the need for this study to look into the statement of the problem which when solved, might close the gap left by all Science enrichment programmes discussed in this section.

1.5 Statement of the problem

The topic of stoichiometry in Physical Science is generally poorly understood at Grade 12 level, as highlighted in the DNEA yearly examiners' reports (Namibia. MoE, 2000-2015). This problem might be due to the teachers' inadequate subject matter knowledge and poor pedagogical content knowledge. Also, the problem might be associated with lack of basic mathematics skills on the part of learners and Science teachers, in topics such as ratio, percentages and proportions (Namibia. MoE, 2000-2015). This also makes one wonder whether the concepts of stoichiometry and basic mathematics being taught are within the zone of proximal development of the learners as proposed by Vygotsky (1978). Due to the extended effect, the continued poor performance impacts negatively on the learners' future careers in the sciences. It becomes imperative to research how Grade 11 Physical Science teachers' SMK and PCK shape their mediation of the learning of stoichiometry. The PCK focuses on Topic Specific Pedagogical Content Knowledge (TSPCK) (Mavhunga & Rollnick, 2013) and brought the Participatory Action Research, in conjunction with a CoP (Wenger, 2000), used in the study for the teaching and learning of stoichiometry by the science teachers.

1.6 Significance of the study

This study sought to explore an intervention in Grade 11 Physical Science teachers' teaching of stoichiometry and to come up with learning and LTSMs for effective teaching delivery. The purpose of any viable research is to provide solution(s) to prevailing problem(s), by investigating and using participatory action research to intervene in how teachers mediate the learning of stoichiometry in the classrooms. The teachers were able to analyse their own pedagogy of teaching as a result of the intervention when teaching stoichiometry in the classroom. Analysing the successful and unsuccessful pedagogy of teaching and mediating stoichiometry, might ultimately assist the teachers to improve learners' learning of stoichiometry.

The study might also empower the teachers to develop the learners' scientific concepts involved in stoichiometry; this might in turn help more learners to understand stoichiometry and encourage them to major in Science and Technology at a tertiary institution of their choice. The study might also assist the Namibian Ministry of Education's policy on teachers' placement and improve the skills, learning and teaching capabilities of all the participants, including me as the researcher. Finally, being a lecturer at the university, this study might also help to improve my own practice and ensure that the student teachers studying at the university are competent enough to teach the topic of stoichiometry.

1.7 Definition of key concepts

The following definitions describe the concepts that have been used in this study.

Chemistry: A branch of Science dealing with the structure, composition, properties and reactive characteristics of substances, especially at the atomic and molecular levels (Zumdahl, 2014).

Stoichiometry: A branch of Chemistry concerned with measuring the proportions of elements that combine during chemical reactions (Myers, Oldham, & Tocci, 2004).

Continuing Professional Development: Professional development activities "as the cornerstone" of school reform aimed at raising academic performance (Ladson-Billings & Gomez, 2001).

Community of Practice (CoP): A group of people who share a passion about practice, ideas, and sets of problems, consequently deepening their knowledge and expertise (Lave & Wenger, 1991; Wenger, 1998).

Mediation: Methods used by the teacher or an instructor to help learners to achieve desirable subject content and skills.

Mediation tools: The means through which the mediation of learning is achieved.

Participatory Action Research: An approach in which researchers and participants collaboratively engage in the various stages of the research processes.

Pedagogical content knowledge (PCK): The ways in which teachers present subject content.

Subject matter knowledge (SMK): The facts, concepts, theories, and principles that are taught and learnt in specific academic courses.

Social constructivism: A theory which advances that knowledge which is acquired through interactions in a social context.

Stoichiometry: A branch of Chemistry concerned with measuring the proportions of elements that combine during chemical reactions.

1.8 Thesis Outline

The study consists of eight chapters:

Chapter One: Situating the study

This chapter presented an overview of the study which included the background of the study, problem statement, and significance of the study, methodology, research goal and research questions and a brief overview of the thesis chapters.

This study situates the research in its Namibian context. Since the Namibian educational system is faced with many challenges due to the apartheid government of the then colonial master, there was a need for such a study to be carried out so as to improve the teaching and learning of stoichiometry.

The following reasons directed this research: the Namibian educational background; the historical and social impact of the apartheid educational system; black education known as the Bantu Educational system, which resulted in a coloured educational system, and a white educational system; and the effect of independence obtained in 1990.

Chapter Two: Literature Review

This is a review of literature relevant to the study. The literature reviewed is in relation to teaching of stoichiometry, including the constraints and recommendations for the teaching of stoichiometry locally and globally.

Chapter Three: Theoretical and Analytical Framework

The chapter describes the theoretical and conceptual framework which informed this study. Thus, the theoretical framework informing this study was the theory of constructivism, namely, Piaget's cognitive constructivism and Vygotsky's social constructivism, as well as Shulman's (1986) PCK. The conceptual framework was Wenger's CoP.

Chapter Four: Research Design and Methodology

The chapter presents the research and methodology. It describes the research paradigm underpinning the study, research site, sampling procedures, data generating techniques, as well as data analysis process, validity and ethical issues.

Chapters Five: Data presentation and Discussion: Pre-intervention

This chapter presents and discusses the data gathered from questionnaires, interviews and individual semi-structured interviews from research question 1. The data presented in this chapter reflected the respondents' own ideas.

Chapter Six: Data Presentation and Discussion: Intervention

This chapter presents and discusses data to answer my research question 2, focusing on how an intervention in the form of workshops supported Grade 11 Physical Science teachers in developing model lessons and LTSMs for mediating learning of stoichiometry.

Chapter Seven: Data Presentation and Discussion: Implementation Process

Presentation and discussion were generated to answer research question 3, aimed at how Grade 11 Physical Science teachers mediated learning of the developed stoichiometry model lessons. The data was coded (Appendix L) and categorised from the observations, stimulated recall interviews and reflections of four research participants. The themes that emerged were then formulated during research analysis.

Chapter Eight: Summary of findings and recommendations

The recommendations for practice emerging from the study are raised; limitations of the study, the **s**ummary of findings, recommendations, conclusion and suggestions for further research are discussed in this chapter.

1.9 Concluding remarks

In this chapter, I outlined the context of the study. The chapter further presented the problem statement; the significance of the study; research design; the goal and research questions, definitions of key concepts and thesis outline. The next chapter presents a review of literature relevant to the study.

CHAPTER TWO: LITERATURE REVIEW

A literature review surveys books, scholarly articles, and any other sources relevant to a particular issue, area of research, or theory, and by so doing, provides a description, summary, and critical evaluation of these works in relation to the research problem being investigated. (Laberee, 2009, p. 45)

2.1 Introduction

This study focused on the exploration of the possibilities of an intervention to support the learning of stoichiometry among Grade 11 Physical Science teachers in selected schools in Namibia. In this chapter, as explained in the epigraph, l present literature relevant to this study, in particular stoichiometry. I first discuss the tenets of stoichiometry as stated in the Physical Science Curriculum documents of the Namibia Secondary School Certificate Ordinary and Higher (NSSCO/H). Secondly, I discuss literature on stoichiometry focussing on learning and teaching, including Chemistry as a subject, as well as its challenges. Thirdly, I discuss the teacher education training programme in Namibia.

2.2 Challenges in stoichiometry literacy

Stoichiometry is an important component of Chemistry. It deals with the quantitative relation between the numbers of moles, and therefore mass, of various products and reactants in a chemical reaction (Brown et al., 2014). These scholars define stoichiometry based on mass-mole, and in this regard, they understand stoichiometry as the quantitative aspect of the mass-mole number relationship, chemical formulas, and reactions and involve the mole concepts and the balancing of chemical equations. This definition of stoichiometry is also supported by Zumdahl (2014). Stoichiometry conceptual understanding aims to understand the concept of chemical reaction with other reacting materials and this is addressed in the NSSCO/H curriculum. Addressing conceptual understanding in the stoichiometry curriculum is difficult for most learners.

In Chemistry, the concept of stoichiometry is considered the most complicated concept to master (Hand, Yang, & Bruxvoort, 2007). On account of stoichiometry dealing with abstract concepts, learners encounter challenges to learn the concepts. Various authors support this and the studies carried out in different parts of the world reveal this as seen in the paragraphs that follow.

Huddle and Pillay (1996), in their study conducted in South Africa, revealed that university students have two major misconceptions when solving limiting reagent questions in stoichiometry. Only one major misconception is mentioned in this study. Students assumed that the limiting reagent implied the substance with the smallest number of moles. Yet, the limiting reagent needs to be calculated with the relevant ratio in order to establish the least moles in the reaction, not on assumption.

Furio, Azcona and Guisasolo (2002) in their study conducted in Spain, reviewed and researched the practice of the learning and teaching of the concepts of amount of substance and moles. These authors found that learners had great difficulty in handling the amount of substance and moles in stoichiometry calculations. Similarly, BouJaoude and Barakat (2003) described their qualitative study about learners' problem-solving strategies in stoichiometry and their relationship to conceptual understanding and learning approaches, carried out with selected private schools in Lebanon. Results from the study confirmed that incorrect procedures were used for solving mole, volume, mass and molar quantities in stoichiometry. Furthermore, several misunderstandings were identified about limiting reagents, the mole concept and balancing of chemical equations (Sostarecz & Sostarecz, 2012). To this end, BouJaoude and Barakat (2003) suggest that international collaboration is a good way to improve the teaching and learning of stoichiometry, as the problem was also noted across different national cultural contexts in countries such as Germany, Lebanon and United States of America (USA).

Fach, de Boer and Parchmann (2007) used interviews in their study to evaluate the effectiveness of stepped supporting tools (SST) for stoichiometry problems among German learners. Their study combined investigation of SST for stoichiometry problems with the development and evaluation of specific teaching and learning materials, to assist learners in solving stoichiometry problems. Findings from their study revealed that many learners had incomplete strategies for solving stoichiometry problems. Learners did not know the definitions and relationships between stoichiometry entities in general (Fach et al., 2007).

Opara (2014), in her research on the concept of stoichiometry in the Eastern part of Nigeria, used collaborative learning after she found that learners faced challenges with understanding stoichiometry. According to Hanson (2016), in an interpretive study about Ghanaian teacher trainees' conceptual understanding of chemical stoichiometry, which was carried out with 78 teacher trainees, confirmed that stoichiometry learning was mostly done by using factor-label undefined strategies and algorithmic methods. The trainees were found to have persistent stoichiometry problems with conceptual interpretations due to the inability to translate word problems into mathematical equations. Hanson (2016) thus suggests that teachers should teach the mole concept and related terms until learners clearly understand them before engaging them in finding solutions to numerical problems. He further emphasises that new terms and basic mathematical computational skills should be taught before the teaching of stoichiometry. Mathematics, a universal tool, is central to teaching stoichiometry, since once learners understand the mathematical concepts involved, learners encounter less problems. Mastery of Mathematics mediates the learning of stoichiometry. In Namibia where the study was carried out, these challenges were also observed, and literature related to this is discussed after a review of what the stoichiometry curriculum emphasises in Physical Science for the NSSC.

2.3 Physical Science curriculum for Namibian Senior Secondary Certificate (NSSC)

The Physical Science curriculum for the Namibian Senior Secondary Certificate (NSSC) is comprised of Physics and Chemistry. Stoichiometry is one of the components of Chemistry. As explained in Table 2.3.1 and 2.3.2, learners are expected to know the terminology and calculations used in stoichiometric calculations (Namibia. NMBEC, 2010).

Table 2.3.1: Higher grade stoichiometry content extracted from the NSSC (H) curriculum 2010

Topic	General Objectives	Specific Objectives: Learners should be able to do:
Stoichiometry	Know all terminology and calculations used in stoichiometric calculations	• use the symbols of the elements and write the formulae of simple compounds. • deduce the formulae, names and% composition of a simple compounds from the relative numbers of atoms present. • use symbols of elements and write formulae of compounds from given information (including the balancing of ions) • define spectator ions.
		• construct ionic equations (including state symbols) to identify the key reactants in the reactions • balance chemical equations • define the mole and the Avogadro constant • define relative atomic mass, Ar, of an atom as the ratio of the average mass of one atom of the naturally occurring atom to 1/12 of the mass of carbon 12 atom • use relative atomic mass in simple calculations • define relative formula mass M_r, of a molecule or chemical compound as the ratio of the average mass of one molecule or compound in the simplest form, of the naturally-occurring atom to 1/12 of the mass of a carbon-12 atom (Note: The term relative molecular mass, M_r, may be used for molecules) • use these concepts to solve simple problems (e.g. empirical and molecular formula, % yield, % purity) • calculate stoichiometric reacting masses and volume of gases (taking the molar gas volume as 24 dm^3 at room temperature and pressure (rtp) and standard temperature and pressure (stp) (0°C) taking the molar gas volume as 22.4 dm^3) • calculate stoichiometric reacting masses and volume of solutions, • solution concentrations being expressed in g/dm^3 and mol/dm^3 • (Calculations involving the idea of limiting reactants may be set) • (Note: The word molarity expresses the concentration of a solution only in mol/ dm^3 and is no longer in use) • use the equation $pV = nRT$ (Refer to Physics Section 2.1)

NSSCH Physical Science Syllabus, NIED 2010

The table below reflects the curriculum of stoichiometry for the ordinary grade known as NSSC (O), the content varies slightly from that of the higher grade.

Table 2.3.2: Ordinary grade stoichiometry content extracted from the NSSC (O) syllabus 2010

Topic	General Objectives: Learners will…	Specific Objectives: Learners should be able to…
Stoichiometry	Know terminology and calculations used in stoichiometry.	• use the symbols of the elements and write the formulae of simple compounds • deduce the formula and name of a simple compound from the relative numbers of atoms present • determine the formula of an ionic compound from the charges on the ions present • construct word equations and simple balanced chemical equations • define relative atomic mass, A_r, of an atom as the ratio of the average mass of one atom of the naturally-occurring atom to 1/12 of the mass of a carbon-12 atom • define relative formula mass M_r, of a molecule or chemical compound as the ratio of the average mass of one molecule or compound in the simplest form, of the naturally-occurring atom to 1/12 of the mass of a carbon-12 atom (Note: The term relative molecular mass, M_r, may be used for molecules) • state the relative formula mass of the molecule or compound in the simplest form, is the sum of the relative atomic masses of all atoms present in that molecule • calculate it as the sum of the relative atomic masses /relative formula mass • deduce the balanced equation of a chemical reaction, given relevant information • define concentration in g/dm^3 and mol/ dm^3 (Note: The word molarity expresses the concentration of a solution only in $mol/dm^3$and is no longer in use) • calculate stoichiometric reacting masses and volume of gases (taking the molar gas volume as $24dm^3$at room temperature and pressure rtp) •calculate stoichiometric reacting masses and volume of solutions, solution concentrations being expressed in g/dm^3 or mol/dm^3, (calculations based on limiting reactants may be set (questions on the gas laws and the conversion of gaseous volumes to different temperatures and pressures will not be set)

The stoichiometry content of both NSSC (H) and NSSC (O) look similar but in the higher grade the curriculum has other components: use of equation pV = nRT; limiting reagents; empirical and molecular formula; % yield; % purity; spectator ions; and balancing of chemical ionic equations. According to Uce (2009), learners find these concepts in stoichiometry difficult, and this is supported by Kanime (2015) in her study.

In an effort to find the solutions to the problems that learners encounter in stoichiometry, Kanime (2015) carried out a study on stoichiometry in the Oshikoto Region in Namibia. The study revealed that learners had negative perceptions of stoichiometry concepts and most of the learners lacked interest. How the negative perception was measured was not clear and from the PCK perspective, negative perception can be controlled if the lesson is supported by LTSMs that motivate learners.

Namibian learners' negative perceptions may be attributed to lack of basic Mathematics computational skills, since stoichiometry concepts are anchored in a mathematical approach (Cardellini, 2012). This might contribute to poor performance in teaching and learning of stoichiometry. In Namibia, the annual examiners' report of 2007, alluded to poor performance in stoichiometry nationwide (see Box 2.3.1 below).

Box 2.3.1: Excerpts of examiner's reports 2007, NSSCO Paper 2, Question 5

Paper 2 NSSC Ordinary 2007

5. **The writing of a balanced equation seemed to be a challenge to many**. Only very few candidates realised that an excess of base was added and hence causes the change in colour to violet/purple/ blue. The calculation of the 1:1 ratio acid-base reaction was weakly treated while it just required the conversion of 25 cm^3 (0.025 dm^3) and application of the formula c = n / v to be rearranged to n = c x v = 0.025 x 1.5 = 0.0375 mol. The remaining was to realise the 1:1 ratio and provide the answers as 0.0375 mol and 1.5 mol/dm^3.

Box 2.3.2: NSSC (H) Paper 2 2016, Question 6

6 This question tested candidates' knowledge of stoichiometry. Calculations proved to be challenging.

(a) (i) Fairly well-answered. Definitions must be accurate and carefully learnt.

Mark scheme/expected answers

The empirical formula of a chemical compound is the simplest positive integer ratio of atoms present in a compound. [1]

(ii) Poorly-answered. Only a few candidates could calculate the number of moles from the %. Even less could go on to find the correct whole number ratio.

Mark scheme/expected answers

48.38 g ÷ 12.10 g = 4.03 mol C
8.12 g ÷ 1.00 g = 8.12 mol H
43.50 g ÷ 16.00 g = 2.72 mol O

(4.03 mol O/ 2.72) = 1.48
(8.12 mol C/ 2.72) = 2.98
(2.72 mol H/ 2.72) = 1

1.48 x 2 = 2.96 ≈ 3 mol O
2.98 x 2 = 5.96 ≈ 6 mol C
1 x 2 = 2 mol H

→ $C_3H_6O_2$ [4]

(b) (i) This was a very straightforward question that caused more difficulties than anticipated. Many candidates used the M_R formula instead of the concentration formula to calculate mole. Others used the values for magnesium, although not known, in their calculation.

Mark scheme/expected answers

HCl concentration = nV = 0.025 × 1.2 = 0.03

moles ratio: MCO_3 : HCl
1 : 2
0.015 : 0.03

M_r of $MCO_3 = \frac{1.26}{0.015} = 84$ g or g.mol⁻¹ [3]

(ii) Fairly well-answered. It was evident though that many candidates guessed that M was magnesium.

Mark scheme/expected answers

(M_r of M = 24 (–60) M is **magnesium** [1]

The comments in Box 2.3.1 and 2.3.2, are all in support of stoichiometry being a challenge to Namibian learners. This justifies why this study was necessary. The ideas enumerated about poor performance in stoichiometry in this study prompted me to look into an intervention that could solve the problem of teaching and learning stoichiometry. However, in order to move away from other studies which only focused on learners' attributes, this study went on to analyse the Namibian teachers' PCK and SMK as well.

2.4 Namibian teachers' pedagogical content knowledge and subject matter knowledge

How can an intervention programme improve teacher understanding and the mediation of learning of stoichiometry in selected schools in the Zambezi Region? My assumption was, that if the PCK and SMK and other knowledge types that Shulman (1987) proposes of teachers were improved, then the outcome result might improve the performance of learners in stoichiometry. The PCK and SMK of stoichiometry of teachers were never reported among all the authors reviewed in the literature. This may be the gap in providing answers to the poor performance in stoichiometry teaching and learning.

PCK is concerned with the representation and formulation of concepts, pedagogical techniques, and knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge and theories of epistemology. It also involves knowledge of teaching strategies that incorporate appropriate conceptual representations to address learner difficulties and misconceptions, and foster meaningful understanding (Shulman, 1986).

The subject matter knowledge (SMK), on the other hand, is the teacher's knowledge of the discipline of content and organisation. This includes knowledge of discipline conceptual schemes and specific knowledge of particular topics. To have a broader view of the mentioned knowledge types, PCK and SMK of Shulman (1987), this study selected schools within the Katima urban area in the Zambezi Region in Namibia. The participating teachers facilitated the selection and use of learners. This then allowed me to look into the learners' attitudes and performance when learning stoichiometry concepts.

2.5 Studies on attitudes and performance about the teaching of stoichiometry concepts

Across many countries, there has been significant research into attitudes towards teaching and learning stoichiometry concepts in Chemistry. Some focused on teachers' and trainee teachers' attitudes to pedagogy. In Kahveci (2009), the study focus was specifically directed at the training of teachers of Chemistry. Likewise, with Kind (2004) the studies targeted teachers' and trainee teachers' misconceptions of Chemistry and its concepts. Coll, Dalgety and Salter's (2002) study aimed to investigate the attitudes of university and school learners to Chemistry. Little has been reported on the attitudes of Physical Science teachers and their pedagogical content knowledge and subject matter knowledge.

According to Linington (2015), studies exploring the attitudes of secondary school chemistry trainee teachers in United Kingdom were conducted. The aim of the initiative was to improve the quality of Chemistry teaching in secondary schools by providing a larger pool of qualified chemistry teachers for secondary school level. A survey was used to generate data from prospective trainee teachers on the subject knowledge enhancement courses at the University of East London over a period of five years (Linington, 2015). Six cohorts of pre-service teachers (cohort size varied from seven to 20) were asked to complete the instruments. Almost all responded to the survey.

The findings showed that the Draw-A-Scientist Test (DAST) instrument used continued to give results that did not match the survey results. It was unclear whether the DAST was not suitable for this type of work, or whether the answers to the questionnaire given by trainees were those they thought were expected of them. More work needs to be done to explore the relationship between the task of drawing a chemist and attitudes towards Chemistry.

Shemhilu (2015) carried out a study about factors affecting Chemistry performance in the ordinary level National Examination in Dar es Salaam. The study used a cross sectional research design to generate data from the population samples. It employed two stage-sampling designs to select the 100 respondents who were learners studying Chemistry from selected schools. Purposive sampling was used to select key informants. Data collection was done by using questionnaires, interviews and document analysis. A stoichiometric topic specific pedagogical content knowledge tool

(Appendix M), developed by Malcolm (2015) was modified to fit the context of the study. Data from questionnaires was collected, edited, coded and summarised and then analysed using the Statistical Package for Social Sciences. For example, graphs were constructed such as that in Figure 5.2.1. Descriptive statistics such as frequencies and percentages were employed to show the patterns revealed from the findings. The major findings that emerged were, insufficient facility distribution and accessibility in secondary schools, lack of qualified Chemistry teachers in schools and lack of adequate home support for the learners. The study provided that if there were enough learning facilities and qualified Chemistry teachers in secondary schools, it might influence the factors affecting learner attitudes towards the teaching of stoichiometry.

2.6 Factors influencing learners' attitude towards stoichiometry concepts

Any malfunction during the teaching and learning process can result in learners' poor performance. According to Okunloye and Awowale (2011), learners' academic performance in any subject is an important guide for measuring the effectiveness of teaching and learning and the extent to which the intended objectives of the subjects are being achieved. The authors' view is in line with the diagnostic test given to learners in this study. The aim was to measure the PCK and SMK of the teachers via the performance of the learners in the diagnostic test. Learners performed poorly in the test and this generated data showing the need to investigate the PCK and SMK of the Zambezi region's Physical Science teachers.

The fact that learners find it difficult to successfully grasp stoichiometry concepts in chemistry, might encourage learners to develop a negative attitude that will hinder them from achieving the desired objectives in the subject as a whole. This makes learners rote learn the concepts. Many learners have the perception that Chemistry is a difficult, complex and abstract subject that requires special knowledgeable talent and too much exertion to understand (Cardellini, 2012). Yet, because learners have a poor understanding of concepts in Chemistry at the secondary school level, it becomes a great challenge for them to study chemistry-related courses at institutions of higher learning. It was revealed in Yunus and Ali's study (2012), that environmental challenges hindered many learners from developing an interest in Chemistry courses, which in turn created negative attitudes that prevented them from taking Chemistry related courses. Consequently, learners were faced with greater challenges which resulted in failing Chemistry and withdrawing from school.

To stop this dreaded situation, educational researchers, teachers, educational providers and many other agencies have tried, using research tools such as questionnaires, to seek the teachers' and learners' perceptions in order to ascertain the areas and causes of their teaching and learning difficulties with stoichiometry. To Gulacar and Bowman (2014), understanding learners' difficulties in Chemistry depends on learners' perceptions of the content of Chemistry.

In spite of the efforts made by the educational researchers, teachers, educational providers and many other agencies, learners' achievement in Chemistry has been poor and unsatisfactory year after year (Nbina & Auwiri, 2014; Okunloye & Awowale, 2011). Despite the numerous findings by quite a number of researchers on difficulties learners encounter when learning Chemistry, these difficulties in Chemistry still persist and negative attitudes remain unchanged.

Only a handful of studies on learners' learning difficulties actually administered a diagnostic test on Chemistry content and compared it with the actual learner perceptions (Adesoji, Omilani, & Dada, 2017). It should be noted that learners' perceptions, which are a mental view about their learning difficulties, are constructed as a result of their social experiences developed through interaction with their environment (e.g. school, home) or the influence of peers, teachers, parents, siblings or mass media (Adesoji et al., 2017). Past experiences, beliefs, attitudes, conceptions and misconceptions are other ideas that might influence the learners' attitudes towards Chemistry. The learners might cultivate the incorrect picture which does not exist about their teaching and learning of Chemistry. On the basis of the facts explained above, this study emerged to investigate the PCK of the teachers, because most studies reviewed so far mainly focused on learners.

Moreover, studies on difficult topics in Chemistry indicated that not all Chemistry topics were perceived as difficult (Ogunkola & Samuel, 2011). This makes it imperative to ascertain the actual branches of Chemistry, where the topics that pose learning difficulties to learners are embedded. The findings of Jimoh (2005), Onuekwusi (2015), Sai (2010) and Gongden, Gongden and Lohdip (2011) revealed that learners perceived topics in Physical Chemistry as being difficult to learn, while electrochemistry (electrolysis) as an aspect of Chemistry was asserted by De Jong and Treagust (2002) to be the most difficult Chemistry topic taught and learnt in secondary school.

Similarly, Staver and Lumpe (1995), BoJaoude and Barakat (2003), Kanime (2015) and Hanson (2016) conducted research on stoichiometry, revealing that stoichiometry concepts were difficult for the learners. All these studies revealed that stoichiometry or Chemistry is difficult, without earmarking the tenets that made it difficult.

Becker and Towns (2012), Shadreck (2013), Turanyi and Toth (2013), Sokrat, Tamani, Moutaabbid and Radid (2014), Taha, Hashim, Ismail, Jusoff and Yin (2014), and Bain, Moon, Mack and Towns (2014) conducted research on Physical Chemistry. They found out the following indicators of learners' learning difficulties: learners' poor mathematical ability; poor understanding of the particulate nature of matter; poor problem-solving skills; mixing up of concepts and the abstract nature of Chemistry, all led to poor learner achievement in Physical Chemistry. Other factors included a lack of learner motivation and poor learner attitude towards Physical Chemistry. The above-mentioned are learner-related factors. However, there were also teacher-centred factors which were PCK related, as well as other environmentally-related factors such as insufficient teaching and learning resources. For effective scrutiny in this study, the teacher-centred factors, PCK and their social interaction was studied. The co-developed teaching materials during the workshop in this study, where teachers socially interacted with each other justified why Shulman's (1987) PCK and Vygotsky's (1978) social constructivism were used as conceptual and theoretical frameworks respectively. These allowed comment on the conceptions and dispositions learners and teachers had when dealing with stoichiometry concepts.

2.7 Conceptions and dispositions towards stoichiometry

To avoid misconceptions in constructing stoichiometry concepts, proper conceptions in teaching and learning can be developed using tenets of social constructivism. This might help learners form a clear understanding of a concept (or idea) through studying a small set of examples of the concepts (Ogunkola & Samuel, 2011). This is a deep conceptual learning rather than superficial knowledge. Dispositions are the values, commitments, and professional ethics that influence behaviour toward colleagues, communities, and affect learners' learning, motivation and development, as well as the educator's own professional growth (Usher & Pajares, 2008). The teaching of Chemistry is supposed to be result-oriented and learner-centred. This can only be achieved when learners are willing and the teachers are favourably disposed to using the appropriate methods and resources to teach the learners (Adesoji & Olatunbosun, 2008).

According to Adesoji and Olatunbosun (2008), Chemistry has been identified as a very important Science subject and its importance in scientific and technological development worldwide has been widely reported. This makes Chemistry a pre-requisite subject for offering most Science-oriented courses in tertiary institutions and this calls for the need to teach it effectively (Adesoji & Olatunbosun, 2008).

Learners by nature are curious. They need to be actively involved in the learning process in which they are continuously constructing, testing, speculating and building their own personal construct and knowledge (Vygotsky, 1978). To Vygotsky (1978) it is only by internalising such knowledge that it becomes valid, meaningful and useful to them. In Chemistry, learners need to actively construct their own personal awareness and meaning (Usman, 2000). To substantiate the argument, Usman (2006) remarks that the brain is not a passive consumer of information, and to learn with understanding, a learner must actively construct meaning of what is to be learnt (Freire, 1993; Vygotsky, 1978). Among the tenets for effective learning, disposition seems to be overlooked and other researchers have not mentioned anything about disposition (Edomwonyi-Otu & Avaa, 2011).

Despite the core position Chemistry occupies in our educational system, learners' performance in Chemistry and the sciences in general are still low. Some of the reasons identified for this failure are laboratory inadequacies, teachers' attitude, examination malpractice, and time constraints for practical activities, non-coverage of the syllabus, class sizes, non-professionalism, and the environment. Disposition has never been discussed (Edomwonyi-Otu, & Avaa, 2011).

Dispositions are guided by beliefs and attitudes related to values such as caring, fairness, honesty, responsibility and social justice (Jones et al., 1995). There are five dispositions for effective teachers and this also might be adapted and apply to learners. These dispositions are empathy, positive view of others, positive view of self, authenticity and meaningful purpose and vision (Jones et al., 1995). Though disposition is not a skill, it remains to be determined whether a stronger tendency towards cognitive maturity predicts greater skill at making mature judgments (Yunus & Ali, 2012). Learners with all the five dispositions might improve academically (Jones, et al., 1995).

A learner's disposition to think critically is a necessary precondition for effective learning to take place. Disposition greatly affects learning and teaching capability. Teacher education training should incorporate disposition and critical thinking in the learner-teacher programme for effective teaching in the classroom.

2.8 Teacher education training programmes in Namibia

In 2001, universal staffing norms for primary and secondary education in Namibia were introduced in the education system, in order to establish staffing needs and ensure an efficient utilisation of teachers across the country. During the staffing norms study (Bennell et al., 2009), the Ministry of Education noticed with concern, significant inefficiencies and inequities of the teaching system in relation to financial constraints currently experienced. This problem motivated the Ministry of Education to carry out a study on the demand and supply of teachers in Namibia in 2008. The study had the following aims:

- Assess whether the current status of teacher supply, utilisation and demand is appropriate in terms of Vision 2030 (National Planning Commission, 2004);
- Establish where there is a projected over- or under-supply of teachers;
- Evaluate and correct inconsistencies in policy that affect teacher supply, utilisation and demand;
- Establish whether practicing teachers have sufficient PCK and SMK; and
- Consider the utilisation of lecturers at initial teacher training institutions and whether such staff is appropriately qualified with an aim to meet the need for a detailed review of teacher staffing.

The study came up with the following findings on the CPD of the teachers that might affect the critical thinking of teachers. This goes with the view of Tshiningayamwe (2015) that teachers in professional learning communities (PLCs) share successful teaching strategies. About three quarters of the Basic Education Teacher's Diploma (BETD) teachers surveyed had completed or were currently undertaking further studies in order to acquire additional qualifications. The major advantage of this programme was that teachers studied independently without formal support or guidance from the Ministry of Education.

Out of the total number of those who took part in the survey, only 3-4% of the teachers had ever been granted study leave. The results of the survey showed that the majority of the teachers (40%) were dissatisfied with the opportunities available for upgrading professional qualifications. The results also indicated that a few teachers enrolled for courses in Computing, Mathematics, Science and Languages while most of the teachers enrolled for education-related courses.

Due to the above scenario, the Ministry of Education (MoE) and the Namibia National Teachers' Union (NANTU – the main teachers' union), signed a Memorandum of Understanding in 1999, that all under-qualified teachers should have obtained the BETD qualification by the end of 2007. The Memorandum of Understanding motivated a lot of teachers to enrol for the BETD program. Therefore by 2008, about 3, 600 teachers had graduated from the NIED-managed BETD In-service Training programme. While on the other hand, 900 teachers acquired the same BETD qualification through the Centre for External Studies at University of Namibia. The overall success rate of this programme is about 80% although there are questions around quality issues with regard to more recent teacher intakes in the BETD upgrading programme. This could not solve the problem of the shortage of teachers in schools.

According to European Mathematical Information Service statistics, about 4,900 teachers in government and private schools were still under-qualified in September 2007. To meet the demand for teachers in schools, about two thirds (13,000) of the number of teachers in Namibia are currently studying through the Institute of Open Learning in one of the following courses: The Primary Teacher Diploma, which allows Grade 10 teachers with Education Certificate Primary only to access higher qualifications, a two-year course in advanced certificate in education and a Bachelor of Education. Those who qualified to apply for the above-mentioned courses were teachers with the Further Diploma in Educational Management, the BETD teacher plus one-year teaching experience; Bachelor's degree graduates with a Higher Education Diploma are eligible to study for the two-year Bachelor of Education (BEd). It was reported that the graduation rate in these courses was low as teachers take a much longer time to complete the courses.

The Namibian Ministry of Education's (1999) study noted that the University of Namibia did not offer in-service professional development support and activities for teachers in schools. Therefore, it came up with recommendations that answered the teachers staffing problems in the country and are listed below.

The unqualified teachers (3,000) were replaced by qualified teachers over a period of three to four years. Only able and committed unqualified teachers were retained up to 2012.

- Teachers to be supported in terms of time, financial support and study leave in order to obtain higher qualifications.
- The Namibia Ministry of Education should undertake a comprehensive training needs assessment for both qualifications upgrading and shorter term in-service-training.
- A comprehensive professional development system should consider developing a structured programme of mentoring and internship for unqualified teachers which should enable teachers to be qualified.

This professional development from the MoE was regarded as upgrading CPD which resulted in the issue of a BETD certificate on completion. The improvement of teacher education in Namibia started to meet the demand of improved quality of teaching. The BETD was introduced and offered as a pre-service programme at the then four colleges of education. The programme aimed to equip teachers to teach basic education (Grade 1-10) according to new educational principles and approaches.

According to the Ministry of Basic Education and Culture (1999), in 1994, the NIED initiated a pilot distance education BETD in-service programme, based on the same broad curriculum as the BETD pre-service programme, to cater for serving teachers. The NIED assumption was that the programme might increase the number of qualified serving teachers in Namibia.

BETD's main aim was to develop professional expertise and competencies, which would motivate the teachers to improve the teaching skills needed for the new Ministry of Education's Basic Education programme for Namibians. The competencies emphasised by the BETD initiators were teaching skills; professional attitudes; knowledge and understanding.

The BETD Inset Programme was not successful. It was not seen as the final stage of formal education, nor as the completion of teacher education. The programme was phased out, and a new programme focusing on Mathematics and Science emerged, coined as the Mathematics and Science Teachers Extension Programme (MASTEP)

2.9 Mathematics and Science Teachers' Extension Programme (MASTEP) in Namibia

The scarcity of well-trained teachers is more acutely felt in the areas of Mathematics and Science education especially at the higher secondary school level in almost all countries in Africa and the outside world (Benson, 1994; Haambokoma, 2003; Pabale & Dekkers, 2003). According to Benson's (1994) study, a high percentage of Science and Mathematics teachers in South Africa were under-qualified, which seems to be the product of a disadvantaged education system. In Namibia, the lack of adequately trained Mathematics and Science teachers has often been attributed to the fact that many schools in the black communities did not offer these subjects at all. This was as a result of the Bantu education system that existed in the country prior to independence. Mathematics and Science were considered not to be useful to blacks. The South African colonial masters believed that Mathematics and Science subjects were irrelevant to the needs of the African child. Dr H.F. Verwoerd (1945), during one of his public speeches emphasised that teaching a Bantu child Mathematics and Science when they cannot use it in practice was useless. In support, Ramananandan (1995) was of the opinion that education must teach people in accordance with their opportunities in life.

Such an official view in place had hostile effects on the learning of Mathematics and Science both in South Africa and Namibia. At independence, the Namibian Government recognised the vicious cycle operating in the schools. That is, the presence of poorly trained or untrained Mathematics and Science teachers produced the same kind of learners who failed to continue with the studying of Mathematics and Science courses at tertiary level. This produced fewer candidates to train as teachers and hence continued the cycle of poor teaching again.

It is this set of factors that acted as the catalyst in trying to find ways of breaking this cycle. The current Mathematics and Science Teachers Extension Programme (MASTEP) is the upshot of the initially envisaged Namibian Mathematics and Science Education Programme proposed early in 1990. Nonetheless MASTEP became a reality in 1999 with joint funding from the Namibian Government and the European Community. The MASTEP programme was a two-year part-time teacher in-service programme tailored for Namibian in-service teachers. The main goals were to improve Mathematics and Science education in Namibia at the junior and senior secondary levels. This upgraded initially about 360 serving teachers who were teaching Biology, Mathematics or Physical Science to the International General Certificate of Secondary Education level.

The last goal was to enhance cooperation among UNAM Faculties and Colleges of Education in the country. At the end of the four years of the European Union's funding, the impact of this was not felt in the country. In addition to the three subjects, lack of proficiency in English among the schoolteachers was recognised as a possible hindrance to effective teaching. Accordingly, communicative English was made an essential component of the MASTEP programme. Each MASTEP teacher was required to specialise in one subject only. A further diploma to MASTEP was awarded to the successful candidates. During its duration, the MASTEP programme's effectiveness, was measured against the stated main goals at the midterm and end of programme points (Francis & Burger, 2003; Leyendecker, 2002). Both evaluations regarded the MASTEP programme as a promising practice in the preparation of Mathematics and Science teachers. This programme is now extinct. Teachers with the MASTEP qualification are being considered for further studies in education at UNAM to improve their PCK as well as SMK.

2.10 Concluding Remarks

This chapter discussed literature relevant in this study. It focused on the challenges found in stoichiometry literacy and the Physical Science curriculum for the Namibian Senior Secondary Certificate. Some aspects of studies on attitude and performance about teaching of Chemistry were engaged with. The conceptions and dispositions towards stoichiometry were discussed, likewise the teacher education programme in Namibia.

In the next chapter, I discuss the theoretical and conceptual framework informing this study.

CHAPTER THREE: THEORETICAL AND ANALYTICAL FRAMEWORK

> *A theoretical framework refers to the theory that a researcher chooses to guide him/her in his/her research. Thus, a theoretical framework provides direct, practical, and interesting explanations and examples to answer particular research problems.* (Molasso, 2006, p. 7)

3.1 Introduction

Molasso (2006, p. 7), as in the epigraph above, explains that “a theoretical framework refers to the theory that a researcher chooses to guide him/her in his/her research. Thus, a theoretical framework provides direct, practical, and interesting explanations and examples to answer a particular research problem”. To Grant and Osanloo (2014), a theoretical framework is the foundation which is used to construct knowledge in a research study. A theoretical framework is also regarded as a working model which allows the researcher to explore the relationships among variables in a logical and prescribed fashion.

Merriam (2009) explains that a theoretical framework is the structure on which research is based. Additionally, a theoretical framework is the vehicle driving all aspects of the research including the research problem, methodology, data analysis and interpretation of the data collected. Miles and Huberman (1994) hypothesise that a theoretical framework is important in the designing of a study as a visual or written product. Thus, the theoretical framework informing this study was the theory of constructivism; namely, Piaget’s cognitive constructivism and Vygotsky‘s social constructivism as well as Shulman’s (1986) PCK. This theory is suitable for this study because teachers within the same community, but who taught in different schools, socially interacted with each other (Vygotsky 1978) to share knowledge (Shulman 1986) in order to solve problems regarding stoichiometric concepts. In this chapter the constructivist-development perspective is discussed, together with other tenets of constructivism: scaffolding, mediation, language and the zone of proximal development. Pedagogical content knowledge and topic specific pedagogical content knowledge (TSPCK) (Mavhunga & Rollnick, 2013) are discussed. The theory around TSPCK is suitable for the research in the specific topic of stoichiometry.

3.2 Constructivist-developmental perspective

Constructivism is a theory of teaching and learning. It has both cognitive and social theories of learning. The most important strands of this theory are discussed below.

3.2.1 Constructivism

Constructivism is a theory about knowledge and learning. It describes learning not as truth to be transmitted or discovered but as emergent, developmental, non-objective, viable, constructed explanations by humans engaged in meaning-making in cultural and social communities of discourse (Gupta, 2008).

According to Dennick (2016), constructivism in education describes learning as a building process where new knowledge can only be added on to and understood in terms of existing knowledge. Learners construct meaning by linking new knowledge to their present knowledge. It views that knowledge is not a 'truth' to be transmitted or discovered. Instead, learning is emergent, developmental, non-objective, constructed explanations by humans engaged in meaning-making (Gupta, 2008). To Moll (2002, p. 8), "constructivism is articulated as the basis of a new approach to teaching and learning in the context of curriculum renovation". Constructivism entails personal studying, learning and teaching with emphasis on mental development and alertness, as learners are not blank slates. The constructivist approach allows learners to have free minds which develop according to how much exposure to learning they get. Constructivism deviates from the traditional approach where the teacher is tasked with the whole learning process, from information gathering for the learners, as well as assessment methods of learning concepts. Below is a discussion of different aspects of constructivism.

3.2.2 Cognitive constructivism

Cognitive constructivism draws on the developmental work of Piaget (1973) who said that learning occurs by active construction of meaning rather than being a passive recipient of knowledge. Stevens-Long, Schapiro and McClintock (2012) opine that the useful effects of constructivism include enhanced cognitive development as a result of deepening multiple levels of perception, and an increased appreciation for theory and research. Learners of Science can effectively and efficiently construct scientific concepts, if proper mechanisms are at their disposal that might enhance their thinking ability. Cognitivists reject the drilling and empirical nature of behaviourism but emphasise thinking skills – the process or means of thinking instead. Learners need to understand the material needed for the teaching of the concept at hand, rather than merely learning and thus be able to demonstrate understanding of the concept (Stevens-Long et al., 2012).

The cognitivist theory was very important for this study as Physical Science teachers ascertained what learners already knew about stoichiometry and built on this knowledge for effective teaching and mediation of stoichiometry. Cognitive theory is an approach to psychology that attempts to explain human behaviour by understanding human thought processes (Fritscher, 2018). Metacognition for example, which entails thinking about one's own perception or understanding of a topic, is a prerequisite for one to understand abstract concepts such as those in stoichiometry. This requires that learners adjust in order to obtain new knowledge.

The ability of learners to adjust their cognitive activity in order to promote more effective understanding, is referred to as "metacognition comprehension" (Gavelek & Raphael, 1996). It is recognised that a teacher teaching stoichiometry concepts must of course have appropriate SMK (Papaleontiou-Louca, 2008). This was in line with the research question 3 that entails how mediation of stoichiometry is attained.

Cognitivists anticipate that teachers need to know how to teach learners to perform difficult tasks, which was the main reason why the theory was needed for this study. Stoichiometry is a difficult and abstract concept, as revealed by literature reviewed (Fach, de Boer, & Parchmann, 2007; Furio, Azcona, & Guisasolo, 2002; Hanson, 2016; Mwene, 2015). Therefore, Physical Science teachers need to have the PCK and SMK needed for stoichiometry, which was the essence of this study. It was understood that in-depth learning of abstract ideas is linked to everyday experiences, while the learning process is often driven by internal factors (Atherton, 2009).

However, cognitive constructivism has been criticised as portraying the individual sealed in a privately constructed world in which the social component of learning is largely ignored (Davson-

Galle, 2000; Ernest, 1993; Garrison, Anderson, & Archer, 2000). This critique led to the development of a broader view of the theory to include the other strand of constructivism, which is social constructivism. To mitigate the problem in which a person is considered isolated and not interacting socially, social constructivism was embraced.

3.2.3 Social constructivism

Vygotsky's (1978) sociocultural theory claims that effective learning lies in the nature of the social interaction between two or more people with different levels of skills and knowledge. According to Dennick (2016), constructivism underpins many human interactions, recognising the prior knowledge and personal constructs of an individual as an important tenet in teaching and communication skills. Learning involves an active process in which learners construct meaning by linking new knowledge to their present or prior knowledge. As a learning theory, constructivism emphasises the idea that learners develop their own understanding that makes sense to them and do not simply receive knowledge from outside sources (Schunk, 2000). McRobbie and Tobin (1997) define constructivism as knowledge constructed and mediated through experiences and interactions with others in the same environment.

The use of constructivism aims at developing knowledge, as well as reducing the gap within the learners' zone of proximal development (ZPD), which is the "distance between actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under the supervision of a guide" (Vygotsky, 1978, p. 86). This theory fosters critical thinking and creates active involvement of the participants in order to reach new understanding. In the context of this study, the Physical Science teachers were actively involved in the participatory action research used in the teaching and learning of stoichiometry. The participatory action research used for the study of stoichiometry ranged from planning, questioning, modelling, implementation and consolidation of the concept of stoichiometry; these all enhanced the teaching of stoichiometry.

The constructivist view of learning is based on the belief that knowledge is not a thing that can simply be given by the teacher in the classroom to learners. Instead, constructivists believe that knowledge is constructed by learners themselves through an active mental process of development (Lester & Onore, 1990). That is, learners are the builders and creators of meaning and knowledge by interacting with other learners, teachers, the environment and society at large. One can infer from this statement that Physical Science teachers constructed meaning and collaborated with other teachers and the community. This action assisted in achieving the study's objective of establishing the Physical Science teachers' understanding of the teaching of stoichiometry. The influence of social interaction in this study played an important role. It was through classroom observation and videotaped lessons that I could observe whether or not the participating teachers created a space for social interactive activities for their learners. This provided an answer to research question 1.

Some visible doctrines were the engagement of the Physical Science teachers in the intra-psychological and the inter-psychological planes. The inter-psychological, or the lower mental function, is characterised by the knowledge constructor interacting socially with knowledgeable individuals (Berge, 1999). Stoichiometric language is important in the intra-psychological plane. The intra-psychological plane/level, also known as the higher mental function, is where a teacher assimilates or accommodates and internalises knowledge initially externalised (McRobbie & Tobin, 1997), while adding personal value to that knowledge (Vygotsky, 1978). This terminology plays a role in the understanding of an individual's environment. Language is used to direct or command and in this way an individual is regulated. The process of adapting knowledge gained in the intra-psychological stage involves transformation of that knowledge using analogies (Jonāne, 2015; Ramasike, 2017).

Vygotsky defines knowledge as temporary and developmental and is mediated by tools such as language. Social constructivism emphasises the idea that learners develop their own understanding that makes sense to them through interaction with knowledgeable individuals who are able to scaffold them (Schunk, 2000). The gained knowledge is internalised individually, as supported by McRobbie and Tobin (1997). The teachers interacted with each other during the workshop intervention, for each one of them to acquire knowledge and internalise it for the effective teaching of stoichiometry. Research question 2 sought to reveal an intervention in the form of workshops to enable or constrain Grade 11 Physical Science teachers to socially interact with each other.

The social constructivist theory assisted me in this study to understand how teachers' socially constructed knowledge and made sense of stoichiometry (Hodson & Hodson, 1998). Additionally, social constructivism guided me to understand how teachers collaborated, mediated learning and made sense of stoichiometry concepts to improve learners' performance as in research question 2.

In conclusion, constructivism entails three principles: encouraging collaboration (Goos, 2004), primeval activity and exploration, respecting multiple points of view and emphasising authentic problem solving (Solomon, 2000). I focused on two tenets of social constructivism, 'mediation of learning' and the 'zone of proximal development'.

3.2.3.1 Mediation of learning

Mediation can be understood as reconciling two or more aspects which can be either in conflict or in agreement. Success in mediation is dependent on mediating artefacts such as practical work, models, and textbooks, past exam papers, and symbols reflecting stoichiometry nomenclature. Support of what mediation and mediating aspects are, is revealed through the lens of Vygotsky (1978). He explains mediation as a tool used in cognitive change. In addition, he further classifies mediational tools as abstract or concrete. In support of this classification, Donato and MacCormick (1994) state that the source of mediation is either a material tool or a system of symbols (stoichiometry), notably language or behaviour of another human being in social interaction.

Signs are an "auxiliary means of solving a given psychological problem" (Vygotsky, 1978, p. 52). The interest was in the teachers' skills in relating how the mediating tools were used in areas around them. Learners' understanding, and interpretation of the stoichiometric scientific process is dependent on how teachers situate the stoichiometric terms. Research question 3 focused on how Grade 11 Physical Science teachers mediated learning of the developed exemplary lessons in the classroom. In this study, I used mediation as a concept in the teaching and learning processes. I was interested in understanding how the participants in their different contexts or schools, dealt with the teaching of stoichiometric concepts. Taking into account learners' prior knowledge, curricular silence, and representation to support their explanations in the teaching of stoichiometry (Mavhunga & Rollnick, 2013), these all assisted learners to further elaborate meaning and make sense of what was taught. These processes in the teaching of stoichiometry fostered the development of sign mediation in the learning and teaching of science.

3.2.3.2 Constructivist views of sign mediation in learning of science

The whole issue of sign-mediated activity in Vygotsky's work (1978) covers a broad spectrum of tool-mediated activity in the process of acquiring scientific concepts. As a researcher, the mediating sign in teaching can be equated to LTSMs associated with the language that enhances the teaching of difficult concepts, for them to be easier understood in the classroom. What to note about Vygotsky's (1978) understanding of the sign, is his manner of approaching it from a developmental perspective. For him, this perspective does not involve writing notes, but it encompasses the holistic progressive development of an individual when engaged in activities. He augmented his definitions of the sign by studying developmental paths of various sign-mediated activities in learners. Vygotsky (1978) postulated that the sign adopts a mediating position in human activity, changing its structure and developmental course. At the same time, he adopted the prevailing epistemological distinction, long nurtured between the object and its representation. This caused an impoverishment in his conceptions of the sign and also created and maintained a gap between the two primary mediators of human activity, the tool and the sign.

The sign acts as an instrument of psychological activity, in a manner analogous to the role of a tool in work. Vygotsky also posits that the development and use of signs – as an auxiliary means of solving a given psychological problem – enhances what was taught to be remembered, compared and reported as analogous to the invention and use of tools (Vygotsky, 1978). Signs in the form of language mediate social intercourse, while tools mediate object-oriented activities. Tools are externally oriented and are used in the modification of objects, whereas signs change nothing in the psychological operation. Signs are regarded as multifunctional tools of communication and representation. Signs can also be seen emerging in the ZPD of a learner or a child, using signs to communicate to others. The ZPD can also emerge in teachers as they socially interact during CoP to enhance their TSPCK, and the possibilities of teachers using signs to communicate can manifest.

3.2.3.3 Zone of proximal development

Vygotsky (1978) describes the ZPD as the difference between the actual development level – as determined by individual problem solving – and the level of potential development – as determined through problem solving under adult guidance or collaboration with more knowledgeable peers. The above definition implies that a student, who cannot carry out a task on their own, would be able to do so with the help from someone who has experience in that task. In other words, interaction with peers helps to assist in developing new skills when a new concept is introduced. Hence, teachers should use a variety of methods, such as co-operative learning, so that less competent learners can mingle with more skilful peers to improve their ability.

Based on Vygotsky's (1978) theories, the ZPD is understood as the space created between the actual development and the potential development of the learner. Vygotsky (1978) further clarifies how learning and development takes place. Development lags behind learning. For Stott (2016), the actual development zone is the skills a learner has which can be used to tackle a given problem without assistance. The potential zone is that which can be developed through assistance from the knowledgeable individual or peer (Stott, 2016). The potential of a learner is made up of stoichiometric concepts constructed during informal learning, thus, learning occurs once the ZPD comes into existence. The ZPD triggering learning is not the only zone; others exist that are revealed in Figure 3.2.3.3.1 below. The research question 1 provided answers for the understanding of teaching stoichiometry by Grade 11 Physical Science teachers, prior to intervention in the ZPD of the teachers.

Valsiner (1997) identifies two more zones: the zone of free movement (ZFM) and the zone of promoted action (ZPA), both different from ZPD. These zones, ZFM and ZPA, aim to further explain how a child's development is organised in terms of the environment and relationships between the child and other people.

<table>
<tr><td colspan="5">Theoretical space
1. What is my theoretical perspective and what theoretical assumptions inform my interpretation of the ZPD?
2. How does this inform the answers to these questions (elements)?</td></tr>
<tr><td colspan="5">Questions /Elements</td></tr>
<tr><td>Who learns/ develops in the ZPD?</td><td>With whom does learning/ development take place in the ZPD?</td><td>What is learnt or developed? Zone of promoted action (ZPA)</td><td>How is it learnt and developed? CPD</td><td>Where does learning / development take place? Zone of free movement (ZFM)</td></tr>
</table>

Figure 3.2.3.3.1: Elements of the organising framework of development (Adapted from Stott, 2016, p. 30)

ZFM and ZPA take into account the tenets of social constructivism (social and personal) which were identified when I discussed the mediation of learning. Using these social tenets contributes to understanding how a learner constructs stoichiometry concepts as they interact with novices and with those in a community of practice (CoP). Stott (2016) brings the ZPD, ZFM and ZPA concepts nearer to this study as she was of the opinion that the ZPD, ZFM and ZPA structures can be used by knowledgeable individuals to enable or constrain cognitive activities in which mediating artefacts are used. The ZPD incorporates the social setting, goals and action of the participants (learners), while ZFM represents the classroom and ZPA represents the set of activities offered by teachers or knowledgeable personnel, oriented towards promotion of new skills. To facilitate the use of the ZPD, ZFM and ZPA the teacher must have certain pedagogical skills reflected in pedagogical content knowledge to enhance the mastering of stoichiometry concepts.

Teachers should therefore determine the ZPD of individual learners in order to encourage them to achieve new levels with tasks beyond their actual level of development and assist them in such a way that they will be able to reach that new level of development. It is in the ZPD that scaffolding, a term used by Wood, Brunner and Ross (1976) plays a crucial role in teachers assisting learners to complete the tasks given. Similarly, when learners work in collaboration with each other they enter another level of development which, through discussions about tasks, could lead them to the solutions of a problem and later on develop appropriate knowledge. Knowledge attained can best be noted by taking into account the zone of proximal development. What children can do on their own is their level of actual development (prior knowledge) and what they can do with help is their level of latent development (concealed knowledge). Teachers' assessment methods must focus both on the level of actual development and the level of potential development which comes as a result of scaffolding.

3.2.3.4 Scaffolding

The concept of scaffolding is a process through which a teacher or more competent peer gives support to the learners in their ZPD (Verenikina, 2008) as necessary, and reduces this support as it becomes unnecessary, much as a scaffold is removed from a building during construction. According to Balaban (1995), scaffolding refers to the way the adult guides the learner's learning, using focused questions and positive interactions. With appropriate adult help, learners can often perform tasks that they are incapable of completing on their own. Having this in mind, scaffolding can best be explained, in my view, as a process, where the teacher or knowledgeable person continually adjusts the level of his or her support in response to the learner's level of performance. This process effectively enhances teaching and learning. Scaffolding has no means of producing the desired results immediately, but it instills the skills necessary for independent problem solving in the future. This justifies why scaffolding or Vygotsky's constructivism theory underpinned this study. The Physical Science teachers in this study worked together and interacted during the workshop's intervention, serving as a scaffold to instill the necessary skills needed to teach stoichiometry in schools. This generated data for research question 2 of the study, focusing on how intervention in the form of workshops supports or scaffolds the Physical Science teachers in developing exemplary lessons for the teaching of stoichiometry.

3.3 Pedagogical Content Knowledge and Subject-Matter Knowledge

Shulman (1986) proposed three categories of content knowledge for teachers: subject-matter knowledge (SMK), pedagogical content knowledge (PCK) and curricular knowledge (CK). According to Shulman (1986), SMK equates to the amount of knowledge in the mind of the teacher. The second category, PCK suggests "the ways of representing and formulating the subject that make it comprehensible to others" (p. 13). The third category, CK, equates to syllabus, scheme of work, textbooks, laboratory demonstrations and other mediating tools in the classroom that make the work understandable to learners. In a nutshell, Shulman (1986), emphasises that PCK is the most useful form of representation of topics, the most powerful analogies, illustrations, examples, explanations and demonstrations. In other words, PCK is a way of representing and formulating the subject to make it comprehensible to others.

PCK also includes an understanding of what makes the learning of specific topics easy or difficult; the conceptions and preconceptions that learners of different ages and backgrounds bring with them to the learning of the most frequently taught topics and lessons. Shulman (1986) summarises PCK as the concept which describes the way in which teachers present and formulate subject matter knowledge in order to make it understandable and meaningful. Lending support, Van Driel, Verloop and de Vos (1998) emphasise that PCK is the knowledge a teacher uses to provide learning situations that help learners make sense of particular given concepts. Okanlawon (2010, p. 30) proposes that "the PCK for stoichiometry includes teachers' 'bag of tricks' and motivational 'tools' that can be used to develop in learners better problem-solving techniques". The PCK thus integrates numerous aspects, such as the instructional approach, subject specific learning, learners' difficulties, the nature of science, curriculum knowledge and context. In summary, Shulman (1987) describes PCK as: The capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the learners.

For instance, in stoichiometry, the PCK component incorporates concepts such as concentration, moles, balancing of equation, percentage composition, theoretical yield, molecular and empirical formula. These are some of the CK a teacher needs to be equipped with. The knowledge of how to impart a sense of these concepts to learners, forms part of the pedagogical aspects of the other component of PCK.

Ngcoza (2007, p. 53) also concludes by saying that "competence in both SMK and PCK is regarded as vital in promoting meaningful learning among learners". The concern of this study was to investigate the SMK and PCK of the teachers and their developmental processes in the teaching of stoichiometry. Shulman (1986) argues that having knowledge of subject matter and general pedagogical strategies is not enough to capture the knowledge of a good teacher. The content and pedagogy must be confronted simultaneously.

PCK for teachers lies in its usefulness in understanding teachers' knowledge (Abell, 2007). Shulman (1987) describes PCK as the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful. Shulman (1987) "comprehends that ideas must be transformed in some manner if they are to be taught" (p. 16). Geddis (1993) points out that teachers need to develop the awareness that teaching requires the transformation of their SMK. The articulation of the kind of knowledge needed to achieve such transformation becomes important. According to Geddis (1993), "knowledge of a 'multitude of particular things' about SMK that are relevant to its teachability is required" (p. 676). Investigating and ascertaining science teachers' PCK of stoichiometry is critical to identifying and designing helpful interventions.

3.3.1 Justification for using PCK and SMK

A central support of the work of Shulman and his colleagues was to reframe the study of teacher knowledge in ways that included direct attention to the role of content in teaching. This focused almost exclusively on general aspects of teaching such as classroom management, time allocation, and planning. Another contribution of the work was to influence content knowledge as technical knowledge key to the establishment of teaching as a profession. Shulman and his colleagues argued that high quality instruction required a sophisticated professional knowledge that went beyond simple rules such as how long to wait for learners to respond (Shulman et al, 1989). To characterise professional knowledge for teaching, they developed typologies. Although the specific boundaries and names of categories varied across publications, one of the more complete articulations is reproduced the Box 3.3.1.1 below.

Box 3.3.1.1: Shulman's major categories of teacher knowledge (Shulman, 1987, p. 8)

1. General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organisation that appear to transcend subject matter.
2. Knowledge of learners and their characteristics.
3. Knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures.
4. Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds.
5. Content knowledge has to do with what the teacher knows and understands.
6. Curriculum knowledge, with particular grasp of the materials and programs that serve as "tools of the trade" for teachers.
7. Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding (Shulman, 1987, p. 8).

These categories were meant to highlight the important role of CK and to situate content-based knowledge in the larger landscape of professional knowledge for Science teachers teaching stoichiometry. In my study, the first four of Shulman's major categories address general dimensions of teacher knowledge that were the backbone of the teaching profession in the teaching programmes. This goes along with research question 1: What is the understanding of teaching stoichiometry by Grade 11 Physical Science teachers prior to the intervention? This justifies why I decided to use the PCK and SMK of the teacher in a broader conception of teacher knowledge that emphasised content knowledge.

The involvement of Science teachers from different schools to collaboratively work together to solve a problem, enhanced the CoP (Lave & Wenger, 1991). The first of the three content knowledges, includes knowledge of the subject and its organising structures (Grossman, Wilson, & Shulman, 1989; Shulman, 1986, 1987; Wilson, Shulman, & Richert, 1987). This is where the content knowledge of stoichiometry as stated in the textbooks used by the teachers was analysed, to see if the textbooks were in line with the expected skills to be acquired.

The second category, curricular content knowledge, is "represented by the full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances" (Shulman, 1986, p. 10).

The last, and arguably most influential, of the three content-related categories is PCK. Shulman (1986, p. 7) defines pedagogical content knowledge as:

> The most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the most useful ways of representing and formulating the subject that make it comprehensible to others. … Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that learners of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons.

According to Shulman, the concept of PCK supported my view on the use of participatory action research with questioning, modelling, examining, reflecting and implementing new concepts on stoichiometry by the science teachers. That is why l find it very useful to explore the possible intervention in mediating the learning of stoichiometry by using the participatory action research in conjunction with TSPCK as an analytical lens (Appendix L) in this study.

3.3.2 Topic-specific pedagogical content knowledge (TSPCK)

Mavhunga and Rollnick (2013) revealed in their studies on improving PCK in Chemistry pre-service teachers, that it is a specialised content knowledge of teaching. Topic specific PCK, is regarded as the understanding that provides the needed knowledge for CK transformation in a particular topic (see Figure 3.3.2.1 below).

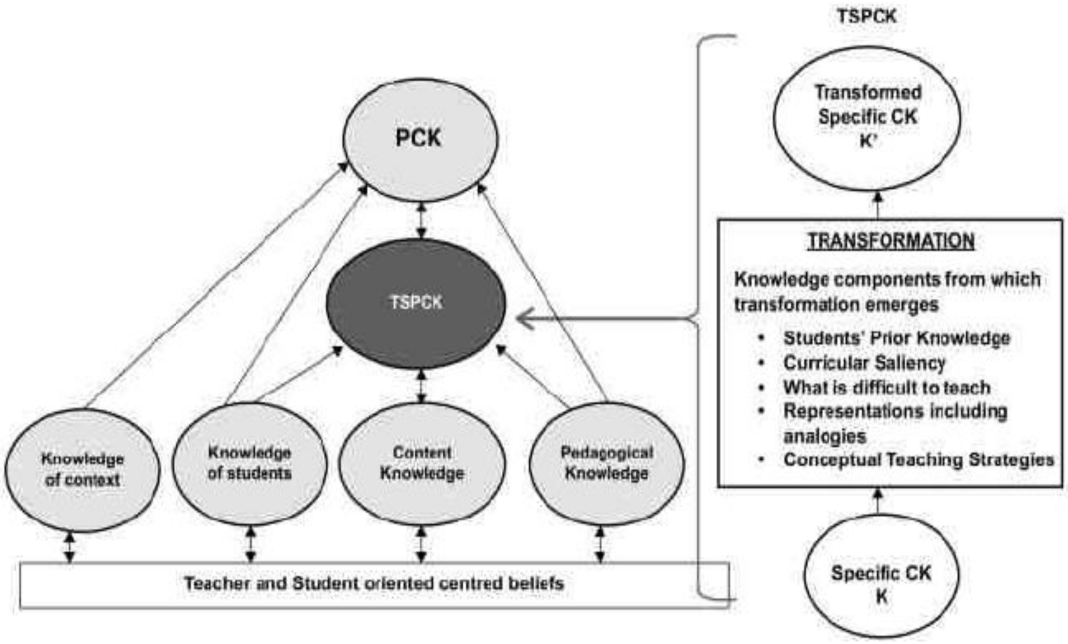


Figure 3.3.2.1: A model for TPCK (Adapted from Mavhunga & Rollnick, 2013, p. 115)

In the Mavhunga and Rollnick (2013) study, the topic specific PCK was regarded as a theoretical construct. They suggested the need for a PCK construct that was defined more sharply to reflect the specificity of the topic rather than reference to a subject or discipline (Mavhunga & Rollnick, 2013). The topic specific PCK in the teaching of stoichiometry might be a viable guide for in-service Physical Science teachers. The listed embedded tenets in Figure 3.3.2.1 where transformation emerged above were (a) Learners' prior knowledge (b) Curriculum saliency (c) What makes a topic easy or difficult to teach (d) Representation including powerful examples and analogies (e) Conceptual teaching strategies (Geddis, 1993; Geddis & Wood, 1997). The content-specific components were oriented to SMK requiring specific considerations. SMK might enhance the effective teaching of stoichiometry within a CoP**.**

Over the years, Namibian Senior Secondary Certificate Examination reports by the Directorate Namibia Examination Assessment, have shown that learner performance in stoichiometry examination questions remains an aspect for concern. In these reports, lack of understanding of the concepts of stoichiometry has been identified as a primary factor. On the other hand, the status of Mathematics and Science teaching has been under critique by several education researchers, pointing to poor teacher training in the subjects (Hanson, 2016). One possible way to respond to the challenge in teaching is to introduce the development of TSPCK as the professional knowledge for teaching science concepts.

TSPCK is renowned for enabling teachers to pedagogically transform difficult concepts of specific science topics into forms best understood by learners (Mavhunga & Rollnick, 2013). Their study examined the impact on the quality of TSPCK following an intervention that explicitly targeted the development of the competence to transform SMK using chemical equilibrium as a topic of learning. Mavhunga and Rollnick's (2013) model proposed that topic specific PCK results from the transformation of SMK; thus, SMK is considered to be a prerequisite to develop TSPCK.

The use of TSPCK knowledge in this study of an intervention that might mediate the teaching of stoichiometry in selected schools in the Zambezi region, was therefore considered, and this might be the missing gap in the teaching of stoichiometry. The TSPCK might enhance the conceptual strategies in the teaching of stoichiometry concepts for effective teaching and mediation of learning stoichiometry concepts in the Zambezi region.

The constructivism theory is a learning theory while PCK/TSPCK is a teaching method, which explains the delivery of teaching concepts for effective learning. The working together of Physical Science teachers to solve the same problem, enhances constructivism, while PCK/TSPCK refers to the methods of teaching. Constructivism and PCK/TSPCK complement one another, so that Physical Science teachers in groups construct new knowledge and then return to the classroom to teach the concepts to learners.

3.4 Concluding Remarks

In the foregoing discussion, I have outlined the constructivist-developmental perspective, constructivism, cognitive constructivism, mediation of learning, scaffolding, zone of proximal development, pedagogical content knowledge and topic specific pedagogical content knowledge (Mavhunga & Rollnick, 2013). In the next chapter, I discuss the methodology for this study.

CHAPTER FOUR: RESEARCH DESIGN AND METHODOLOGY

The procedures by which researchers go about their work of describing, explaining and predicting phenomena are called research methodology. (Rajasekar, Philominathan, & Chinnathambi, 2013, p. 5)

4.1 Introduction

Research methodology, as stated in the epigraph, is a way to systematically solve the research problem. It is the science of studying how research is done scientifically (Kothari, 2004). Similarly, Rajasekar, Philominathan and Chinnathambi (2013, p. 5) postulate that research methodology is the procedure by which "researchers go about their work of describing, explaining and predicting phenomena". Research methodology is defined by different social scientists in different terms. Research methodology can be summarised as an arrangement of situations for collecting and analysing of data in a style that adds significance to the research purpose. McMillan and Schumacher (2001) use the term 'research methodology' in referring to the plan and structure of the investigation used to obtain evidence in order to answer the research questions.

In this study the mediation of learning the stoichiometry concepts is of paramount importance, especially the exploration of the development of teachers participating in the intervention for the teaching and learning of stoichiometry. This chapter provides the research goal and research questions that guided this study. In addition, the research paradigms and research methods are discussed. The research goal and research questions that guided this study are stated below.

4.1.1 Research goal

The main goal of the study was to explore an intervention that might support teachers' understanding and the mediation of learning of stoichiometry concepts.

4.1.2 Research questions

1. What are Grade 11 Physical Science teachers' understandings of teaching stoichiometry prior to the intervention?
2. How does an intervention in the form of workshops support Grade 11 Physical Science teachers in developing exemplary lessons for teaching stoichiometry? and
3. How do Grade 11 Physical Science teachers mediate learning of the developed exemplary lessons?

Mouton (2001) views research methodology as focusing on the research process and the kind of tools and procedures to be used. Similarly, Leedy and Ormrod (2010) posit that research methodology is the researcher's general approach in carrying out the research project.

The research methodology describes the procedures the researcher uses to carry out the study, explaining when, from whom and under what conditions the data has been obtained; this is the point of departure for research methodology, and this study's research methodology is situated within a qualitative research approach. The qualitative research approach involves the use of qualitative data, such as interviews, documents and observation, in order to understand and explain a social phenomenon. According to Denzin and Lincoln (1994), a qualitative research focuses on interpretation of phenomena in their natural settings to make sense in terms of the meanings people bring to these settings.

Researchers such as McMillan and Schumacher (2001), Mouton (2001) and Kothari (2004) affirm that the fundamental objective of the research methodology is to develop a set of methods and procedures that answer the research question or test the research hypothesis with a high degree of confidence. The various methods used for data gathering for this study were, survey questionnaires, interviews, semi-structured interviews, stimulated recall interviews, observations, videotaped lessons and reflections. Data generated were colour-coded (Appendix L), categories and themes were developed and used for analytical processes.

In any study the research paradigm engaged needs to be discussed. A research paradigm is a plan, structure and strategy of investigation formulated to obtain answers to research questions. In this study the main paradigm was the interpretive. The research paradigm used is discussed below.

4.2 Research paradigm

According to Polit, Beck and Hungler (2001, p. 167), a research paradigm is a "researcher's overall strategy for answering the research questions or testing the research hypothesis". The research paradigm thus incorporates sampling, participants, methods of data gathering, research instruments and implementation procedures of the instruments and data analysis and quality measures.

A research paradigm can be understood as a belief system (or theory) that guides the way we do research or how practices are engaged. A research paradigm is an all-encompassing system of interrelated practice and thinking that defines the nature of enquiry, along three dimensions, *ontology*, *epistemology* and *methodology* (Guba & Lincoln, 1994; Terre Blanche & Durrheim, 1999).

4.2.1 Interpretive paradigm

According to Gephart (1999), research paradigms are classified into three philosophical distinct categories, namely, positivism, interpretivism and critical postmodernism. This study was underpinned by an interpretive paradigm (Bertram & Christiansen, 2015; Cohen, Manion, & Morrison, 2018).

Research is about constructing new knowledge, where claims are made to the 'truth' based on our understanding of reality (ontology), as well as of how we gain knowledge of what exists (epistemology) (Bhaskar, 1998). Mack (2010) points out that ontology is the beginning point which paves a researcher's theoretical framework. That is, our ontological and epistemological assumptions have a direct effect on how the research is conducted. The study is located within Shulman's PCK and constructivist epistemology, a belief that our knowledge of this world is based on our own constructions and that we can never produce a completely objective account (Maxwell, 2005).

By making a clear distinction between ontology and epistemology the 'what is' questions do not get reduced to the 'how do we know what is' questions, and we circumvent the 'epistemic fallacy' (Bhaskar, 1998) that is common to much education research. Mertens (1998) opines that the basic assumption guiding the interpretive paradigm is that knowledge is socially constructed by people active in the research process. The interpretive paradigm is used to create a complete vision of how we interpret knowledge; how individuals see themselves in relation to knowledge and the methodological strategies we use to surface it. This is reinforced by observation and interpretation. Thus, to observe, is to collect information about events, while to interpret is to make meaning of that information (Aikenhead, 1997).

The interpretive paradigm therefore fits this study as the interpretivists purport to understand the meaning which informs human behaviour and to make "interpretations with the purpose of understanding human agency, behaviour, attitudes, beliefs and perceptions" (Bertram & Christiansen, 2015, p. 26). This was the case in this study of the intervention intended to improve the teaching and mediation of learning stoichiometry of teachers in selected schools. The six Physical Science teachers, the subject adviser, a critical friend (who is a university lecturer) and me (the researcher), would collaboratively co-plan and implement the intervention lessons based on stoichiometry. This generated the data that answered research question 3.

Creswell et al. (2016) state that interpretivists recognise the complexity of the world and acknowledge that reality can only be accessed through social constructions such as language, consciousness and shared meanings. In the context of this study, the new knowledge was developed by the collaborative effort of all the participants. Vygotsky (1978) posits that effective learning lies in the nature of social interactions between individuals and their peers. Re-contextualisation or re-description understood as abduction, eliminates the weakness of ending in the level of description of the interpretive paradigm. According to Jensen (1995), to re-contextualise involves observing, describing, interpreting, explaining and reflecting on concepts or constructs using a relevant methodology context.

4.2.2 Justification for using the interpretive paradigm in the study

This research is within the interpretive paradigm. My ontological position in education is that of someone sharing knowledge with others to understand the world around us. Also, it is important to have good relationships with people in order to enable the knowledge they have and the knowledge I have, to be exchanged for effective learning and teaching of stoichiometry to take place. For the purpose of this research, I used the interpretivist research approach. Use of interpretive research methods were part of the research and helped me understand my research participants' opinions on how stoichiometry concepts should be taught.

Within the interpretive paradigm there were a number of research instruments that I used to generate data. I used document analysis, stoichiometry topic specific pedagogical content knowledge tool (Appendix M), diagnostic tests (Appendix N), observation, and recorded and transcribed audio-interviews. The triangulation of all these methodologies and the data, enhanced the research methods for the intervention programme to improve the teaching of stoichiometry.

4.3 Research methods

Epistemology is the study of how we come to know things, or, it is the pondering and analysis of theories relating to how knowledge is able to be attained. As for ontology, it comes from the Greek words '*ontos*' and '*logos*' meaning "being" and "study" respectively. Therefore, ontology literally is the "study of being".

Due to the nature of the study I used both qualitative and quantitative research methodology. Even though this is a mixed method research, the qualitative outweights the quantitative data.

Terrell (2011) posits that mixed-method studies have emerged from the paradigm wars between qualitative and quantitative research approaches to become a widely used mode of inquiry. Studies that are products of the pragmatist paradigm show that combining the qualitative and quantitative approaches within different phases of the research process is mixed-method study (Tashakkori & Teddlie, 2008). Bazely (2004) says that mixed-methods are inherently neither more nor less valid than specific approaches to research and that its validity stems from the appropriateness and effectiveness with which methods are applied and evidence is obtained weighing the evidence obtained.

4.3.1 Mixed-methods approach

There are quantitative and qualitative mixed-method designs. This study used an exploratory mixed-method design, which would lead to a better understanding of the existing problem about stoichiometry (Creswell et al., 2016). Quantitative data were generated from diagnostic tests given to learners without coercing them. The data generated was analysed using the Statistical Package for Social Sciences. It should be noted that the focus in this study was on teachers and not learners. However, the purpose of the diagnostic test given to learners was intended to explore what teachers know, something which is central in Shulman's (1987) PCK.

Qualitative data were generated from workshop discussions, observations, interviews and reflections and it had greater weight compared to the quantitative data. The approach involved workshops that were divided into four phases, namely, Phase 1, Phase 2, Phase 3 and Phase 4 and are related to the tenets of the participatory action research shown in Figure 4.3.1.

PHASE 1

In this phase of planning, learners' document analysis, questionnaires and semi-structured interviews were used to generate base line data in this study. Ary, Jacobs, Razavieh and Soreseen (2006) highlight that document analysis can provide the researcher with prevailing conditions. In the event of this study, document analysis of the stoichiometry concepts was employed to contextualise the study, and to understand if this curriculum policy is clear on guiding teachers on how to teach stoichiometry. The raw data from questionnaires, and semi-structured interviews was analysed to understand the participants' views and perceptions on the stoichiometry concepts. The questionnaire was composed of open and closed-ended questions that focused on exploring teachers' profiles with regards to their academic qualifications, understanding of stoichiometry concepts and their thinking about stoichiometry.

Therefore, questionnaires helped me to better understand and describe the context of this study with regards to its goal, and these assisted me to comprehend the participants' context and their teaching background. The interview questions were both closed-ended and open-ended. The aim of the interviews was to find out the participants' perceptions and approaches in the teaching of stoichiometry. The questionnaires and semi-structured interviews when analysed, assisted me to better understand and describe the context of this study and question 1 of my study was answered (this is reflected in Figure 4.3.1: Cycles of Stoichiometry PAR). The interviews were 30 to 40 minutes long and these times varied because of the individual responses. The main questions will be in the appendices section.

PHASE 2

The second phase of action which exemplifies participatory action research was explored. The actions in this phase were made up of workshops organised for the participating Science teachers with their consent in a school laboratory. The content of workshops was: (a) analysis of curriculum documents with the participating teachers; (b) identifying the difficult stoichiometry topics as found in literature and learners' related difficulties; (c) the development of sequential intervention lessons; and (d) micro teaching of the intervention lessons to the team members. In this study as the researcher, my first phase of data analysis was to extract the raw data using the research questions. This was inserted in all methodological instruments, questionnaires, semi-structured interviews, video recorded lessons, stimulated recall interviews and group reflections. This assisted me to look at what came out as categories or episodes as influenced by the research questions and the research aim in the presented raw data. Data obtained from this phase assisted in answering research question 2.

PHASE 3

Phase 3 was the implementation and monitoring phase where the developed agreed intervention lessons were taught to a group of volunteer Physical Science Grade 11 learners after school so as not to interfere with the school programme. Agunbiade (2015) posits that such programmes might provide enriching experiences that widen learners' views on stoichiometry concepts. All the lessons were videotaped by a critical friend and observation notes were written. The participatory action research members also met to review and reflect on the experiences from the lessons, compare notes on their experiences with the lesson and make further adjustments to the lessons. This phase provided answers to research question 3.

PHASE 4

Phase 4 was reflection. It was here that the evaluation of the experience and the intervention process in teaching of stoichiometry occurred. What seemed to work in the learning and teaching of stoichiometry was acknowledged. Also, the area where improvement was needed in the stoichiometry lessons was considered and worked on. This phase provided answers to research questions 1, 2 and 3.

In this study, a mixed-methods approach was used. A stoichiometry topic specific pedagogical content knowledge tool (Appendix M) developed on stoichiometry concepts by Malcom (2015) were given to Physical Science teachers during the workshop organised in the Zambezi region, from the eighth to ninth February 2018. I made a presentation about stoichiometry at the workshop. To ensure that validity was addressed in the instrument, all concepts in stoichiometry were included. This ensured that concepts of stoichiometry were being measured. The responses to the stoichiometry topic specific pedagogical content knowledge tool by the teachers were used as base line data to answer research question 1. The selected volunteering learners also completed the stoichiometry topic specific pedagogical content knowledge tool (Appendix M) to generate base line data aimed at investigating what teachers knew and did not know about learner difficulties, and their content knowledge of stoichiometry. Learners' stoichiometry diagnostic achievement tests (Appendix N) were marked with the teachers in one of the workshops. Semi-structured interviews were conducted with the Physical Science teachers (participants). These were recorded and transcribed verbatim. Stimulated recall interviews were conducted with each of the three teachers, one from each of the participating schools. These were also recorded.

4.3.2 Gaining access to the research site

In order to gain permission, acceptance and support for the study, I negotiated access to the research site with the various "gatekeepers". In support of this, Lincoln and Guba (1985, p. 253) state that:

> The keys to access are almost always in the hands of multiple gatekeepers, both formal and informal. In most cases, those gatekeepers, before giving approval, will want to be informed about the inquiry in ways that will permit them to assess the costs and the risks that it will pose, both for themselves and for the groups to which they control access.

The Director of Education in the Zambezi region and the principals of the participating schools were identified as the gatekeepers whose official consent was critical to the success of my study. In order to obtain permission to conduct the study at the research sites, I wrote an official letter to The Director of Education in the Zambezi region (Appendix C). After consultation with his management team, the Director of Education in the Zambezi region granted permission (Appendix B). In keeping with the ethical commitments for the study, I decided to delete any information in Appendices B and C that might reveal the names of the research sites. Engagement with the research sites only started after official consent had been secured.

I also thought it necessary to negotiate access with other significant gatekeepers such as the Heads of Departments of the schools in which the study was to be conducted, and with the individual Physical Science teachers who participated in the study. It was very easy for me to gain the consent of these gatekeepers as the approval by the Director was handed over to the principals of participating schools. The principals disseminated the information to the teachers and the entire management of the schools. In order to promote friendliness and cooperation, and to ensure the success of the study, it was essential for me to negotiate access with all significant figures.

Qualitative research requires purposeful sampling (Bloomberg & Volpe, 2008). I chose purposeful sampling to select participants based upon their having specific characteristics needed to be included in the study (for example, teaching high school Physical Science) (Bloomberg & Volpe, 2008). The six Physical Science teachers purposefully selected in the Zambezi region had taught stoichiometry in Physical Science for more than six years. The sampling plan selected two teachers from three secondary schools. This sample was implemented.

These schools were within the Katima Mulilo urban area where most of the learners at Grade 12 level are potential leaners feeding the University of Namibia, Katima Mulilo Campus in the Zambezi region. Learners at these schools were motivated and intended to further their education at the University of Namibia. The Zambezi Regional Education Council gives a motivational talk yearly to learners all over the Zambezi region. Learners are being motivated because the University of Namibia, Katima Campus has introduced more courses, apart from Education. The Wildlife and Animal Health departments are the two departments newly introduced, where the core prerequisite subjects for admissions are Physical Science, Mathematics and Biology.

The identities of all participants, both Physical Science teachers and the learners remained and still remain confidential; all information obtained during the teaching, interview and reflection processes were kept confidential. The participants were exposed to minimal risk as a result of joining the study. The names and profiles of the participants were not included in any reports of the completed study in order to compliment the research approach etiquette.

Table 4.3.2.1: Summary of the research process

Phase	**Method**	**Purpose**	**Source**	**Research questions addressed**
Phase 1 Baseline data gathering.	Planning entails sending survey questionnaires out to research participants. Semi-structured interviews.	To collect base line data.	Survey questionnaires (teachers). Semi-structured interviews with teachers.	Research question 1
Phase 2 Exploration	**Workshop 1** Introductory workshop aimed to kick start action **Workshops 2 & 3** Planning and organising (using document analysis)	Introduce the research project. To negotiate participatory action research activities & signing of consent forms. Enhancing the mediation and strategies of teaching stoichiometry.	Workshop discussions. Syllabus, scheme of work, textbooks, question papers and learners' answer scripts for both internal and external examination.	Research question 1
Phase 3 Intervention	**Workshops 4 - 6** Collaboratively developing intervention lesson plans to monitor the planning and execution of the lessons. Monitoring the implementation of the intervention lesson plans and conducting the stimulated recall interviews while watching the videos with each teacher.	To enhance content knowledge and mediation of learning and the teaching of stoichiometry. To gain full understanding of teachers' PCK and SCK about stoichiometry.	Workshops discussions Agreed and written intervention lesson plans. Observations and videotaped lessons Stimulated recall interviews.	Research question 2
Phase 4 Reflection	**Workshops 7 & 8** Reflections on the implementation of intervention lesson plans.	To enhance and validate the usefulness of the intervention lesson plans developed.	Participatory action research members reflect on the implementation of the agreed and written intervention lesson plans. Reflective journals.	Research question 2 and 3

4.4 Research approach

The approach used in the study embraced participatory action research and community of practice (CoP) and these are explained below.

4.4.1 Survey questionnaires

Bertram and Christiansen (2015) and Mukeredzi (2015) posit that a questionnaire can be used as one method of data collection to investigate the professional knowledge that teachers bring with them when they enrol for teaching activities. I physically distributed 30 questionnaires to Grade 11 Physical Science teachers in the Zambezi region with the hope of getting back 25 questionnaires. The six participating teachers voluntarily completed the questionnaires. The questionnaire included demographic data focusing on the conceptions of teachers' views and experiences of teaching stoichiometry. The questionnaires assisted me to understand the context of the study, and data generated here contributed to answering research question 1 and the baseline data question (see Table 4.3.2.1).

Challenges faced during the survey questionnaire needed to be discussed. Some questionnaires were not answered by the teachers. One particular teacher collected five questionnaires, and none were answered.

This study focused on how to diffuse the beliefs of some teachers and learners about stoichiometry. With this notion, I decided to carry out a document analysis during the first workshop.

4.4.2 Participatory action research

The participatory action research approach was appropriate in this research study since the study's central theme was exploring the development of teachers participating in the intervention that enhanced the teaching of stoichiometry (Senge, 1990). The reason for the participatory action research approach was to do research on Physical Science teacher development, for the effective teaching of stoichiometry. The Physical Science teachers who were from different schools, collaboratively socially interacted with each other, sharing and constructing new knowledge (Vygotsky, 1978). In a nutshell the main focus of this study was to do with teachers' transformative and continuous professional development.

According to Babikwa (2003), participatory action research emphasises a deliberate move by people to learn continuously from their own experiences in order to keep on improving their situation in life. The underlying assumption is that actors are active agents capable of taking responsibility for addressing issues of importance affecting them. In the case of this research study, the teachers were viewed as being capable and responsible in promoting the teaching and learning of science. David (2002, p. 130) states that PAR:

- Seeks to go beyond traditional forms of research; and
- Seeks to avoid the ethical and epistemological pitfalls of covert forms of research by involving actors in the formulation and conduct of research.

Some advocates of participatory action research like Kemmis, (1995), and Kemmis and McTaggart (2000) reiterate that without the involvement of actors in the formulation and conduct of research, all research remains opaque. Research could be viewed as dialogue between co-researchers forming a 'community of inquiry' (Wardekker, 2000).

The community of inquiry entails active co-engagement of all involved in research and offers the actors opportunities for the kind of collaboration and reflection needed to build a learning organisation (McNiff, 2002; Robinson, 2002). Wardekker (2000) posits that learning and the resulting change are objects of the research and should be interpreted as a result of change and development.

Robinson (2002) too, contends that participatory action research is an approach to research which emphasises two key principles in its research design: the active participation of all actors in the process, and the link between research and the improvement of practice. It thus brings together participatory research and action research.

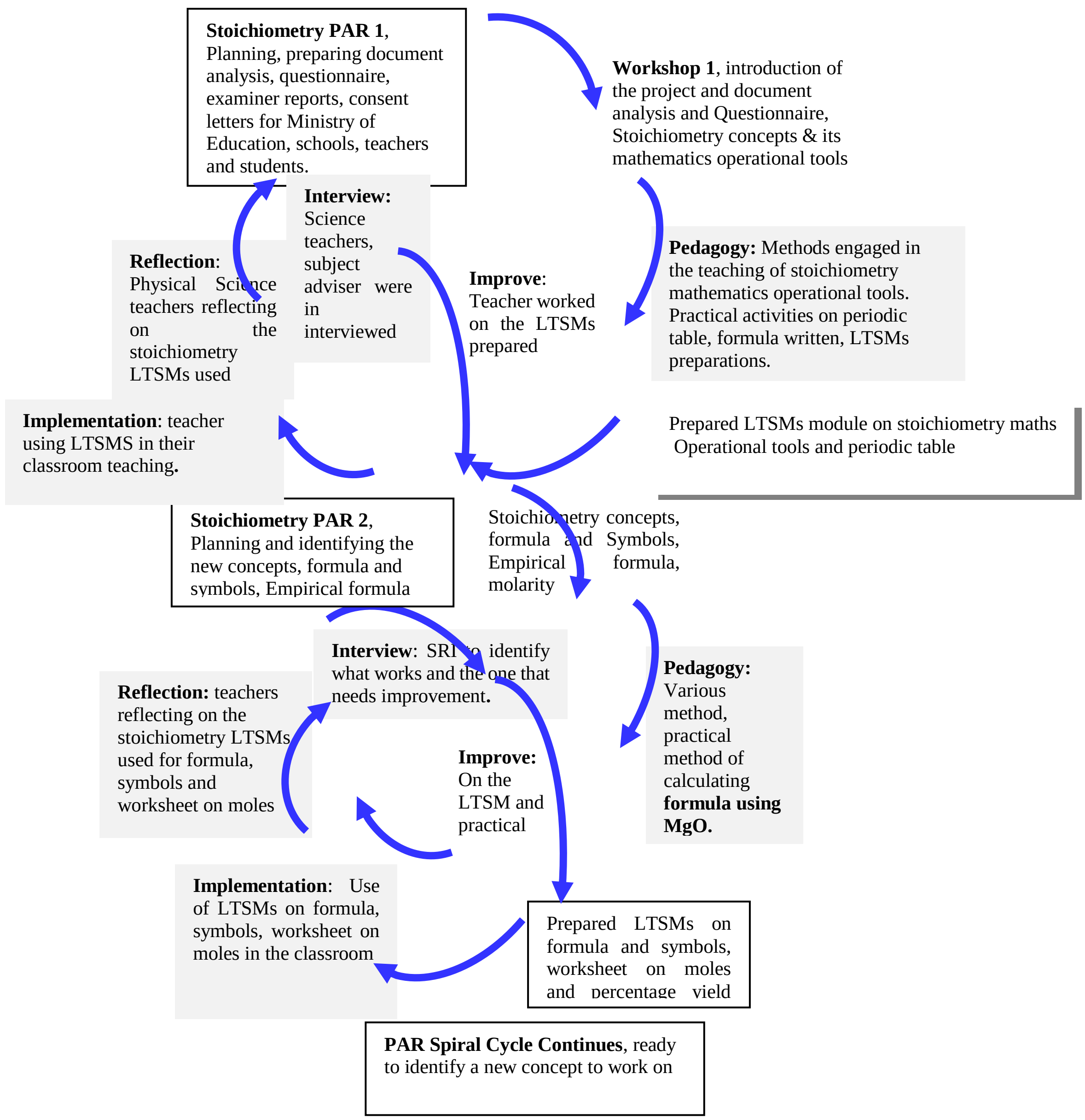


Figure 4.4.2.1: Cycles of Stoichiometry participatory action research (Adopted from Coghlan & Brannick, 2001, p. 19)

Even though the cyclic character of participatory action research reflects two stages as shown in Figure 4.4.2.1 above, the activities in the phases were redone until a satisfactory intervention was attained. These participatory action research cyclic activities were experienced in all the phases; teachers interacted with each other as a result of CoPs. Data was generated from the phases answering research questions, coupled with the activities engaged during the study in which community of practices were engaged.

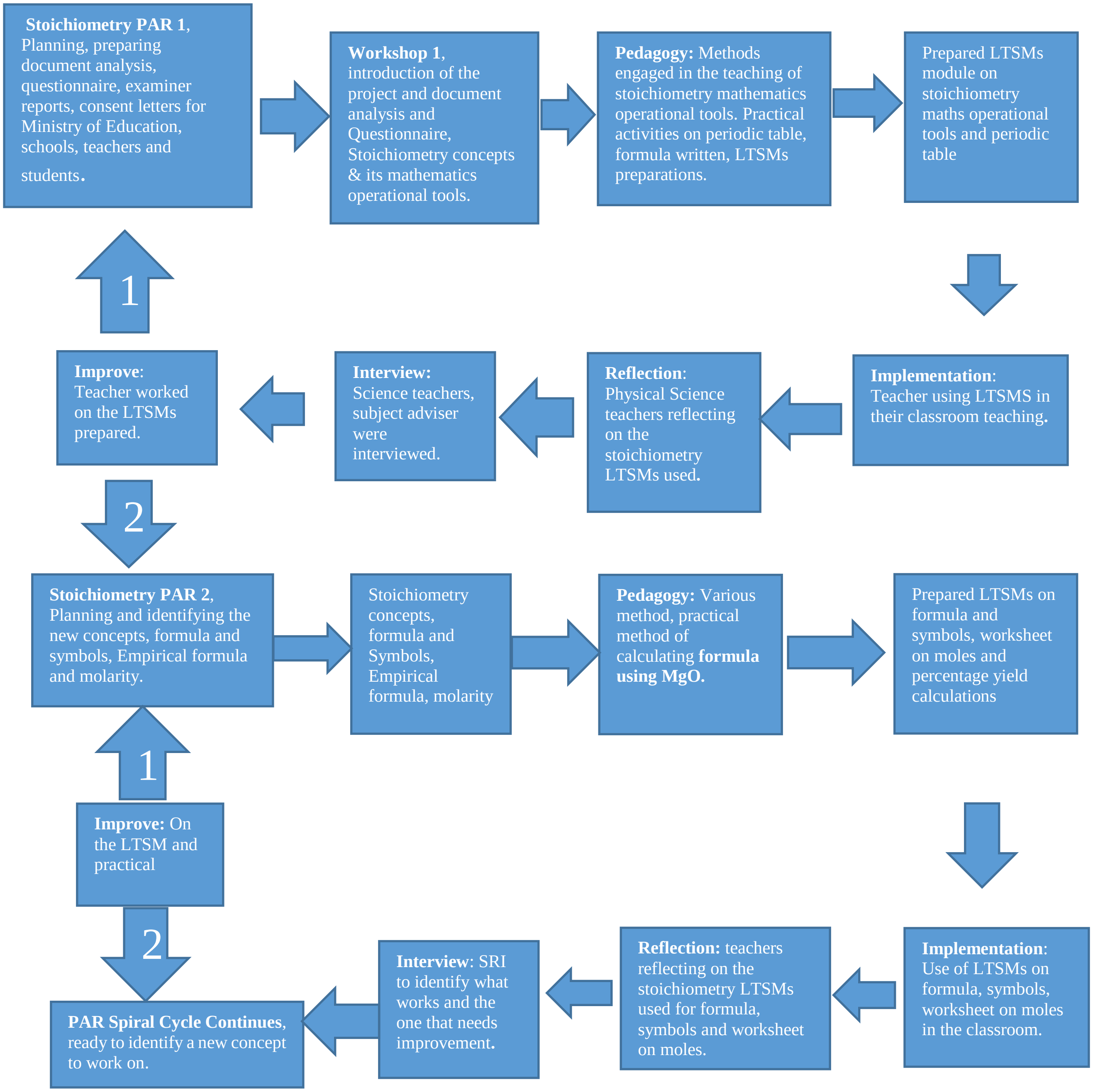


Figure 4.4.2.2: A simplified diagram of cycles of Stoichiometry

Arrows labelled 1 indicate repeat of the process when a concept has not been successful. Arrows labelled 2 indicate continuation to identify a new concept after satisfactory intervention is attained.

4.4.3 Community of Practice

According to Wenger (2000), a CoP is a group of people who share a passion about practice, ideas, and sets of problems. They seek their knowledge and expertise by continuously interacting with each other. The concept of CoP has found a number of practical applications in all spheres of community like education, business, government and other areas. In this study of improving teacher understanding of the mediation of learning stoichiometry, CoP might enable the research participants to take collective responsibility in making sense of stoichiometry through PAR, using CoP as an approach. The function of CoP using participatory action research is to promote activities and discussions that teach the Science teacher participants to engage, participate and contribute to a collective knowledge base. This might change the way the Science teachers interact with each other. This meaningful contribution might establish legitimacy and a place within the CoP to support the learning of other Science teachers who may not have had the same learning experiences (Lave & Wenger, 1991).

Wenger (2000) sees the structure of a CoP emerging over time through a process of legitimate peripheral participation. Legitimation and participation together describe the characteristic ways of belonging to a community. The legitimate peripheral participation is concerned with location and identity in the social world where knowledge is shared. The aspect of knowledge sharing engaged during the research when teachers collaboratively worked together on the teaching of stoichiometry concepts, creating links between learning and performance. CoP research participants addressed the tacit and dynamic aspects of knowledge creation and sharing.

The mixed-methods approach used needs to be justified; a questionnaire was given to learners, while interviews, stimulated recall interviews, observations and videotaped lessons were also used.

4.5 Justification for using mixed-methods

According to Onwuegbuzie and Johnson (2004), mixed-methods research is a natural complement to traditional qualitative and quantitative research. Ponce and Pagan-Maldonado (2015) emphasise that mixed-methods studies are based on the belief that there are existing problems whose complexity cannot be fully researched when the combination or integration of quantitative and qualitative approaches are not undertaken as components of the study.

Onwuegbuzie and Teddlie (2003) posit that some individuals who engage in the qualitative versus quantitative paradigm debate appear to confuse the logic of justification with these research methods. Howe (1992) postulates that there is a tendency among some researchers to treat epistemology and method as being synonymous. The logic of justification which is an important part of epistemology does not dictate what specific data collection and data analytical methods researcher must use. Different epistemological beliefs should not prevent a qualitative researcher from utilising data collection methods more typically associated with quantitative research and *vice versa*.

In this study I used a stoichiometry topic specific pedagogical content knowledge tool (quantitative data) for teachers and a stoichiometry diagnostic achievement test for learners. This was done to answer research question 1. In order to understand the teaching of stoichiometry by Grade 11 Physical Science teachers prior to the intervention, a stoichiometry topic specific pedagogical content knowledge tool was given to participating teachers to understand this phenomenon. For research questions 2 and 3, interviews, observations, and document analysis were used.

4.6 Research site and sampling

During the conceptualisation of my study, l planned to work with many Physical Science teachers across the whole of Namibia. The idea was rejected because of the large data analysis. Eventually, six participating teachers were selected from three different senior secondary schools in the Zambezi region where Physical Science is taught from junior level up to senior level of Grade 12. The sampling of participants was purposeful. Purposive sampling is used in order to access “knowledgeable people, that is, those having in-depth knowledge about issues by virtue of their professional roles, expertise or experience” (Ball, 1990 as cited in Cohen, Manion, & Morrison, 2011, p. 157). The Physical Science teachers had been teaching Physical Science for seven to 10 years. Two teachers per school were chosen, one was teaching Grade 11 and the other one was teaching both Grade 11 and 12. This allowed one of the teachers to act as a critical partner each time the other was teaching. Stenhouse (1978) points out that critical partners or critical friends are research participants who take a proactive role through the building and maintenance of a partner relationship with the researcher throughout their research projects.

The participants were initially a broader sample of 25 high school Science teachers from the Zambezi region of Namibia who voluntarily completed questionnaires. For my main study, the intervention was to involve a sample of six Physical Science teachers (two per school), selected from three schools in the Zambezi region, and 60 volunteer Grade 11 participating learners, 20 per school, who were taught by these teachers in the afternoons (Agunbiade, 2015) while I observed them. The criterion for learners who were chosen to participate was determined by their enrolment as Science learners currently in Grade 11; learners volunteered without being coerced. The teachers' profiles are explained below.

It appeared that Science teachers' profiles in this study varied, and that could have had an influence on the level of their involvement. Questionably, the six Physical Science teachers' diverse profiles and the varied teaching experiences and qualifications might affect their zone of proximal development (ZPD) (Vygotsky, 1978). In terms of PCK and SCK needed for teaching stoichiometry or Science generally, there might be a remarkable gap (ZPD). For easy identification of teachers' profiles, coding of their profiles was used. Smith and Davies (2010, p. 155) argue "that coding does not constitute the totality of data analysis, but it is a method to organise the data so that underlying messages portrayed by the data may become clearer to the researcher". The coding of the teachers was in logical order. The profiles of the research participants from School A, B and C are as follows.

Table 4.6.1: Profile and teaching experience of teachers in the study

T= Teacher, Q= Questionnaire, M= Male, F= Female.

Teachers	**Highest qualifications**	**Teaching experience**	**Involvement in the study**
T1Q1F	Diploma	9	Participant
T2Q2M	Diploma	8	Participant
T3Q3M	B.Th.	29	Participant
T4Q4M	Diploma	17	Participant
T5Q5M	B.Sc.	8	Participant
T6Q6M	Diploma	12	Participant

Below are the full details of the participating teachers, featuring their qualifications, teaching experience and their nationality. The numbering of the teachers' questionnaires is not in logical order, the indicator used here now is the participating school.

The profiles of the research participants from School A are as follows.

T3Q3M

T3 has a diploma in Education, Advanced Diploma in Education, with specialisation in Physics, Mathematics, Biology and Chemistry. The highest degree he has is BTh. which I presumed to be a bachelor's in theology because he is a Pastor of a certain church. He teaches Physical Science to Grade 11 and 12, both higher grade and ordinary. He has 29 years of teaching experience and is a Zambian national.

T6Q6M

T6 has a BETD, MASTEP and HED which all reflected Mathematics as the field of specialisation. He is the HOD for Mathematics and Science. He has been teaching Physical Science for 12 years and attended all the workshops.

At School B the profile of the research partners are as follows:

T2Q2M

T 2 has a BETD from Windhoek College of Education and a MASTEP with University of Namibia. He teaches Physical Science to Grade 11 and 12 as has eight years of experience.

It is thus evident from the questionnaires answered by School A and School B that most of the Physical Science teachers had diplomas but none had a degree, yet they were teaching Science. In my view, it could be argued that quality was compromised at the expense of the number of learners doing Physical Science. This might have an influence on the PCK and SCK of these teachers. I would suggest, therefore, that there is a strong case for professional development for these in-service teachers in order to ensure a quality standard of education.

T4Q4M

T4 has a BETD from the Caprivi College of Education, a Diploma in Education with the University of Namibia and a Diploma in Transformational Leadership with the African Leadership Institute. He is the HOD for Science and Mathematics at their school and teaches Physical Science. He has about 17 years of teaching experience.

The teachers' profiles at School C are as follows:

T1Q1F

T 1 has a BETD and did participate in many activities like the individual task on electronic configuration, and she was positive about being part of the team. She has five years teaching experience.

T5Q5M

T5 who teaches Grade 11 and 12 has six years of experience. He is not a permanent teacher. He came as a hired teacher to help in Physical Science. He has a degree in Wildlife Management, not in education. In my view, it could be argued that quality was compromised, and this affected the standard of teaching, the PCK and SMK. This teacher was keen to learn, and he needed to be supported in the area of PCK as well as SCK, for effective teaching of Science. However, in my study, I guarded against teachers' coercion and any behaviour that might threaten or compel my participants to be part of this project against their will; therefore, the issue of positionality is discussed below.

4.7 Positionality

One of the major dilemmas in educational research is that of positionality. According to Skelton (2001, p. 89), positionality refers to factors that "impact on the way we do our research and how the people we work with perceive us". These factors include gender, race, ethnicity, religion, age, position and the power dynamics related to it.

In this study my participants were Physical Science teachers from different schools in the Zambezi region. To deal with the power imbalance created by this scenario, I positioned myself as a co-learner since I was not their immediate supervisor, just a research participant. My study was located in their field of expertise which made me a co-learner or a colleague in the field of Physical Science. This placed us at the same level as members of a CoP, collaboratively engaged in exploring how an intervention supported Physical Science teachers in the understanding and mediation of learning of stoichiometry in the Zambezi region.

4.8 Data generation methods

Creswell et al. (2016) argue that methods are the tools that researchers use to collect data. The tools enable researchers to gather data about social reality from individuals, groups, and texts in any medium. This study made use of the following data gathering tools: survey questionnaires for teachers; document analysis (including a diagnostic test for learners (Appendix N); interviews (semi-structured interviews) (Appendix K); stimulated recall interviews (Appendix O) for teachers; workshop discussions with reflective notes with teachers; lesson observations; as well as a research journal. As emphasised by Cohen et al. (2011), the use of a variety of data generating techniques afforded me an opportunity to triangulate the data. Also, as a researcher, keeping the research question in mind was of paramount importance because more than one method gave valuable data. I now summarise in Table 4.8.1 the data generating methods and thereafter, discuss them in detail in the section which follows.

Table 4.8.1: Data generation methods

Method/instruments	Purpose	Actors
Survey questionnaires	To obtain information and opinion on successes and challenges teachers face in teaching Stoichiometry.	All research participants.
Document analysis	To enable the researcher to interpret documents and give voice and meaning around an assessment topic (Bowen, 2009).	Six Physical Science teachers, subject adviser, critical friend and the Education officer.
Interviews • Semi-structured interviews • Stimulated recall interviews (SRI)	To find out about the experiences, assumptions, procedures, methodological guidelines and beliefs about the teaching of the stoichiometry concept. It allows the investigation of cognitive processes through inviting Physical Science teachers to *recall* their current thinking during an event when prompted by a video sequence.	This was conducted individually with all the six participating Physical Science teachers and the researcher. Subject adviser. SRI was done with three participating Physical Science teachers, one teacher from each school.
Workshop discussions	Working together collaboratively to develop LTSMs and to construct knowledge	Six Physical Science teachers plus the researcher.
Videotaped lesson observations	To test the LTSMs for the teaching of stoichiometry. To critique the teaching methods through collaborative efforts.	3 Physical Science teachers and the researcher.
Research journal	Recording experiences and challenges during the research journey.	All research participants.

4.8.1 Document analysis

Bowen (2009) defines document analysis as a systematic procedure for reviewing or evaluating documents. The documents analysed can be both electronic and printed. Like other analytical methods in a qualitative research, document analysis requires data to be examined and be interpreted to elicit meaning, gain understanding, and develop empirical knowledge (Corbin & Strauss, 2008). Stake (1995) explains that generating data by studying documents follows the "same line of thinking as observing and interviewing" (p. 68). In this study, I analysed the following: one Physical Science scheme of work; one Physical Science syllabus; five different textbooks; and examination question papers and examiners' reports for the past five years (2010 to 2015). This also helped in developing and formulating the interview questions for the semi-structured interviews in this study. Lesson plans of participants were analysed as documents based on the participants' PCK of teaching stoichiometry curriculum (Shulman, 1986) and analytical framework on the Topic Specific Component of PCK discussed in Section 3.9.

Document analysis was challenging because some teachers did not contribute much during the workshops, such as talking, or discussing their teaching experiences. However, some of the challenges were able to be solved by interviews conducted with individual teachers. If these teachers had contributed fully, the strategies they used could have been helpful in this study. Also, their challenges could have been aired and the study might have come up with recommendations to mitigate these challenges in the teaching of stoichiometry concepts.

4.8.2 Interviews

Bertram and Christiansen (2015) state that "an interview is a conversation between the researcher and the respondent'' (p. 80). It is different from an everyday conversation, however, in that the researcher is the person who sets the agenda and asks the questions. Interviews enable participants to express themselves and helped me gain in-depth data from a small sample size. In this study, semi-structured and stimulated recall interviews were used. The interviews are explained in the next paragraph.

4.8.2.1 Semi-structured interviews

According to Cohen et al. (2018), "the semi-structured interview is a flexible tool for data collection, enabling multi-sensory channels to be used: verbal, non-verbal, spoken and heard" (p. 349). Semi-structured interviews are usually conducted before observing the teachers' lessons. The semi-structured interview guide was structured in such a way as to obtain the level of pedagogical and content knowledge of teachers on the stoichiometry concepts. The interview with each of the six teachers lasted for about thirty minutes. I employed semi-structured interviews in my study because I wanted to get the participants' views on teaching of stoichiometry in schools.

Wilkinson (2004) posits that open-ended questions allow a respondent to pronounce his or her own views, ideas or suggestions about the question posed. The semi-structured interviews helped in clarifying some concepts and questions after observing teachers' lessons. The data obtained from these interviews augmented (qualitative) data were colour-coded and provided the answers to the baseline data question and question 1 (see Table 4.3.2.1). All information generated was tape recorded and transcribed selectively and not verbatim (Kvale, 1996).

4.8.2.2 Stimulated recall interview

Stimulated recall interviews (SRI) entail interviewing individuals using audio-visual recordings of their own behaviour in situated social interactions as emphasised by Vygotsky (1978). The studies of Rosen, Lunderberg, Cooper, Fritzen and Terpsita (2008) and Powell (2005) reflect that stimulated recall discussions have been found to enhance reflection on one's teaching. This resonates with the participatory action research discussed above. In this study, the stimulated recall interviews were employed as a way of giving descriptive explanations to the events that occurred during the lessons taught. These also helped to clarify some questions that the researcher had after watching and analysing the lessons. Both the semi-structured and stimulated recall interviews were recorded for an in-depth analysis to give clearer descriptions of the participants' narratives. The stimulated recall interviews were conducted individually with each teacher while watching their videotaped lessons. Stimulated recall interviews were done with three teachers, one from each school. Data generated from SRI contributed to answering research questions 1 and 2 (see Table 4.3.2.1). In addition to stimulated recall interview, observation was also used to generate data from the participating Physical Science teachers.

4.8.3 Observation

According to Cohen et al. (2018), observation is the technique researchers use to generate data in a social situation and this technique resonates both with Vygotsky's social constructivism theory and Shulman's (1986) PCK. Of the six teachers, three teachers, one from each school were observed. Six lessons (two lessons per teacher), were observed and videotaped to gain some insight on how these teachers mediated the learning of stoichiometry using the intervention lessons co-developed during Phase 3 in the PAR. Observing the teachers generated data from a real situation to answer research question 2 (see Table 4.3.2.1). Observation is a data-generating method used to enable the researcher to gain deeper insight into and understanding of the phenomenon being observed. Along the same line, Bertram and Christiansen (2015) and Cohen et al. (2018) affirm that observation means that the researcher sees for him/herself the context and site of the research study and thus the researcher can gather information about a wide range of phenomena. For instance, the teacher's classroom practice, the interactions that take place between the teacher and learners, and the educational environment (teaching styles, the use of resources, and the curricula). During the course of using all the instruments, details of active events were recorded in the research journal entries

4.8.4 Research journal entries

Research journal entries can be regarded as journal metrics that measure the performance and activities during the research journey. Each metric has its own particular features, but in general, they all aim to provide information into researcher performances based on recorded activities during the research journey. Research journal entries reflect all activities during the research. This reflective writing is an analytical practice in which the researcher describes a real or imaginary scene, event, interaction, passing though, memory, form, adding a personal reflection on the meaning of the item or incident, thought, feeling, emotion, or situation in his or her research journey. Moon (1999) likens reflective writing to the use of the page as a meeting place in which ideas can intermingle, and in developing, give rise to new ideas for new learning. The most important component of a research is the ability of the researcher to provide a transparent account of a research journey throughout the research process. Accordingly, a research journal was used in this study as a diary, a tool promoting development and understanding of the research process Borg (2001).

Many other scholars like Lotz (1996), Taylor and Bogdan (1998), Penney and Warelow (1999) and Southwood (2000) are advocates and supporters of journal entries. Southwood (2000) points out in the research project that:

> Writing the research journal proved to be a fundamental aspect of the research process facilitating greater personal insight, greater connection with 'events' and greater realisation and understanding. (p. 50)

Borg (2001) in his work emphasises that:

> The database of experience in a journal greatly enhances the researcher's ability to make informed decisions about the research process, provides a global picture of patterns and themes in the researcher's work and thinking, and also allows for both greater precision and wider use of the researcher's voice in the reporting of the study. (p. 172)

The term 'journal' has been used in the research to denote reflective writing about the research and other research activities. The research journal is useful in encouraging and motivating the research process. From a researcher perspective, reflective writing can be seen as a useful device for an effective research process. Motivation to explore the issue of journal-writing was proposed by my supervisor, who had found it effective in his own research. The reflective process of writing the research journal proved to be useful in my study also.

During the course of my study, I used journal entries as well and the dates and activities carried out during the study were recorded. The discussions with gatekeepers were recorded and discussions with critical friend were also recorded. Babikwa (2003) encourages performers in his research project to keep journals of events. Some participants failed to keep a journal of events. Participants were all meant to keep the journals.

I developed a method of reflection on location by encouraging the participating teachers to reflect during the workshops or immediately after the lesson was observed. I was also mindful of professional coercion (Skelton, 2001), which would contradict the research ethical code of conduct. I harmonised with Borg (2001) that research journals can play a central role in collaborative study contexts by allowing a member of a CoP to express, record, and share their experiences. This was the core of my study where participatory action research was used with the research participants, reflecting during or after the workshops. This reflection is shown in Figure 4.8.4.1 below, where all the components of participatory action research procedures in the teaching of stoichiometry were embedded.

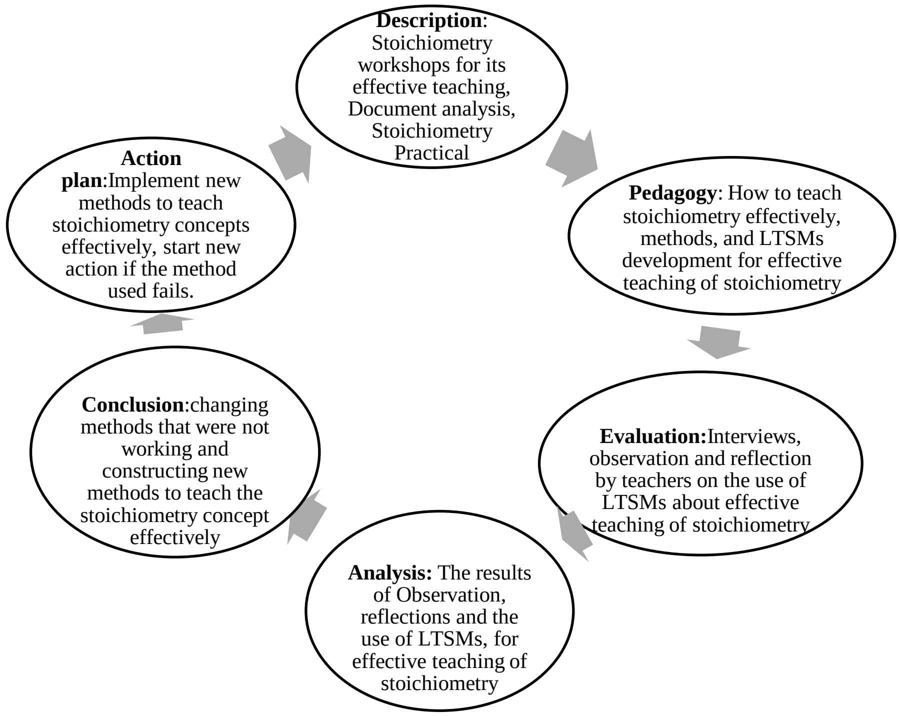


Figure 4.8.4.1: Gibbs's (1988) learning by doing: A guide to teaching and learning methods

Gibbs' reflective cycle entails the details used in my research reflective writing. It was really useful in thinking through all the phases of an experience or activity during the study process. This enhanced the trial study of learning and teaching support materials (LTSMs) in participating schools, to justify its effectiveness of the teaching of stoichiometry.

In each of the stages of Gibbs' (1988) learning by doing cycle, the activity of reflection features in most stages. For instance, in the stage of pedagogy, reflection allows one to come up with better methods to teach stoichiometry. Similarly, in the evaluation stage, teachers surface what they have; in the analysis stage the results of the previous stages, which include reflection are discovered and these are then included in the conclusion in order to take action.

4.9 Data analysis

Data analysis is described as a process of bringing order and reducing a large amount of data to make sense of it (Bertram & Christiansen, 2015). For qualitative data, I used an inductive approach to data analysis; for example, a large amount of data was used to deduce the conclusion. Kline (1985) views inductive analysis as a good way of reasoning to come up with solutions or responses to the research questions, as categories and themes emerged. The categories, themes and patterns emerge from the collected data, unlike deductive data where theories are imposed on data. The qualitative data analysis used was content analysis. Mayring (2000) contends that "content analysis is a method for summarising any form of content by counting various aspects of the content'' (p. 5). Content analysis differs from other kinds of social science research in that it does not require the collection of data from people. Similar to documentary research, content analysis is the study of recorded information, or information which has been recorded in texts, media, or physical items. According to Krippendorff (2004), content analysis is the systematic reading of a body of texts, images, and symbolic matter, not necessarily from an author's or user's perspective. This stoichiometry qualitative data was compared with data from the documents, teacher's questionnaires, interviews, observations, as well as reflections, which transformed data into patterns. From the patterns, categories and themes were constructed. These themes were used to form analytical statements. For example the green coded colour categories (Appendix L), the conceptual teaching strategies, where the successful intervention to mediate learning emerged. Another example of the categories was curricular saliency, coloured light green (Appendix L), which came with an analytical theme, periodical sequential teaching procedure building on acquired knowledge.

Quantitative data is different from qualitative data; it was analysed using Statistical Package for Social Sciences. From the table of data collected a bar graph was constructed. A bar graph was found suitable because data was obtained through counting. Coding was not applicable for quantitative data.

4.10 Validity and trustworthiness

Toma (2011) coined the word 'trustworthiness' to describe the standards of validity, reliability, generalisability and objectivity in qualitative work. Toma (2011) further accentuates that qualitative researchers establish the trustworthiness of their findings by demonstrating that they are credible, transferable, dependable and confirmable. In this study, I worked with these four standards to guarantee trustworthiness. Below is the explanation of how I tried to adhere to each of these standards.

Credibility is recognised if participants agree with the constructions and interpretations of the researcher, and the description of the study is correct based on the understanding of those studied (Toma, 2011). Credibility measures, tests or studies what is actually intended. Merriam (2009) urges researchers to ask themselves the following questions to ensure credibility: How consistent are the findings with reality? Do the results capture what is really there? Are researchers recording and measuring accurately what they are supposed to measure?

Marshall and Rossman (2011) posit that if the reporting processes and interactions are within the boundaries of the cases have been done with sufficient depth, this gratifies the credibility standard. Reflection from the participants during the workshops and during stimulated recall interviews also revealed whether the reporting and interaction were within the boundaries of the study.

Peer review is another strategy that I used for credibility purposes. I presented my study during the PhD week to get critical feedback on the study. I also asked a critical friend to go through the script, and he responded to supervisory feedback.

According to Merriam (1998), transferability is the magnitude to which the findings of the study can be applied to other circumstances. To make transferability possible in this study, I used participatory action research and the afterschool-programme to observe and videotape the teachers during lesson presentations. I observed how the teaching of stoichiometry was conducted with the usage of LTSMs and their application during the afternoon school programme. Lessons with the participants were done in the afternoon (afternoon-programme) outside of school time for convenience purposes.

Dependability is another standard that ensures trustworthiness. Dependability reveals that under the "same context, with the same methods and with the same participants, similar results would be obtained" (Shenton, 2004, p. 71).

According to Toma (2011), dependability can be attributed to the applicability of the study design as it applies to qualitative research to be aligned to research questions. The findings also should reflect similarity across data obtained.

Confirmability means to ensure that the findings are indeed the results of the study, the result of the experiences and ideas of the participants (Patton, 2002). To adhere to confirmability, I used triangulation to reduce the effect of my own contribution as a researcher. Triangulation using multiple sources of data meant comparing and cross-checking interview data collected from Physical Science teachers with different perspectives. For example, I carried out in-depth interviews, stimulated recall interviews with Physical Science teachers and observation of Physical Science teachers during the after-school programme. The Physical Science teachers did reflect, during and after workshops, to ensure that stoichiometry teaching was effective and in alignment with the curriculum. I also ensured an audit trail of the data sources and analysis process which were included in Table 4.8.1, to guarantee confirmability and dependability.

Member checking, according to Merriam (2009) is another trustworthiness strategy. Creswell et al., (2016) argues that member checking determines the accuracy of qualitative findings by reverting certain concepts or findings back to participants for accuracy confirmation. Also, Maxwell (2005) debates on member checking as a significant approach for ruling out the possibility of misinterpreting the meaning of what participants say and do. I used member checking to solicit feedback on emerging findings from the Physical Science teachers during workshops, and persistent contact with research participants made this achievable.

4.11 Ethical considerations

To ensure good research, I observed ethics that comprised appropriate informed consent, obtaining access and acceptance, ensuring privacy and anonymity of respondents and confidentiality of information. Informed consent is an ethical and legal requirement for research involving human participants. It is the process where a participant is informed about all aspects of the research process, which is important for the participant to make an informed decision. After studying all aspects of the research process, the participant voluntarily confirms his or her willingness to participate in the research.

According to Cohen et al. (2018), informed consent is the procedure in which individuals choose whether to participate in research after being informed of the facts that would be likely to influence their decision. I concurred with Cohen et al. (2018) and made sure that the participants were aware of the major phases in the research process; phase 1 – semi structured interviews, phase 2 – workshops and phase 3 – observations in the classroom. They were informed of their right to withdraw at any stage of the process.

Obtaining access and acceptance was another ethical parameter that I followed. The first stage was getting official permission to undertake my research from EHDC at Rhodes University (Appendix A). For the participating schools, I wrote to the Zambezi Director of Regional Education Council (Appendix C). The permission letter from the Director allowed me to contact the principals of the three participating schools (Appendix B). I was referred in writing to relevant gate keepers. (Appendix F, G, H). Knowing that my study would involve interviews, workshops, observation and reflections, I had to prepare an outline in writing of the precise nature and scope of the research. After all this, I made actual contact with all the would-be participants. After getting the consent of the teachers verbally, I then wrote to them requesting their participation in my research. In the formal letter I tried by every means possible to adhere to the principle of honesty in research. I tried to fulfil the principles of informed consent, obtaining access and acceptance in order to avoid emotional harm to my research participants.

Cohen et al. (2011) list some ethical considerations that I found applicable to my research. All participants remained anonymous and all information was treated with strictest confidence. I was confident that information revealed by the participants did not in any way disclose their identity. I made use of pseudonyms. This guaranteed the participants privacy. On the basis of this I decided to include this excerpt of ethical consideration, for my position to be seen as a co-learner in this study.

The participants in this study were the Physical Science teachers and subject adviser (Appendix E) who had been teaching the subject for between six to eight years or more and had been producing good results. Being a lecturer at the University of Namibia in the Zambezi region, I am in no way a foreigner to the participants, as we had been working together at Science Fair meetings and other community programmes for schools within the Zambezi region, thus the issues of positionality might not arise because of the long-term trust. I thus positioned myself as a co-learner in this study (see Section 4.7). Additionally, in my informal conversations with some of the participants they showed interest in the study as they felt that it would enhance their teaching skills. However, I ensured that the teachers participated voluntarily in the study and I established trust and developed collegiality, regardless of the fact that some of the teachers were my students at high school.

All participants were informed about the nature and expectations of the study in order for them to get a clear indication of what the research study was all about, who was involved and the means by which the data would be gathered (Smith, 2003). The participants were made aware of any risks that they could be exposed to due to the processing and dissemination of the data (Smith, 2003). Participants were further informed that they had the right to privacy and confidentiality, and the role that each one would be expected to play during the research process. They were also made aware that they were free to withdraw at any stage during the research process.

It is deemed to be unethical if information is collected without the knowledge of the participants, their informed willingness, and expressed consent. Kumar (1996) states that informed consent entails making the participants aware of what it means to have informed consent. Before the commencement of the research, l wrote a letter to the Director of Education in the Zambezi region (Appendix B), circuit inspector (Appendix D), Science subject adviser (Appendix E), school principals of the participating schools (Appendices, F, G and H) and the participating teachers (Appendix I). Also, a referral letter from my supervisor that sanctioned my access to schools and other relevant stake holders was obtained to authenticate that I was a PhD scholar. In addition, the University of Rhodes research "Ethical Approval Application" form was completed and submitted to the Education Higher Degrees Committee (EHDC) with the research proposal which was accepted (Appendix A). The following aspects were taken into consideration during my research process.

Respect and dignity

A consent form was compiled and handed to the participants. I read the contents of the form to them and explained all that needed to be explained. I explained to the participants that they were not forced to participate in the research and they could withdraw at any time if they felt like doing so. In addition, participants were told that pseudonyms would be used in compiling the study and when publishing the results. Thereafter, participants were asked to read and sign the consent form.

Transparency and honesty

A thorough explanation of the study was done. Its aim and how it would benefit the participants were explained to them. The aim was to motivate them to participate in the study. I ensured the participants that I would be honest with them as I would not exaggerate the aims and the importance of my study.

Accountability and responsibility

I submitted letters to participating schools and organisations. The aim of the letters was to seek permission from the organisations under which the schools fell. These organisations were: the Namibian Directorate of National Examination, the Director of Education, circuit inspectors whose schools had teachers who participated in my study, the principals of schools where the teachers were teaching and the participating teachers. When conducting the workshop as indicated in Table 43.2.1, I ensured that I accurately recorded all the data generated.

Integrity and academic professionalism

To ensure that I exercised integrity and academic professionalism in this study, I gave an accurate account of the data to be generated. In the workshops that were conducted, a colleague was invited to assist with the data capturing so that data were not lost. The captured data were given to the participants to verify that what had been captured was a correct or true reflection of what transpired.

4.12 Concluding Remarks

This chapter has uncovered the methodology within the qualitative research and the interpretive paradigm used in this study. Within this paradigm, the participatory action research approach was embraced in order to explore the PCK of the Physical Science teachers as a way to mediate effective teaching of stoichiometry enhancing continuous professional development.

The dynamic participatory action research approach used among all the Physical Science teachers may be regarded as an instrument to explore the development of teachers participating in the intervention for the effective teaching of stoichiometry. All the Physical Science teachers in this study were actively involved in the generation of data through active collaborative roles during this study.

The next chapter deals primarily with the research data analysis answering research question 1 for this study. It explores the understanding of teaching stoichiometry by Grade 11 Physical Science teachers prior to the intervention.

CHAPTER FIVE: RESEARCH PROGRESSION AND DEVELOPMENT: DATA PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

> *Teaching involves complex and multilevel knowledge and understanding of learners, curriculum, learning materials, cultures, and society and its communities and institutions. Working together, teachers develop their interpretation of good teaching and learning*. (Kosunen & Mikkola, 2002, p. 143)

5.1 Introduction

In the previous chapter, I presented the research design and methodology informing this study whose focus was an intervention for Physical Science teachers' continuing professional development (CPD) to improve the teaching of stoichiometry. Essentially, the study explored how the Physical Science teachers involved in this study were working or teaching stoichiometry in schools prior to the intervention. As indicated in the epigraph, teaching involves teachers identifying the right teaching strategies, suitable learning methods, understanding of learners, curriculum, learning materials, cultures, society and its communities, in order to derive the best fit approach to enhance the teaching methods for effective teaching both in and out of the classroom (Kosunen & Mikkola, 2002).

In this chapter, I thus present, analyse and discuss data from document analysis (learners' stoichiometry diagnostic test), teachers' questionnaires and interviews. The aim of the stoichiometry diagnostic test for learners, was to elicit learners' prior knowledge and find out what is difficult to teach about stoichiometry. However, the focus in this study was on teachers and not learners *per se*, but the stoichiometry diagnostic achievement test was used as a mirror to reveal the challenges learners might have with this topic. This is central in Shulman's (1987) PCK, involving learners' prior knowledge and what is difficult to teach (Mavhunga & Rollnick, 2013).

Also, the diagnostic test was intended to inform the analysis of curriculum documents, textbooks and to assist in developing intervention strategies that might enhance teaching of stoichiometry. Questionnaires and interviews were used to gather information about the participants' views regarding the teaching of stoichiometry prior to the intervention. I gave the participating Physical

Science teachers one week to complete the questionnaires. To augment data from the questionnaires, I followed up with individual semi-structured interviews. The participants' personal responses about the teaching of stoichiometry were explicit because of the face-to-face interviews adopted. As I already explained in Section 4.6, the interviews were about 30 to 40 minutes long and varied because of how participants explained themselves during this process. The marked learners' diagnostic achievement tests, questionnaires and interviews generated data aimed at answering research question 1:

What is the understanding of teaching stoichiometry by Grade 11 Physical Science teachers prior to the intervention?

5.2 Research process

There were three schools involved in this study (school A, B and C) and the profiles of Science teachers involved in this study are coded and explained below in Table 5.2.1.

Table 5.2.1: Profile, qualification and school of teachers involved in this study

T= Teacher, Q= Questionnaire, M= Male and F= Female.

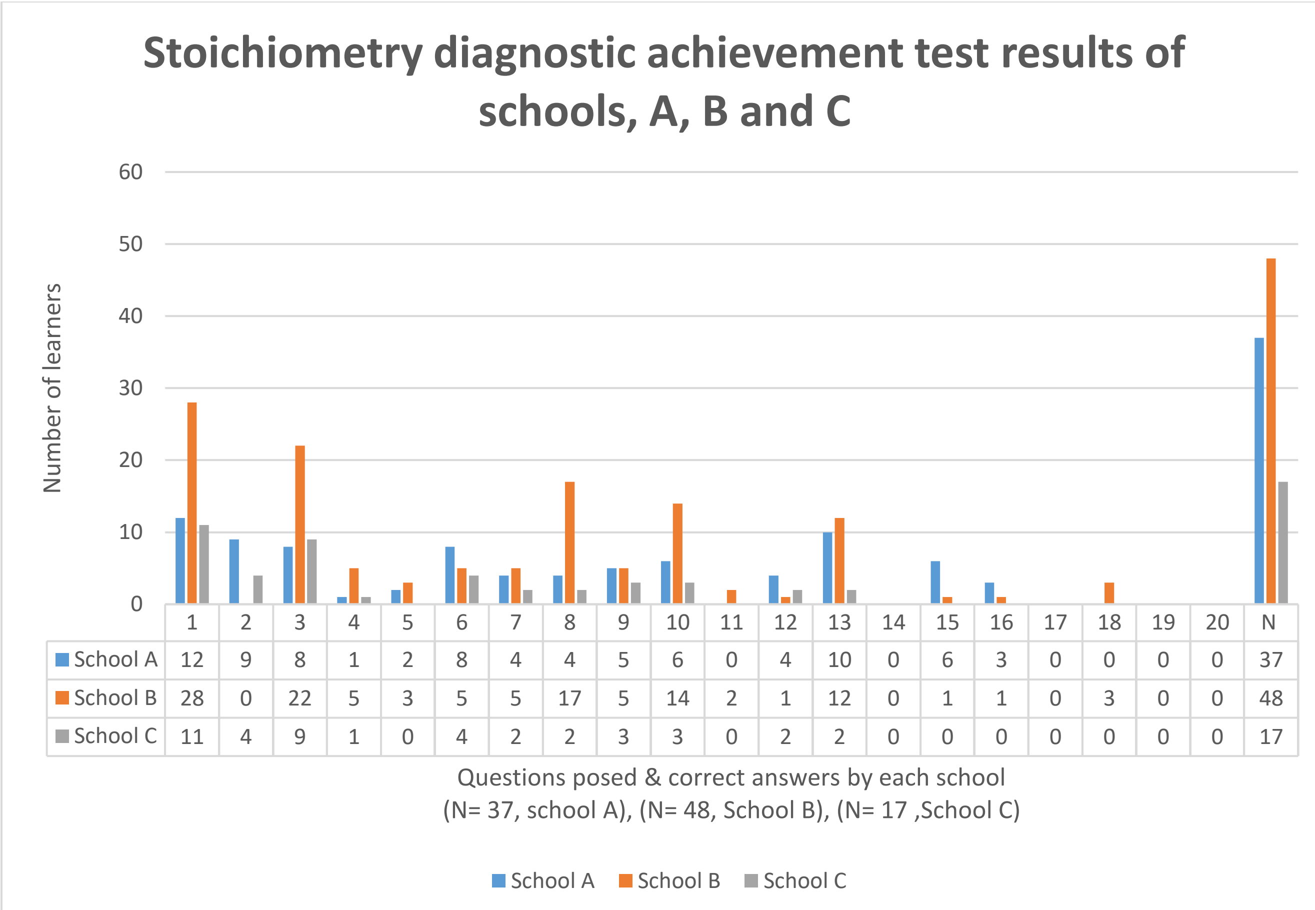
Teachers	Highest qualifications	School
T1QF	Diploma	**C**
T2QM	Diploma	**B**
T3QM	B.Th.	**A**
T4QM	Diploma	**B**
T5QM	B.Sc.	**C**
T6QM	Diploma	**A**

Each participating school arranged learners to answer the stoichiometry diagnostic achievement test. The criteria qualifying a learner to participate were: being a Grade 11 Physical Science learner. The stoichiometry diagnostic achievement test covered most of the stoichiometry concepts questions (see Appendix J). Multiple-choice questions were used for the stoichiometry diagnostic test, as they have the advantage of being able to be used in different subject-matter areas and can be used to measure a great variety of educational objectives. This idea agrees with Klufa's (2012) view that multiple-choice tests are widely used in testing the knowledge of students and has the advantage that the results can be evaluated quite easily even for a large number of students. On the other hand, multiple-choice test questions have the disadvantage of having limited types of knowledge that can be assessed and lack of explanations to answers (Klufa, 2012).

The learners' scripts were marked by the teachers and me in order to establish learners' prior knowledge and what they found difficult to understand as alluded to earlier. The results of the diagnostic achievement test are shown in Table 5.2.2. The graphs show the number of learners against the diagnostic achievement test questions they got correct. As illustrated below, School A had 37 learners, school B had 17 learners and school C had 48 learners.

Table 5.2.2: Stoichiometry diagnostic achievement test results for school A, B and C

	Diagnostic Test Results		
Questions	**School A**	**School B**	**School C**
1	12	28	11
2	9	0	4
3	8	22	9
4	1	5	1
5	2	3	0
6	8	5	4
7	4	5	2
8	4	17	2
9	5	5	3
10	6	14	3
11	0	2	0
12	4	1	2
13	10	12	2
14	0	0	0
15	6	1	0
16	3	1	0
17	0	0	0
18	0	3	0
19	0	0	0
20	0	0	0
N	37	48	17



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	N
School A	12	9	8	1	2	8	4	4	5	6	0	4	10	0	6	3	0	0	0	0	37
School B	28	0	22	5	3	5	5	17	5	14	2	1	12	0	1	1	0	3	0	0	48
School C	11	4	9	1	0	4	2	2	3	3	0	2	2	0	0	0	0	0	0	0	17

Figure 5.2.1: Diagnostic test results of schools A, B and C

The graph shows the results of the stoichiometry diagnostic test for all three schools (A, B, and C). It also indicates the number of learners that did well in each question.

It emerged from these results that the learners' diagnostic test results concurred with the Examiners' Reports for 2009-2015 that learners were not doing well in some stoichiometry concepts such as moles, mole ratios, relative molar mass, percentage yield, balancing of equations and calculating volumes at STP (DNEA, 2015). The teachers also commented on the results, for instance, T5 reflected that "*I have never taught limiting reagent and percentage yield*". It seems T5's view is in line with his school's performance – questions 15 to 20 is about limiting reagents, percentage yield and molecular and empirical questions (See Appendix N) and no student in school C passed (see Table 5.2.2). T3 also commented that, "*Avogadro's number is not real, and this concept is difficult to explain*".

To address this problem, the participating teachers and I collated the stoichiometry concepts where learners performed poorly in the test. This action motivated the teachers to be interested in the study as to how these stoichiometry problems might be solved. For ethical reasons l presumed this approach of giving questions to learners, to be a new knowledge. Learners' work was used to access teachers' SMK. In response, T3 and T5 confirmed that the topics of Avogadro's and limiting reagents were difficult concepts during the compilation of difficult stoichiometry concepts. From literatures accessed so far, none include this approach of using learners to access teachers' views.

5.3 Analysis of Physical Science Teachers' Questionnaires

The analysis of teachers' questionnaires was done by using the TSPCK components as an analytical lens (Appendix L) (Mavhunga & Rollnick, 2013). The structure of the questionnaire was thus divided into five different categories, namely: learners' prior knowledge, curricular saliency, what makes stoichiometry difficult or easy to learn, representation/models, and conceptual teaching strategies, as proposed by Mavhunga and Rollnick (2013).

5.3.1 Teachers' responses on learners' prior knowledge

The responses of all six participating Physical Science teachers about learner's prior knowledge in the stoichiometry topic specific pedagogical content knowledge tool (Appendix M), were analysed and the emanating results are recorded in Table 5.3.1.1 and Figure 5.3.1.1 shown below.

Table 5.3.1.1: Teachers' responses on learners' prior knowledge

Correct	**Partly correct**	**Wrong**	
Response C	Response A	Response B	Response D
67.00%			
17.00%	17.00%		

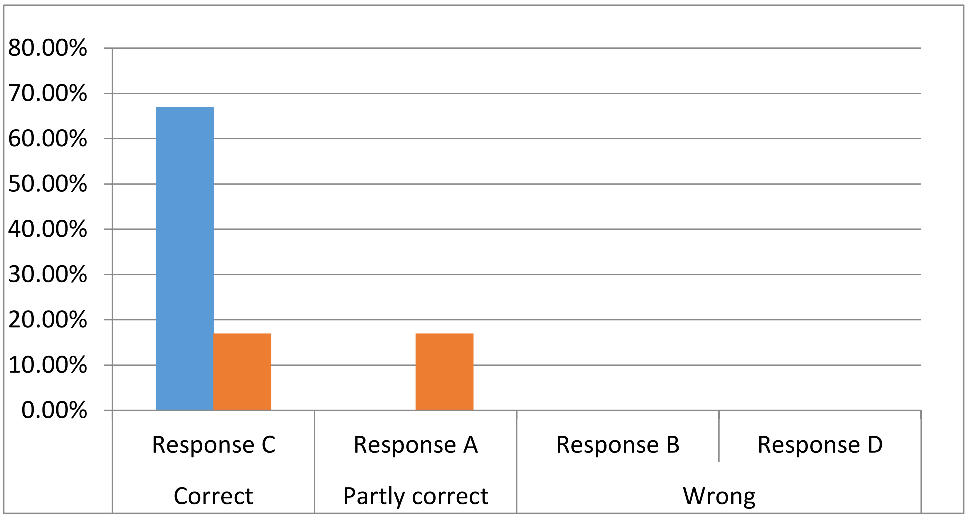


Figure 5.3.1.1: Teachers' responses on learners' prior knowledge

The responses shown in Figure 5.3.1.1 above indicate that four out of six teachers (67%) indicated the correct answers for the volume and amount of gases at STP (see appendix M). One of the teachers, T1, further explained that: *"It's because response C all contains gases and any gas contains or occupies a volume of 22.4dm^{3}at STP. Each substance in response C has 1 mole and the components are in the same phase".*

From this excerpt, it seems T1 had adequate SMK of the stoichiometry concept since he was able to identify that the components were in the same plane. This confirms that SMK is necessary for effective teaching and delivery of stoichiometry concepts. This is in line with Kind's (2009) view that Science teachers' PCK development and the relationship between PCK and SMK will help establish Science teaching practice of consistently higher quality.

In addition, prior knowledge on moles and phases of substances might have assisted T1 in choosing the correct response. Prior knowledge provides an anchor to assimilate new knowledge into the cognitive structure (Taber, 2001). To some of the teachers, prior knowledge was very important because four out of six (67%) teachers got the answer correct. T4 got the answer correct but gave no explanation to back up the chosen answer. For example, neglecting prior knowledge can result in learners learning things that are not in line with the concept being taught (Rochelle, 1995). Thus, the role of prior knowledge could be seen as the foundation of the learning and mediating processes, which enhance the understanding of concepts being taught (Fisher, 2007).

Table 5.3.1.2: Percentage Response on Concentration question

Partly Correct			Correct		Wrong
Response A	Response C		Response B		Response D
50	33		17		

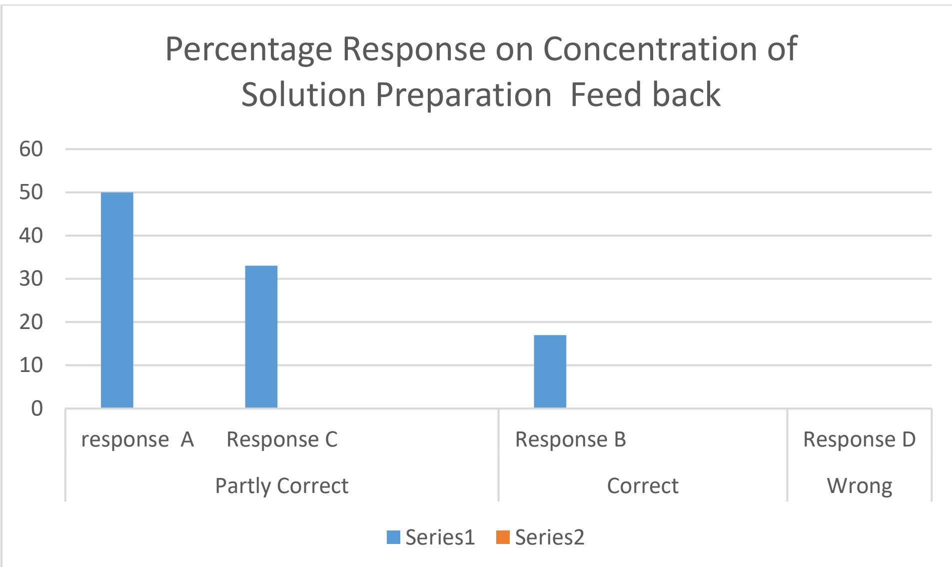


Figure 5.3.1.2: Teachers' responses on concentration question

From Table 5.3.1.2 above, five out of six teachers (83%) chose a partly correct answer which was wrong for the learners (see appendix M). Choosing wrong answers confuses learners more.

According to Savinainen and Scott (2002), learners' performance improves when the instructions are designed to deal with difficulties revealed in their prior knowledge. For learning to occur, however, learners should be able to connect the present with the past for effective understanding and internalisation of the concepts as emphasised by Vygotsky (1978). To Taber (2001), a null learning impediment[1] describes the situation where meaningful learning does not take place

[1] Null learning impediments – where the intended learning may not take place because the student is unable to make sense of the teaching in terms of existing ideas.

because the learner does not make a connection between the present material and existing knowledge. Based on such literature, the importance of prior knowledge cannot be overlooked and that is why this study engaged teachers with experience to interact with each other using a community of practice (CoP) to solve the stoichiometry problems (Lave & Wenger, 2001).

5.3.2 Teachers' responses on the questions about curricular salience

The questionnaires and interviews were used in this study to understand the participants' views about stoichiometry before the intervention (Appendix M). According to Brookhart and Durkin (2003) and Lai and Waltman (2008), questionnaires and interviews are often used together in mixed-method studies.

In the section of curricular saliency, different concepts of stoichiometry were listed. Teachers were allowed to make their own selection of concepts needed to be taught before the others. According to Mavhunga and Rollnick (2016), curriculum saliency refers to the learning of the various topics relative to the curriculum as a whole. It is the understanding of which topics are considered to be most central and peripheral. Such understanding enables teachers to judge the depth to which a topic should be covered and hence the amount of time to be spend on it. I now present the teachers' responses below. T1 highlighted that:

(1) Balanced chemical equations provide the combining ratios of reacting substances and their products in a chemical reaction.

Reasons: *Chemical equations need to be balanced in order to yield wanted results.*

(2) Molar Mass of an element or compound expresses the equivalent relationship between one mole of a substance and its mass in grams.

Reasons: *Learners need to know how to calculate number of moles in elements, molecules and compounds.*

(3) *Concentration is a property of a solution and relates to the number of solute particles per unit volume.*

Reasons: *Learners need to know and able to define the term concentration for their better understanding of what they are doing.*

In my view, the order which these concepts were arranged was a challenge. For instance, these are not in sequence, and there is no correlation or association between previous and latter concepts. It could be deduced then that there is need for an intervention to assist in sequential arrangement of stoichiometry concepts.

T2 could not answer this section on curricular saliency. My assumption is that it could be possible that he does not understand what curricular saliency all is about. It could also be linked to BouJaoude and Barakat's (2003) assertion that sequencing of concepts might be difficult for some Science teachers. It seems T2 might benefit from an intervention to improve the SMK and PCK of teachers' teaching of stoichiometry in the Zambezi region.

With regards to T3, his responses are listed below,

(1) *Balanced chemical equations provide the combining ratios of reacting substances and their products in a chemical reaction; and*

(2) *Reaction stoichiometry involves the determination of molar ratios of the number of reactants and products in a chemical reaction through balanced chemical equations.*

T3 was able to select only two concepts to be taught. He further gave the reason for the choices made. These selected concepts set the basis for the law of conservation of matter. One can construe from this method of answering questions that curricular saliency was a challenge for T3. The two components listed by the teacher involved only balancing of chemical equations. This is aligned to BouJaoude and Barakat's (2003) view that sequence of Chemistry subject matter is still debatable. For most of the concepts of Chemistry it is difficult to determine the sequence. In my view, sequencing of stoichiometry concepts is a challenge because the concepts are interwoven and coming up with proper stoichiometry sequential concepts may need an intervention. This challenge would surely affect the teaching and learning of stoichiometry concepts, and an intervention might make a difference in the teaching and learning of stoichiometry.

T4's selection and order of teaching the concepts are arranged below.

(1) The mole is the SI unit for amount of substance and allows us to connect the macroscopic scale of matter with the microscopic scale of matter and can used to help count elementary particles that make up substances.

(2) Volume is the amount of space occupied by a sample and from the volume of a gaseous substance the amount of substance can be determined.

(3) *Concentration is a property of a solution and relates to the number of solute particles per unit volume.*

T4 further explained to justify his choice of selections saying that, "*When teaching concentration, learners should have a better understanding of moles and volume, since concentration is how many moles are present in a given volume of solvent*".

From the above selection, it is evident that T4 is experienced. This is line with Bridges (2015) who says that teachers should be knowledgeable, creative, and resourceful in their subject areas to help their students learn stoichiometry. The concepts selected were in sequence which could enhance the teaching and learning stoichiometry effectively; other teachers could learn from him as well.

T5 is the youngest teacher having about six years teaching experience and the selected concepts about curricular saliency were arranged as follows.

(1) Calculations combine balanced chemical equations and the concept of the mole to calculate the masses of all reactants required and products formed in a chemical reaction.

(2) The actual yield of product formed depends on the reagent that limits the amount of the other reactant that reacts.

(3) Balanced chemical equations provide the combining ratios of reacting substances and their products in a chemical reaction.

In my view, this sequential order is not compatible, though all these concepts are in stoichiometry. Also, T5 gave no reasons for the choices he made. This is in contrast with Bridges (2015) who advocates for knowledgeable teachers to guide novices for effective teaching of stoichiometry. This supports the point on which this study is based, exploring an intervention within a CoP that might be needed to assist Physical Science teachers to share knowledge in the teaching of stoichiometry concepts.

T6 is an experienced teacher who has been teaching Physical Science for 10 years and his selected concepts are listed below.

(1) Molar Mass of an element or compound expresses the equivalent relationship between one mole of a substance and it's mass in grams.

(2) Balanced chemical equations provide the combining ratios of reacting substances and their products in a chemical reaction.

(3) Molar ratios can be used to determine the number of reactants used or the yield of product formed.

T6 further explained the reasons for the concepts selected as follows,

> *Learners should be able to obtain the masses from elements and compounds to understand masses. Learners should be in position of consistently simple formulas, balancing number of moles and able to determine the mole coefficient to understand the concept of mass per mole.*

This is aligned with Gabel and Bunce's (1994) claim that the didactic problem is no longer limited to the student's difficulties, and that its cause can rather be found in instruction, even though T6 is an experienced Science teacher. It is against this backdrop that my study sought to explore an intervention for Physical Science teachers and my assumption is that T6 might benefit from the intervention to strengthen the SMK and PCK needed in the teaching of stoichiometry.

5.3.3 Understanding what makes stoichiometry easy or difficult to understand

The section focused on selecting difficult stoichiometry concepts and each teacher gave reasons why they felt that the concepts were difficult to teach. (Appendix M). According to Furio et al. (2002), not understanding the concepts can make it difficult to teach. From my own view, the teaching of these concepts can be compromised by the teacher because of their not understanding which concepts need to be taught. Below are the responses of all the participating Physical Science teachers.

T1's views are listed below,

> ***Amount of substance/mole****: Not easy for learners to really understand the definition of mole.*
>
> ***Avogadro's number****: Difficult for learners to relate the Avogadro's number to the molecular mass of an atom or element.*
>
> ***Molar ratios****: Learners find it difficult to use the ratio from a balanced chemical equation*
>
> ***Stoichiometric calculations****: Most learners find it difficult to balance a chemical equation and use ratio.*

T2 selected only one concept – stoichiometry calculations – with reasons below.

> ***Stoichiometric calculations****: It is a challenge for learners to remember stoichiometry calculation formula*.

T3 selected Avogadro's number, giving the reason that *"It is difficult to make the learners accept that concept"*. With T4, Stoichiometric calculations was selected, and the reasons were that *"learners cannot write formulae and construct chemical equations"*.

The second option for T4 was *"**Limiting reagent**: It is difficult to measure practically the amount that is used up in a chemical reaction and to determine the products*".

T5 could not choose any concept as easy or difficult to teach. One can infer that the stoichiometry concepts generally might be a challenge to T5, hence assistance on the concepts might benefit him. Put differently, the intervention might help and that is the focus of this study.

T6's choice of concepts that are difficult or easy to teach and the reasons are as follows:

> ***Avogadro's number****: A figure is not practically done.*
>
> ***Stoichiometric calculations****: Complicated formula and terms.*
>
> ***Limiting reagent****: Cannot establish how a fact can be limiting.*
>
> ***Theoretical yield and actual yield****: Learners find it difficult to use actual figure.*

In my own view regarding the opinions of the participating teachers about what makes a topic easy or difficult to understand, it seems that Mathematics is a challenge in the teaching of stoichiometry. In my view, what emanated from the participating teachers' responses supplements the difficulties in stoichiometric calculations, where Mathematics is needed. This concurs with Wulf and Shea's (2002) findings on the basic Mathematics skills such as scientific notation and working with exponents that are needed in learning stoichiometry. This might reduce the cognitive load and allow one to focus on solving the problem, if students can be engaged with Mathematics intervention prior to stoichiometry teaching. This might help stimulate the learners' prior knowledge when they are being taught stoichiometry.

5.3.4 Teachers' responses on representations

Representations include thinking through the important ideas to be presented in a lesson and determining different ways of representing the ideas to learners (Shulman, 1987); (Appendix M).

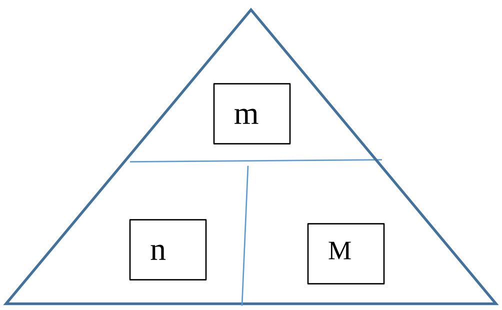
These representations may contain analogies, examples, similes, elucidations and demos that the teachers can draw on that can be used to help make content clear to learners (Shulman, 1987).

Gess-Newsome (2013) posits that teachers with SMK and PCK are able to use a wide variety of content representations to make the necessary links between the teachers' understanding of the topic and the ideas being constructed by learners. Choice involves the selection of appropriate instructional strategies and methods for teaching from a repertoire of strategies that include modes of teaching, organisation, managing and arranging the learning environment (Shulman, 1987). During selection, teachers who possess the necessary TSPCK are able to develop meaningful and engaging activities, practices and discussions and are not restricted to learning activities with strict procedural methods (Loughran et al., 2012). On the contrary, teachers without the necessary TSPCK may not be able to use effective analogies and often use analogies and examples that are less accurate and less relevant when compared to teachers with good TSPCK (Rollnick et al., 2008). In addition, Duit and Treagust (2003) also highlight that analogies can create misconceptions if not effectively handled. Below is an excerpt from the questionnaire about representations for teaching the relationship between mass, moles and number of elementary particles.

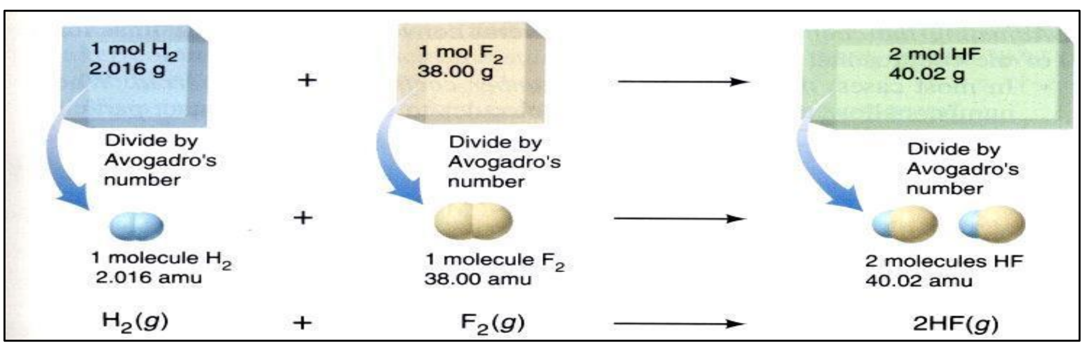
Representation 1

Items	Kind of Set	Number in Set
Socks, dice, eggs	Pair	2
Oranges bottles	Dozen	12
Cans, brushes	Case	24
Pencils	Gross	144
Sheet of paper	Ream	500
Atoms, Molecules	Mole	$6{,}02 \times 10^{23}$

Representation 2



Representation 3



5.2. Which representation do you like most?

5.3 How would you use the representation that you like most in a lesson?

Figure 5.3.4.1: An excerpt from achievement stoichiometry diagnostic test

From the questionnaires, the responses of all the teachers focused on Representation 3 and below were the views of teachers accordingly.

T1 said, "*It shows and tells learners about the law of conservation of mass. It teaches learners about when A + B $\longrightarrow$ C + D, in other words in a reaction there are reactants and products*".

T2 said he would "*show it to the learners for them to visualise the concepts and foster understanding of the mole concepts*".

T3 said he will "*tell the learners to write the balanced equations and work out the mole ratios, and then do the calculations on the reacting quantities and products*".

T4 an experienced teacher, explained in point form, how he would use representations in his teaching;

> *Step 1: Learners learn how to write formulae from the symbols of elements on the periodic table.*
>
> *Step 2: Learners then learn how to balance chemical equations.*
>
> *Step 3: Learners should then read the mole ratios from coefficient of both reactants and products.*
>
> *Step 4: Learners use the periodic table to write/calculate the relative molecular or formula mass.*
>
> *Step 5: The mole ratio also allows the learners to reduce the number of molecules present in both the reactants and products*
>
> *Step 6: Learners then multiply the number of moles times the Avogadro's number to get the number of particles or molecules present.*

T5's focus was on the chemical reaction of two reactants that give rise to one product and explaining the word equation and symbol equation with representations. He would help learners do calculation of mass for the reactants and products in terms of molar mass, as seen below.

> *Explain to learners what makes up a one mole (Avogadro's number) as well as the relationship of the number of moles to balancing chemical equations.*
>
> *i.e.* $H_{2\,(g)} + F_2 \longrightarrow 2HF_{(g)}$

1 molecule + 1 Molecule $\longrightarrow$ *2 molecules*

1 mol H_2 *+ 1 Mol* F_2 $\longrightarrow$ *2 mols HF*

.2.016g $H_{2\,(g)}$ *+ 38g* F_2 $\longrightarrow$ *40.02g* $HF_{(g)}$

T6 could not complete the section for representation and the response was that the questions asked seemed to be of university standard.

From the views of most teachers, responses from T1, T2, T3, T4 and T5 did not support the usage of representations. This is contradictory to Gess-Newsome's (2013) view that teachers with SMK and PCK of the concepts can develop and use a variety of representations to teach stoichiometry. T6 could not answer this question. This suggests that teachers who cannot develop representations in a coherent manner need intervention to improve the SMK and PCK which is the focus of this study.

According to BouJaoude and Barakat, (2003), teaching strategies that focus on representation learning, results in learners being able to build complete descriptions of content or reorganise new content by relating it to their prior knowledge. However, many studies have focused on how learners solve stoichiometric problems (Schmidt & Jignéus, 2003; Tóth & Sebestyén, 2009). Most of these studies highlight that learners tend to utilise representation approaches in solving stoichiometry problems. It has been found, however, that learners can solve problems relating to stoichiometry by using representation approaches without the necessary conceptual understanding (Agung & Schwartz, 2007; Dahsah & Coll, 2007).

Developing conceptual understanding is essential since other concepts might interfere with future learning making it easy for learners to form links between science concepts (Canpolat, Pinarbaşi, Bayrakçeken, & Geban, 2006). Furthermore, competence in representation problem-solving has been found to be independent of ability in conceptual questions (Gauchon & Méheut, 2007; Stamovlasis et al., 2004, 2005). In my view, teachers need to engage conceptual teaching strategies coupled with representation in their teaching activities.

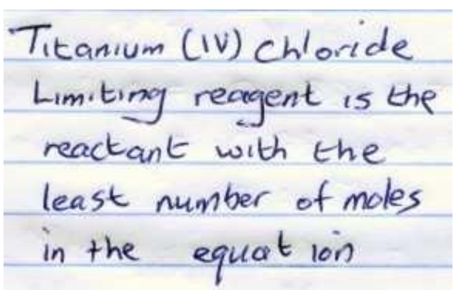
5.3.5 Teachers' responses on conceptual teaching strategies

The previous section outlined an alternative conception that impacts on learners' ability to solve stoichiometric problems, which is the use of representation or models to teach the concepts. This section now focuses on conceptual teaching strategies (Appendix M).

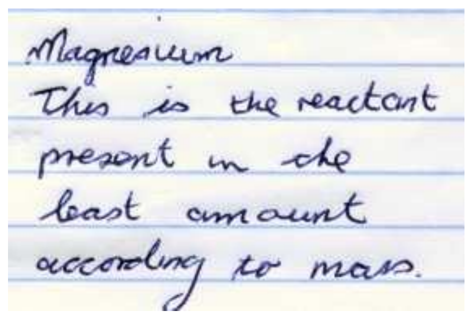
Learners were given the following question in the mid-year examination.

> About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:
>
> $$TiC\ell_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgC\ell_2(\ell)$$
>
> In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.
>
> Source: Department of Education (2007). Grade 11 Chemistry Paper, November Examination

The learners were asked to determine the limiting reagent of the reaction, giving reasons for their answers. The learners provided the following answers.



Extract 1



Extract 2

Explain how you would assist these learners to move towards the correct answer, explaining what their errors are and highlighting the strategy you will use.

(1) Explain why you think your strategy will work.

(2) Indicate what you consider as important in your strategy.

Figure 5.3.5.1: Excerpt from stoichiometry topic specific pedagogical content knowledge tool

The teachers' views are explained below on how conceptual strategies can influence the teaching of the concepts.

T1 only explained how he would guide the learners: "*Firstly, by changing the mass of the reactants and products into moles. Secondly, by using the ratios of the balanced chemical equations to calculate its number of moles which is unknown*". The answers provided were not fully aligned to the corresponding question.

In case of T2, he was unable to answer the question, and this spoke volumes about the SMK of the teacher on the question of stoichiometry. T2, further explained that personally the questions were not clear. This shows that an intervention might be appropriate for T2 so that both SMK and PCK may be enhanced via CPD, which the study was focusing on using participation action research within a CoP.

T3 explained that he would "*look at the balanced equations and use the mole ratio to calculate the number of moles in each of the reacting reagents. The reagents with the least number of moles is the limiting reagent*".

T4 started by explaining the procedures of how to determine limiting reagents:

(1) Write the balanced chemical equation for the chemical reaction.
(2) Calculate the available moles of each reactant in the chemical reaction.
(3) Use the balanced chemical equation to determine the mole ratio of the reactants in the chemical reaction.
(4) Compare the available moles of each reactant to the moles required for complete reaction using the mole ratio.
(5) The limiting reagent is the reactant that will be completely used up during the chemical reaction

In contrast to other teachers, T4 gave a more detailed explanation on how to guide the learners on how to calculate limiting reagent.

Similar to T6, T5 was unable to answer this question on limiting reagents.

From the six teachers only three teachers (50%) were able to answer or respond to conceptual teaching strategies. Therefore, a lack of conceptual understanding in stoichiometry by the learners might impede the understanding of more advanced topics such as percentage yield in stoichiometry of reactions and chemical equilibrium (Canpolat et al., 2006; Okanlawon, 2010). Teaching strategies should therefore focus on conceptual change as one of the components of the transformation of content knowledge. The conceptual change approach starts on the premise that learners hold deeply rooted conceptions that are consistent with science views (Duit & Treagust, 2003).

A large body of research exists regarding conceptual change and Mackay and Hobden (2012) outline four teaching strategies that can facilitate conceptual change, namely, cognitive conflict, conceptual ecology, conceptual progression and conceptual appreciation. Cognitive conflict is the discomfort one feels when one's beliefs, values or behaviours contradict one another. The conceptual ecology provides a context for understanding individuals' conceptual change learning, as it is the environment through which all information is interpreted. Conceptual progression refers to the purposeful sequencing of teaching and learning expectations across multiple developmental stages. Lastly, conceptual appreciation might be aligned to appreciation obtained after adequate concepts have been used. These four strategies when properly engaged in teaching might achieve effective learning through conceptual change (Mackay & Hobden, 2012).

According to Dahsah and Coll (2007), the main aim of teaching stoichiometry should be to develop learners' conceptual understanding of underlying concepts in order to solve numerical problems. An important aim of science instruction should also be to develop interest in Science (Hasson, 2016). Such affective factors play an important role in conceptual change (Duit & Treagust, 2003), which possibly is not happening in the teaching of stoichiometry if learners find the topic uninteresting (Fach et al., 2007).

In my view, to encourage conceptual understanding is to present content in a context from which learners can derive meaning and the significance of chemistry in everyday situations, environmental issues and industrial processes (BouJaoude & Barakat, 2003). For example, stoichiometry could be taught within the context of practicals. This attests to the need for an intervention to assist teachers to improve their SMK and PCK. The intervention might enhance the development of the teachers in effective teaching of stoichiometry. Hasson (2016) also supports the idea of scaffolding teachers (intervention) in the mathematical component of stoichiometry, but scaffolding can go beyond Mathematics to other concepts of stoichiometry. This can be extended to conceptual teaching strategies for effective understanding of stoichiometry teaching. These research findings seem to support the use of conceptual strategies for the effective teaching of stoichiometry concepts. The questionnaire was followed by interviews conducted with three teachers as per my supervisor's advice that only three teachers should be interviewed due to the large amount of data. All three teachers taught Grade 11.

5.4 Teachers' Responses to Interview Questions

Three teachers teaching Physical Science were interviewed before the intervention, focusing on how teachers mediate the learning of stoichiometry. I was directed by Vygotsky's (1978) socio-cultural perspective to understand how teachers expressed their views, experiences and input. The responses from these teachers were colour-coded resulting in the development of sub-themes and themes. Five themes were thus subsequently derived from the interview data, presented in Table 5.4.1 below.

Table 5.4.1: Emerged themes from interviews linked to theory (literature and conceptual/theoretical)

Research Question 1: What is the understanding of teaching stoichiometry by Grade 11 Physical Science teachers prior to an intervention?		
Themes	**Theory**	
	Literature	**Conceptual/Theoretical**
Building on what learners already know	Kurlaender & Howell, 2012; Okanlawon, 2012; Ambrose et al., 2010; Kuhlane, 2011; Graven & Schafer, 2013.	Learning theory constructivism (Vygotsky, 1978).
Lack of understanding of concepts	Mazur, 1996.	Learning as a social process from society (Vygotsky, 1978). Contextualised teaching and learning helps learners to see the relevance of science concepts (Mukwambo, 2016).
Learning and teaching support materials and practical for effective teaching	Shulman, 1986; World Bank, 2008; Fleisch, Taylor, Herholdt, & Sapire, 2011.	Provision of continuing professional development in Natural Science (Frick & Kapp, 2006).
Periodical sequential teaching procedure building on acquired knowledge	Mavhunga et al., 2016; Geddis & Wood, 1997.	Provision for periodical sequential teaching procedures.
Successful intervention to mediate learning	(Geddis et al., 1993; McMurry & Fay, 2008.	Interventions within professional development practices are needed (Eun, 2008).

Five themes were generated. These themes were then related to the literature reviewed and the theory which was used as an analytical lens. These are discussed below.

5.4.1 Discussion of themes from interviews

I now discuss each of these themes below.

Theme 1: Building on what learners already know

Research in educational psychology demonstrates that learners' prior knowledge can directly impact their learning in class. For example, learners who have more extensive K-12 academic preparation tend to have greater academic success in college (Kurlaender & Howell, 2012).

During the interviews, teachers were asked to share their understanding of the concept 'prior knowledge'. Their responses showed that they had slightly different views. For instance, T3 explained that the use of prior knowledge enhances effective teaching. This agrees with Lee and Rivas's (2007) view, that for effective teaching to occur, teachers need to be enthusiastic, knowledgeable in his/her subject specialty, and have effective pedagogical skills to provoke learners' prior knowledge.

T4 expressed the following view on prior knowledge, *"I will group learners and introduce the concept to them and tell them to go and research and later build on what they will bring".* T4 teaches after learners have done the homework or assignment given to them pertaining to the concept to be taught or discussed. He uses the prior knowledge when teaching to strengthen the teaching strategies for effective teaching delivery. This concurs with Hestenes, Wells and Swackhammer's (1992) research of college Science classes, whose findings supported that the prior knowledge of learners determined to a large extent what each individual could learn from a particular situation. It is not productive simply to try and pour facts into students' brains. Each student must assimilate and make sense of new ideas by connecting them to what they already know (Hestenes et al., 1992).

T6's views about prior knowledge was similar, where he suggested that that new concepts came after the foundation had been built:

> *I use prior knowledge during teaching activity. After prior knowledge has been used in the class, then a new concept can be taught.*

T6's view resonates with Stears, Malcolm and Kowlas's (2003, p. 109) assertion that, "linking learner's science learning to every day knowledge is broadly advocated in science education to give learners the science they can use in their everyday lives and build on their experiences, interests and prior knowledge". These research findings seem to suggest that prior knowledge has the potential to promote effective teaching of science concepts.

Theme 2: Lack of understanding of concepts

Teachers view about lack of understanding of concepts are explained below.

T3 explained that,

> *Some leaners may not grab the concept very easily, and I get frustrated when I don't see the desired results from the learners. I sometimes need to push learners by giving them activities and extra classes in the afternoon. They continue having problems with stoichiometry and the depth of stoichiometry is not taught in most schools.*

In my view, T3 came up with a problem-solving strategy when he said, "*Sometimes I need to push learners by giving them activities and extra classes in the afternoon*".

T4's experience on the component 'what is easy or difficult to understand' is quoted below,

> *Chemical equations and mastering formula are very difficult to understand, and the stoichiometry is abstract in nature. Learners find balancing of equations to be a challenge and once the formula is not written correctly, they seem to struggle with the balancing and this discourages them from paying attention or learning stoichiometry.*

T4's view concurs with Fach, de Boer and Parchmann's (2007) ideas about difficult stoichiometry concepts that support developing problem-solving models and instructional strategies to enhance students' success. In my view, it is for this reason that Okanlawon (2010) posits that if pedagogical content knowledge can be properly infused and weaved into lesson instruction, students might be able to gain a deeper understanding of the content they are learning, resulting in meaningful and transferable knowledge.

In view of the above T6 said that,

> *After I have taught and given learners work to do, they still don't perform well, and I find that frustrating. I give learners all the resources I have, show them strategies and yet performance will still be unsatisfactory which is discouraging. Learners don't seem to understand whatever they are taught and that makes me teach and explain slowly, right from writing formulas.*

Regarding T6's concern, Okanlawon (2010) posits that weaving in appropriate strategies into the lesson instruction might improve the teaching of these concepts. T6 has developed this unknowingly by teaching and explaining slowly, starting from the writing of formulas. This research finding appears to focus on problem-solving strategies, helping to make difficult concepts easier to understand.

Theme 3: Learning and teaching support materials and practicals for effective teaching

The teachers involved in this study shared their opinions regarding LTSMs and practicals for effective teaching (representations). It seemed that their past educational experiences about the teaching of stoichiometry might have influenced their current instructional teaching on representations. Representations refer to the forms of LTSMs that can be used as analogies, illustrations, examples, explanations, simulations and demonstrations (Shulman, 1986). For instance, T3 highlighted that: "*Using of worksheets or tests or do some written exercise to help those that are still lagging behind with the concept that is being taught"*.

Looking at T3's current situation, one can infer that his own representations focused on tests and worksheets as problem-solving strategies to assist lagging learners in the classroom. This corroborates with Fleisch et al. (2011) and World Bank (2008), that representation supports the interaction between teachers and learners, with the aim of improving learner performance.

T4's view on representation is highlighted below:

> *The use of the practical approach – I strengthen that – in all my teaching I use a practical approach, and wherever possible I need to demonstrate. All my works were more of hands-on experiments, practicals and the results facilitate learning.*

The finding from this study in my view, is that representation, models and LTSMs enhance teaching and learning of concepts being taught, which concurs with Bušljeta (2013).

T6, had his own view about representation when he said that,

> *I like to prove things. Whatever I do I really want to prove because it is based on reality. Stoichiometry should be taught in a standard laboratory and demonstrated … carry out experiments where possible.*

According to T6, if stoichiometry could be taught in a standard laboratory where practicals can be carried out to enhance learning and teaching, then learners would improve in the learning of stoichiometry concepts. There is a concern here now about the teaching of stoichiometry in schools where there are no standard laboratories as is the case in the Zambezi region. I am of the opinion that without standard laboratories, the teaching of stoichiometry can still be done once teachers are encouraged to develop and improvise relevant representations to enhance their teaching. This relates to Bušljeta's (2013) view that the role of teaching and learning resources do not only consist of making the educational process more attractive and interesting, but also of encouraging active learning.

Theme 4: Periodical sequential teaching procedure building on acquired knowledge

The teachers involved in this study shared their feelings regarding curricular salience – the sequential teaching procedure of concepts. T3 for instance, highlighted his view of curricular salience when teaching stoichiometry and said:

> *That manipulation of terms involving measuring the moles concept, which is the theoretical concept of the substances, was very amazing. Learners should understand the periodic table, how to balance chemical equations, and they need to know the balancing factors of chemical equations.*

T3 further explained that he made the learners master the periodic table and that is why they need to know the mass of elements and how to write formulas. T3's statement resonates with Mavhunga and Rollnick's (2016) assertion that 16 pre-service teachers were able to apply the approach taught to them for chemical equilibrium following curricular salience and displayed newly developed PCK in the topic taught.

Likewise, T4's view about curricular salience, follows Mavhunga and Rollnick's (2016) model, when teaching symbols and formula writing,

> *Start by introducing or revising the periodic table, and then go to symbols and formula writing, then teach the learners exchange of valences or charges, then go to balancing of equations.*

T6 explained how he applied curricular salience when teaching valence by saying, *"I start with the valence from the periodic table on how to get valence and then write formulas".*

T6 further said that learners struggled with writing formulas and that made it difficult for them to balance equations. Further, he stated that if this part of formula writing was not very clear in stoichiometry, learners would face problems in all other calculations associated with stoichiometry. From my own point of view, T6 follows Mavhunga and Rollnick (2016), but he aided students to achieve the desired objectives, in order to enhance the teaching and learning of valence in stoichiometry.

Teachers' understanding of what is important to teach or necessary for learners to know at a point in time describes their knowledge of the TSPCK component 'curricular saliency' (Mavhunga et al., 2016). According to Geddis and Wood (1997), curricular saliency refers to the teacher's understanding of the place of a topic in the curriculum and the purposes of teaching it. Curricular saliency is considered to influence the teachers' decisions to leave out certain aspects of a topic.

What can be inferred from this finding is that teachers value the curricular salience as a concept; when adequately engaged it might improve their teaching and learning of concepts being taught.

Theme 5: Successful intervention to mediate learning

The strategy used should be able to help the teachers in focusing more on the development of conceptual knowledge, that is, content knowledge or the ideas of the topic which should be known, rather than on the development of procedural knowledge which is merely knowing how something is done (Geddis et al., 1993). The views of teachers about conceptual teaching strategies are explained as follows. T3 lamented that, *I have interest in chemistry, playing around with figures and symbols. For me, the percentage of substances and components of particular elements in certain substances are great and interesting. I taught the stoichiometry concepts and mastered all the tricks. I engage and assist learners with stoichiometry activities and see how they perceive the stoichiometry concepts.*

T3's view in my own opinion seems to be out of track with the concept at hand. This resonates with Okanlawon's (2010, p. 27) view, "that even when students complete a chemistry-degree programme and the pedagogical course requirements necessary for teacher professionalism they may still be found wanting as they begin teaching without a firm grasp of how to teach specific chemistry concepts".

T4's view about conceptual teaching strategies focused on the teaching of atoms, elements and compound; below is the quote from T4:

Learners did not understand anything about the stoichiometry concepts. The background knowledge on atoms, elements, and compounds is necessary and as much as possible, learners must understand these. Learners have difficulties in conceptualising the notions attached to stoichiometry.

T6's opinion about conceptual teaching strategies is explained below.

For an equation to balance the number of atoms of the elements on the reactants should be the same as the product. I use the basic method of drawing a line and then checking to see if the number of atoms on the left are same as the number of atoms on the right.

From this excerpt, it seems T6's view is in line with McMurry and Fay's (2008) ideas on how to use a table to tally the number of atoms of each element on the left-hand side of the equation and the right-hand side of the equation.

In my view, while all three teachers appreciated the conceptual teaching strategies, their implementation seemed to be a challenge, and this warrants the need for CPD. This finding also corroborates with Okanlawon's (2010) assertion that to teach stoichiometry a teacher must command not only a firm understanding of stoichiometry, but also sound knowledge of effective pedagogical practices relative to stoichiometry and the intentions and abilities to fuse these two elements in the classroom. In conclusion, fusing the stoichiometry knowledge and effective pedagogical practice needs an intervention which this study targets, to enhance the effective teaching of stoichiometry.

5.5 Concluding Remarks

In this chapter, I presented, analysed and discussed data from document analysis (focusing on the learners' achievement test results), questionnaires and semi-structured interviews. In the next chapter, I present, analyse and discuss data from the workshop discussions.

CHAPTER SIX: WORKSHOP INTERVENTION PRACTICE FOR CONTINUOUS PROFESSIONAL DEVELOPMENT: DATA ANALYSIS AND FINDINGS

> *Professional development consists of all natural learning experiences and those conscious and planned activities which are intended to be of direct or indirect benefit to the individual, group or school, which contribute, through these, to the quality of education in the classroom. It is the process by which, alone and with others, teachers review, renew and extend their commitment as change agents to the moral purpose of teaching; and by which they acquire and develop critically the knowledge, skills and emotional intelligence essential to good professional thinking, planning and practice with children, young people and colleagues throughout each phase of their teaching lives.* (Day, 1999, p. 4)

6.1 Introduction

In the previous chapter, I presented, analysed and discussed findings from the document analysis (learners' diagnostic test), questionnaires and interviews. The focus of this chapter is on the workshop intervention practices for professional development for the Physical Science teachers involved in this study. As indicated in the epigraph, professional development consists of all natural learning experiences and those conscious and planned activities which are intended to be of direct or indirect benefit to the individual, group or school, which contribute, through these, to the quality of teaching and learning in the classroom. This chapter further explores how the Physical Science teachers developed and constructed new knowledge about stoichiometry for effective classroom teaching.

In this chapter, I thus present, analyse and discuss data generated from all the intervention workshops. The aim of the workshops was to generate data about how teachers mediate the learning of stoichiometry, to understand and improve the teachers' SMK and PCK in relation to teaching and learning of stoichiometry. As described in Section 4.3.1, my research participants and I carried out intervention workshops in the form of collaborative workshops which took place over a period of eight weeks. The intervention workshops were carried out at the schools of participating science teachers on a rotational basis. That is, moving from one school to the other to enhance collaboration and teamwork. The data generated from workshops were aimed at answering my research question 2:

How does an <u>*intervention*</u> *in the form of workshops support Grade 11 Physical Science teachers in developing exemplary lessons for teaching stoichiometry?*

During the workshops, teachers requested for reflections to be done immediately after each activity. This was needed because according to these teachers it would help them recall and contribute to the discussions as a result of the freshness of the topic in their minds.

6.2 Stoichiometry First Intervention Workshop

It became evident that the goal of the workshops would be to co-develop exemplary lessons, worksheets, as well as learning and LTSMs with the aim of improving the teaching and learning of stoichiometry. We also recognised that improvement could only be achieved by active participation (Sedláček & Sedova, 2017) and commitment of all the Physical Science teachers within the CoP. In the Zambezi region where the research was conducted, 14 Physical Science teachers completed the questionnaires, but on my supervisor's advice only six Physical Science teachers I worked with participated in the workshops.

The first workshop was about document analysis (textbooks, scheme of work, stoichiometry curriculum, Examiners' Reports and NSSC (H)/(O) past examination question papers). All six Physical Science teachers attended the workshop and they were fully involved. This seemed to be an opportunity for the Physical Science teachers to engage themselves in professional development (Eun, 2008). During the workshop, the Physical Science teachers were able to identify which of the Physical Science textbooks would be more appropriate for the teaching of stoichiometry. Below, in Table 6.2.1, is the list of textbooks, analysed and accepted or rejected by the teachers for the teaching of stoichiometry.

Table 6.2.1: Shows identified stoichiometry textbooks

	Name of the book	**Stoichiometry textbook page number**	**Reasons for accepting or rejecting**	**Publisher**
1	Certificate Physical Science for senior secondary	Pages 221-244.	Stoichiometry worked activities, but it did not cover all the stoichiometry concepts. **Rejected.**	Longman
2	Complete Chemistry	Pages 62-75	Stoichiometry worked activities and practice samples. Covers all the stoichiometry concepts. Accepted**.**	Oxford
3	Chemistry counts	Pages 56-64	Too shallow in worked activities. Does not cover all the stoichiometry concepts. **Rejected.**	Hodder & Stoughton
4	Macmillan Physical Science for Southern Africa.	Pages 340-356	With a lot of representations on stoichiometry, worked and practices sample activities. Covers all the stoichiometry concepts. **Accepted.**	Macmillan
5	Thinking Chemistry	Pages 231-266	Excellent. Stoichiometry worked and practice samples. Covers all the stoichiometry concepts. **Accepted**. Recommended for reference also.	Oxford.
6	Chemistry for GCSE	Pages 217-227	Excellent. Stoichiometry worked and practice samples. Covers all the stoichiometry concepts. **Accepted**.	Heinemann Educational Books

The teachers were given an opportunity to share their experiences about the type of textbooks they were using in their schools. To this end, T3, T6 and T4 from the most well-performing schools in the region supported their choice of textbooks with evidence as to why their schools were doing well. T1 said that this information was supposed to be shared a long time ago with all Physical Science teachers. Her comment was backed up by others (T2 and T5).

At the same workshop, the teachers were able to go through the scheme of work, stoichiometry curriculum, examiners' reports and Physical Science examination question papers focusing on stoichiometry in particular. From the examiners' reports and examination papers, some difficult stoichiometry concepts were identified such as calculating the amount of moles, limiting reagents, percentage yield and Avogadro's constant. These were similar to Furio et al.'s (2002) findings in the study of difficulties in teaching the concepts of 'amount of substance' and 'mole'. For instance, Furio et al.'s (2002, p. 1301) findings revealed that "the way the 'mole' concept is introduced in the syllabuses of normal teaching reveals epistemological deficiencies that could be one of the main causes of the little meaningful learning achieved by the students".

The identified difficult stoichiometry concepts concurred with the results of the diagnostic achievement test questions answered by the learners (see Section 5.1). The problematic stoichiometry concepts identified by the teachers from the examiners' reports, as well as the NSSC (H)/(O) past examination question papers on stoichiometry, were in agreement with the findings of Chandrasegaran, Treagust, Waldrip and Chandrasegaran's (2009) study. The difficult stoichiometry problems were harmonised with some other researchers who came up with ideas about the stoichiometry concept difficulties and these are stated below.

- Limiting and excess reagent (Gauchon & Méheut, 2007);
- Calculations of moles (BouJaoude, & Barakat, 2003; Chandrasegaran et al., 2009);
- Concentration formula to calculate moles in solution (BouJaoude & Barakat, 2000);
- Ratio calculation of moles in stoichiometry (Dahsah & Coll, 2008);
- Empirical and molecular formula calculations (BouJaoude & Barakat, 2000);
- Percentage composition (Gilbert, 1998);
- Balancing of equations (Tóth & Kiss, 2005); and
- Actual yield and theoretical yield (Hanson, 2016).

The question about limiting and excess reagent was raised by T5 who felt that this concept is a challenge. The limiting reagent was thus the first concept among the difficult concepts identified by the teachers (Gauchon & Méheut, 2007). As per the teachers' requests, and being a co-learner with these colleagues, I contributed to avoid the issue of positionality (see Section 4.10). I subsequently tried to explain the limiting reagent experiments with local materials using an analogy for conceptual understanding of the terms *limiting* and *excess* concepts in stoichiometry (Chandrasegaran et al., 2009). Below is the analogy of limiting and excess reagent experiment procedures carried out with the teachers about stoichiometry during the workshop.

6.2.1 Procedures of the experiment

Experiment: Limiting and excess reagent experiment.

Materials: Candles, beakers, matches, flat table or flat object, air.

Step 1: Two burning candles were set up and lit as seen in Figure 6.2.1.1, having enough supply of wax and air (oxygen).

Step 2: One of the two burning candles was covered with a beaker (Figure 6.2.1.2). Air access controlled.

Observations: The burning candle covered with the beaker went off. Why?

Figure 6.2.1.1: Both candles where burning, having supply of air and fuel (nothing was limiting the combustion)

Figure 6.2.1.2: One of the burning candles was covered with a beaker, limiting the access of air to the burning candle

Conclusion: There is limited supply of air to the burning candle and as a result it went out**.**

One of the teachers (T4) was able to construct the meaning of limiting and excess reagents (Vygotsky, 1987). For instance, he commented that the limiting reagent is the substance that finishes first when carrying out experiments. Air limits the amount of products produced. In the case of the burning candle, air (oxygen) reacts with the wax in the candle to produce light and heat (see Figure 6.2.1.1)

In Figure 6.2.1.2, where one of the burning candles was covered by a beaker, it limited the air's (oxygen) access to the wax in the burning candle and as a result it went out. The other candle continued burning because nothing limited the supply of air. The first workshop came to an end with this limiting analogue experiment. T4 raised a point about a misconception with the analogy in the teaching of the concept. T4 claims that an analogue experiment should be followed immediately or at the next lesson with a real practical example, because the learners might not be able to comprehend if time overlaps. T4's views agree with Duit and Treagust's (2003) assertions that analogies can create misconceptions if not properly handled. The analogue experiment was meant to motivate teachers to come up with practicals or analogies for all their selected stoichiometry concepts during the second workshop.

At the end of the first workshop, all six Physical Science teachers agreed to choose a concept each and prepare lessons based on the concepts, which would be shared in the next workshop. I also chose one concept (balancing of equations) to work on and share the lesson in the next workshop.

6.2.2 Reflections and Impressions of our First Workshop

My reflections and impressions of our first workshop was that the Physical Science teachers were fully involved, and they were willing to collaborate and work as a team (Lave & Wenger, 1991; Wenger, 1998). Also, what seemed to inspire the CoP members during the 1st workshop was the analogue experiment that was carried out about the limiting reagent and excess reagent.

For instance, T6 reflected that analogies might assist in the teaching of this concept to learners, commenting about getting real apparatus for examinations a day before learners were to write the Physical Science examination. That is how learners might practice and master the skills needed before writing the examination which is important. T5 made a remark that a lack of practical skills influences the learning of any concept being taught. T5 compared apparatus in their School C with School A where the workshop was being conducted and resolved that a lack of teaching materials might have been the basis of their school's poor performance. Additionally, T5 supported the use of analogies and asked for an analogy for teaching reversible reactions. In response, T4 gave an analogy which I did not think about, stating that standing at the door of a supermarket and watching the movement of people going in and out can be used to teach the reversible reaction concept.

T4's action agreed with the trans-personal knowing process of *thinking together* – Polanyi (1962) argues that without thinking together a CoP cannot exist. Thinking together is conceptually based on the idea of *indwelling*: when peoples' indwelling is interlocked on the same cue, they can guide each other through their understanding of a mutually recognised real-life problem, and in this way they indirectly 'share' tacit knowledge. This suggested that some teachers involved in this study felt free to share their knowledge.

At the end of the workshop the CoP members felt good about analogies – that their use might enhance teaching. The coordinator, one of the CoP members reminded the other colleagues that would be sharing in the second workshop to prepare for the second intervention workshop – only two teachers were able to share their lessons.

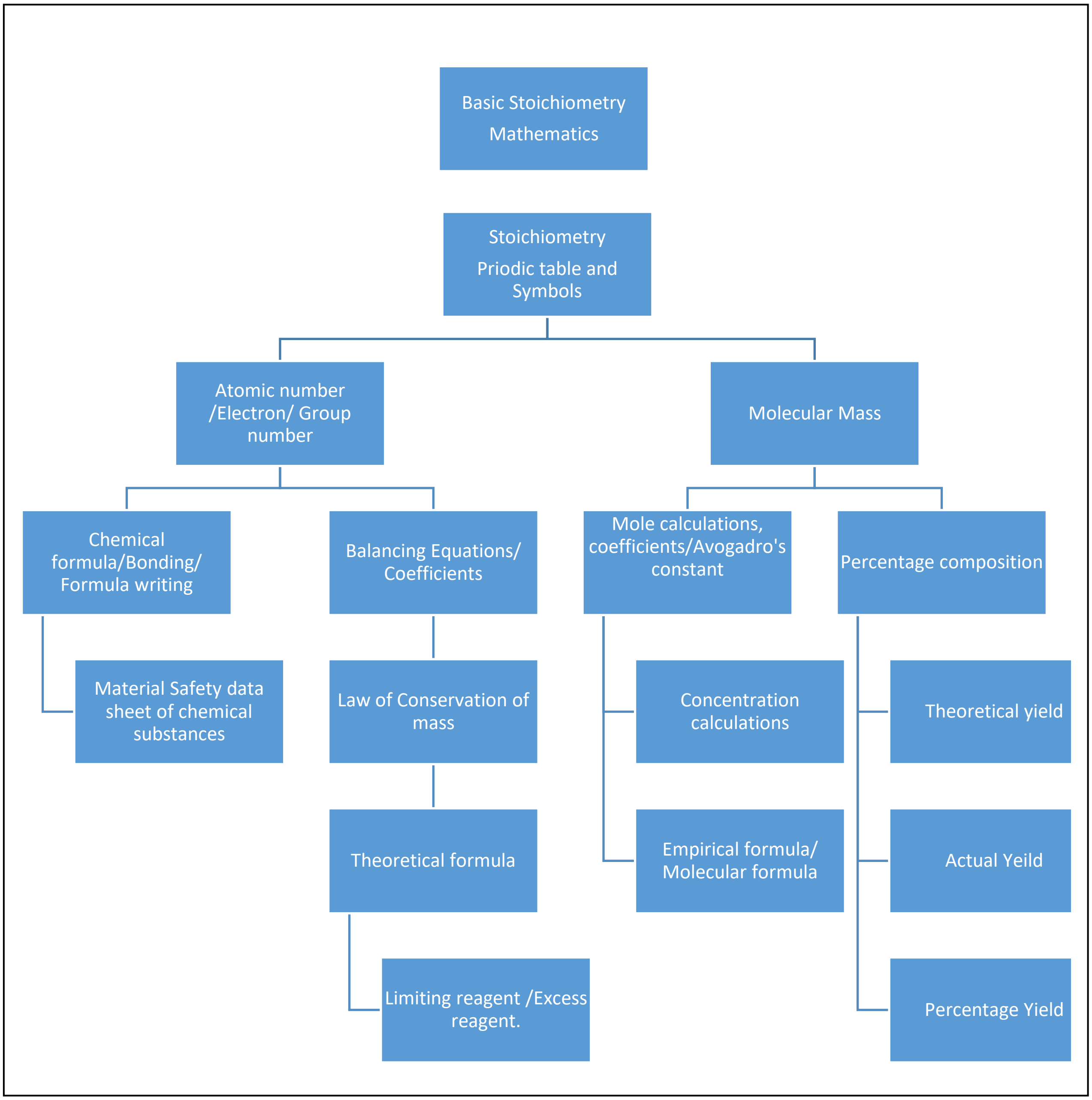
6.3 Stoichiometry Second Intervention Workshop

During the second workshop, only two out of the six Physical Science teachers could not attend this workshop. One of the Physical Science teachers received a promotional post and moved to another school, while the other teacher's contract was sadly not renewed. Apologies were sent by the teachers, and the information was also disseminated to the CoP members by their partner teachers. Nonetheless, the two Physical Science teachers who had left our team were replaced by new Physical Science teachers who needed to be orientated before the commencement of the workshop so that they were not left behind. After a short orientation the two new teachers joined the members of the CoP for the stoichiometry workshop intervention. All four Physical Science teachers prepared lesson plans and worksheets on the stoichiometry concepts given (mapping, basic Mathematics, moles and percentage yield) and they were ready to share their experiences in the teaching of the stoichiometry concepts.

T3 discussed the concept, mapping of stoichiometry and basic Mathematics. T3 started by saying stoichiometry mapping was a tentative scheme of work for the teaching of stoichiometry specifically. When T3 started, the other teachers came up with contributions before arriving at the final stoichiometry mapping in Box 6.4.1.

Mapping relates to curricular saliency, one of the tenets of TSPCK components (Mavhunga & Rollnick, 2013); stoichiometry mapping shows which concept comes before the other for coherence and for effective teaching of stoichiometry in the classroom. The first mapping concept was basic Mathematics (see Box 6.4.2). This was discussed by T3 and all CoP members agreed that Physical Science teachers can liaise with Mathematics teachers for difficult stoichiometry mathematics concepts before teaching learners. This is in agreement with Croteau, Fox and Varazo (2007) that in the beginning of teaching Chemistry, learners should be taught a variety of Mathematics involving balancing of equations. I agreed with the teaching of Mathematics because stoichiometry involves calculations, and learning basic operational Mathematics before the commencement of stoichiometry teaching might influence the teaching and learning of stoichiometry. Teaching of basic Mathematics actually constitutes learners' prior knowledge which might inspire learners to pay attention when teaching similar components in stoichiometry.

Box 6.3.1: Stoichiometry mapping by T3 supported by other CoP members



Below is the lesson plan or guide prepared by teacher T4, on basic Mathematics needed for the teaching of stoichiometry.

Box 6.3.2: Basic Mathematics lesson plan

BASIC MATHEMATICS OPERATION 1

Objective: To teach the **basic** mathematics operations for real numbers on addition, subtraction, multiplication, and division to learners.

Introduction:

The four *basic mathematical operations*–addition, subtraction, multiplication, and division–have application even in the most *mathematical* theories. Thus, mastering them is one of the keys to enhance the understanding of *mathematics* that can be applied in the teaching of Stoichiometry in chemistry.

Basic Mathematics (operational) for stoichiometry.

The purpose of this Basic Mathematics is to review basic mathematics operational concepts so that learners will be able to enhance the learning of stoichiometry. This will be fundamental to better prepare the learners for the stoichiometry concepts.

Step 1: Introduce the Basic Mathematics to learners by reviewing the material and working through problems.

Step 2: Mention the Basic Mathematics refresher concepts (I) fractions and decimals, (II) percentages (III) order of arithmetic operations; (lV) basic algebra.

Step 3: Content to be covered.

Fractions and Decimals

Fractions, decimals and percentages are all numbers that represent a part of the whole. We often need to convert from fractions to decimals or from decimals to fractions.

Example:

Fraction **Decimal**

$$\frac{12}{40} = 0.3$$

Converting a fraction to a decimal

Divide the numerator (the top number) by the denominator (the bottom number) using your calculator.

This fraction is necessary when calculating the number of moles (n) in a given sample, molarity or concentration of samples.

Numerator is the mass of a given sample.

Denominator is the molar mass of the given sample as obtained from periodic table of elements.

Where number of moles (n) = $\frac{mass\ of\ the\ sample}{Molar\ mass\ of\ the\ sample}$

The teaching of Mathematics by either the Mathematics teacher or by the Physical Science teacher might enhance the understanding and teaching of stoichiometry.

Box 6.3.3: Basic Mathematics operation in stoichiometry calculation

BASIC MATHEMATICS OPERATION 2

Example: Using fractions to solve Stoichiometry questions.

Question 1: Find the number of moles of 12g of Calcium metals

12g is the mass of Calcium (numerator)

40g is the Molar mass of Calcium as obtained from periodic table of elements (denominator).

$\frac{12}{40} =$ 0.3 **Moles or 0.3mols**.

Note that the final decimal in this example is expressed to one decimal place. Final decimals can be expressed to two or three places.

Rounding up or down of decimal numbers

Decimal numbers can be rounded up, when the number following is 5, 6, 7, 8, or 9.

$$\frac{6}{7} = 0.857142857$$

I. To round up to two decimal places, the answer is 0.86
II. To round up to three decimal places, the answer is 0.867

When you round off a decimal, you round upwards if the number following ranges from 5 to 9 (as seen in I above), and you round downwards or same, if the number following ranges from 0 to 4 (as in II above).

Converting a decimal to a percent

When converting a decimal to a percentage move the decimal point two places to the right. This is basically multiplying the decimal by 100.

6.3.1 Reflections on basic mathematics

Doing Mathematics at the workshop seemed to be a good idea. T2 opened up saying that they learnt something new. He further reflected on their Mathematics during their school days, that how he passed was a miracle because everything was learned by rote. The topics covered geared up their Mathematics knowledge acquisition. T4 further explained that it was because of Mathematics that teaching Science seemed to be easy.

Below is the lesson plan prepared by T2 who volunteered to share it at the workshop**.**

Box 6.3.1.1: The lesson plan on calculation of moles prepared by T2

Topic: Mole Conversion

The mole is the central unit for converting the amount of a substance from one type of measurement to another. The number of moles of a substance can be calculated once the mass of the substance is known. Knowing the number of moles allows for a direct conversion to the number of particles. Two conversion factors are thus needed to convert mass to number of particles. The mole is also used to convert between the number of particles of a gas and the volume of a gas at STP. This molar volume of the gas is identical for all gases and has the value of 22.4 L/mol. The moles can be expressed in terms of the Avogadro's number **[6.02×10^{23}]**

Learning Objectives: Learners should be able to:

1. Convert among the number of particles, moles, and mass of a substance; and
2. Define molar volume and use it to solve problems.

Key words: Molar mass, Relative atomic mass, Atomic mass, Molar volume

LTSMs: Mole Conversions worksheet, Mass ↔ Moles, Moles ↔ Particles

Procedures: Discuss how to make the following conversions, using the line method:

- Mass ↔ Moles
- Moles ↔ Particles
- Mass ↔ Particles

Explain the concept of Molar mass, Relative atomic mass, Atomic mass, Molar volume, Avogadro's constant.

- Molar volume, volume of one mole of gas at STP = 22.4 L/mol. 1 mol of a substance = 6.02×10^{23}
  - Standard Temperature and Pressure (STP) = 0°C or 273K, 1 atmospheric pressure

Work some samples of stoichiometry questions for learners in the classroom and allow learners to practice.

Conclusion: Summarise concepts taught and give Mole Conversions worksheets as assignment to learners.

1. How many atoms are in 0.62 moles of Ag?
2. How many moles of $BaNO_3$ contain 102.3 g?
3. How many atoms are in 56.3 g of copper?
4. A room with a volume of 3500 L contains how many moles of air at STP?
5. A glass of milk contains 5 g calcium. How many atoms of calcium is that?
6. If you burned 4.0×10^{24} molecules of natural gas (methane CH_4), what mass of methane did you burn?

Box 6.3.1.2: Some highlights on calculation of moles by T2

The Mole: - can be defined as the amount of substance, which contains Avogadro's number of particles. The particles involved may be different kinds. It may be atoms, molecules, ions, electrons, protons etc. It is very necessary to state the type of particle involved.

Note: the Avogadro's number of particles is a constant and the value is 6.02×10^{23} atoms, molecules, ions, electrons, protons

THE MOLE CONCEPT

The mole concept can be expressed in the following ways.

The moles can be expressed in terms of the formula

The moles can be expressed in terms of the relative molecular mass. (RMM)

The moles can be expressed in terms of the Avogadro's number **[6.02×10^{23}]**

The moles can be expressed in terms of the Molar Volume [**$22400cm^3$ or $22.4\ dm^3$]**

The expression of the mole in different ways mentioned above is known as **mole concept.**

The moles in terms of the formula mass

The mole can be expressed thus: Mole = Mass of the element/ Relative atomic mass = Mass/ Molar mass

Example 1 Calculate the number of moles of atoms present in 20g of Sodium hydroxide

Mass of sodium hydroxide [NaOH] = 20g

Relative atomic mass of NaOH = $40gmol^{-}$= 20/40 = 0.5mole

Mass of Oxygen gas =2g

Relative molecular mass of oxygen [O_2 = 16 X 2 = $32gmol^{-}$

= 2/32

=0.06moles

T2 explained the mole concept by defining the mole concept explicitly as in the lesson plan in Box 6.4.1.2. Representation was used to make the mole concept easy to understand. He supported teaching with representation for other Physical Science teachers to visualise the meaning of moles

(Evagorou, Erduran, & Mäntylä, 2015). From this representation, a game was developed by the T2 for others to play. This game can be played by learners when teaching mole concepts.

6.3.2 Moles triangular game

How to play the moles triangular game:

1. Have a periodic table at hand;
2. Have the masses or moles of substance at hand or develop yours;
3. Two out of the components of triangular stoichiometry mole house must be known;
4. The game is played by three people with calculators in their hands;
5. 1^{st} player chooses mass number e.g. 12 g;
6. 2^{nd} player chooses mole e.g. 0.2 moles;
7. 3^{rd} player tells you what to do and gives points to the first person to give the correct answer, 2 points for correct answer and 0 for wrong answer; and
8. Approximate the answer obtained to the nearest ten.

To Wang (2010), by using games, teachers might create an atmosphere that might enhance learners' desire to learn. Learners learn better when they have the feeling that they are making progress and games might afford them an opportunity to practice and overcome their fear of the subject. The game idea is supported by Ersoz (2000) who believes that games are highly motivating in foreign language teaching because they are amusing and interesting and they can be used in practice for any concept. I agree with Ersoz (2000); if it works for languages it will do just as well in the sciences, as well as the teaching of stoichiometry.

T2 further explained that learners might learn better and improve their skills and understanding when they practice all types of stoichiometry games. Wright, Betteridge and Buckby (2005) mention that games provide a context for meaningful scientific communication, which takes place as the learners seek to understand how to play and communicate through the game. By playing games, learners are offered a practice as conventional drill exercises, but in a more meaningful way to improve their stoichiometry concepts. By doing so, learners might be immersed in using the stoichiometry language concepts, which could assist them to better internalise a newly constructed stoichiometry concept as reiterated by Vygotsky (1978). The constructed triangle Figure 6.4.2.1 houses all the tenets of moles calculating components.

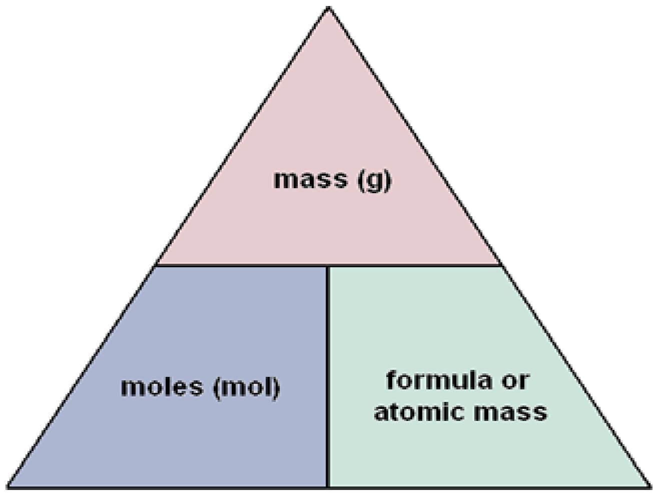


Figure 6.3.2.1: Formula triangle for calculating moles

The formula triangle representation can be used to explain the concept of moles, concentration and volume in solutions. This representation in the teaching of stoichiometry was very helpful, and it was seen during the time learners answered the diagnostic achievement test questions. Question 1 of the diagnostic achievement test was aligned to the representation and learners were able to complete the question successfully. It could be inferred that using representations during the teaching of stoichiometry enhances effective teaching and learning of stoichiometry.

Stoichiometry concentration formula to calculate moles in a solution, Figure 6.4.2.2 is similar to Figure 6.4.2.1 **(**BouJaoude & Barakat, 2000)

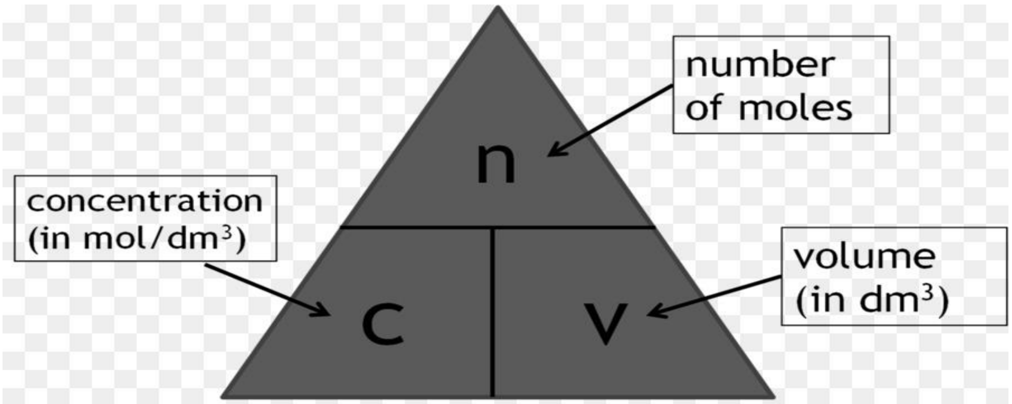


Figure 6.3.2.2: Formula triangle for calculating concentration in solutions

6.3.3 Reflection on moles and molecular mass calculation

The game that was brought to explain moles calculations was very interesting. After playing the game, the use of analogies became popular among the teachers. As a result, all the teachers were actively engaged in playing it at the workshop. Examples of moles calculations were carried out at the workshop using the game analogue.

6.4 The Third Stoichiometry Intervention Workshop

It should be realised that there are many ways that teachers can be exposed to educational workshops which could contribute to their professional development. During the third workshop, T5 came up with an idea requesting that all the participating teachers be taught how to make models or learning and teaching support materials (LTSMs). T6 responded that the Model or LTSMs development was on the workshop programme. I allowed the other Physical Science teachers to deliberate on the request because the workshop used participatory action research within a CoP. This enhanced collaboration and ownership of this study by the participating teachers.

According to Wenger, McDermott and Snyder (2002, p. 27), in order for a community to be recognised as CoP members, a combination of three characteristics must be cultivated in parallel. The three are *the domain, the community,* and *the practice*. All the three characteristics manifested during the workshop. *The domain* is what "brings people together" (Wenger et al., 2002, p. 31), and in this case stoichiometry problems brought the Physical Science teachers together. The experience and interaction during this intervention influenced their learning and teaching of stoichiometry (Wenger et al., 2002). The teachers' attitudes towards the CoP members had improved because of social interaction and the shared knowledge of teaching of stoichiometry or Physical Science.

What was inspiring about the workshop was the way teachers interacted with each other and communicated during the workshop. This must have motivated T12 to ask the question above for his own benefit and other CoP members (Physical Science teachers). This was *the community* and, according to Wenger et al. (2002, p. 34), "community is a group of people who interact regularly, build relationships and help with each other, share the understanding of their domain and approach to their shared practices for the benefit of others". The members of a CoP are practitioners; *they practice,* they develop a "shared repertoire of resources" (Wenger et al., 2002, p. 34), such as experiences, stories, tools, artefacts and ways of addressing recurring problems, thus learning from each other. Due to the manifestation of CoP characteristics explained, during the workshop we all agreed that T3 should present and after that I would discuss model or LTSM development. I used this opportunity to discuss one of the modules, project-based learning with the teachers after T3's presentation and it seemed to be expedient. In a CoP, members engage in joint activities and discussion, help each other in developing the pedagogical skills to teach specific content (TSPCK) (Mavhunga & Rollnick, 2013) with positive effects on practice and share information by reflecting on their practices. The model or LTSMs were discussed after T3's presentation.

6.4.1 T3's Presentation

T3 prepared a lesson on empirical and molecular formula of stoichiometry concepts. This was shared with the participating Physical Science teachers or stoichiometry CoP members during the workshop. Below is the lesson plan prepared by T3.

Box 6.4.1.1: Lesson plan on empirical formula

Topic: Empirical formula

Step 1: Introduce empirical formula, by defining it.

- Empirical formula is the simplest whole number ratio of atoms

Step 2: Work a sample of the question on the chalk board, to explain the concept and teachers practice in class.

Question: Given a compound that is 80% carbon and 20% hydrogen, find the empirical formula.

Step 3. Work on a 100 g basis. 80 g of C, 20 g of H.

Step 4. Convert to moles by dividing the % converted to grams by the atomic mass of the element.

80 g C / (12.0 g C/mol) = 6.67 mol C

20 g H / (1.01 g H/mol) = 19.8 mol H

Step 5: identify the smallest mole.

Step 6. Divide each mole value by the smallest mole value.

C 6.67 / 6.67 = 1.00

H 19.8/6.67 = 2.97 (round to 3.00)

Answer: Empirical formula = CH_3, the simplest whole number ratio of the compound

Box 6.4.1.2: Lesson plan on molecular formula

Step 1: Introduce molecular formula.

Molecular formula is the multiple of empirical formula, shows actual number of atoms of each element in compound.

Step 2: Ask class this question: Which formula do you think is more useful, empirical formula or molecular formula? Why? A: molecular tell us more

Step 3: Work sample problem on the board for class. Explain step by step how to calculate the empirical and molecular formula.

Example: Ribose has molar mass = 150 g/mol, and is composed of 40% C, 6.67% H, and 53.3% O. Find the molecular formula.

Step 4. Find empirical formula. Divide the elements percentage by atomic mass to convert to moles.

C 40 g / (12.0 g/mol) = 3.33 moles

H 6.67 g / (1.01 g/mol) = 6.60 moles

O 53.3 g / (16.0 g/ml) = 3.33moles

Step 5: divide the moles with the simplest or smallest.

C= 3.33moles/3.33 moles, H= 6.67 moles /3.33 moles, O= 3.33 moles / 3.33 moles

C=1 H= 2, O= 1

Step 6: Write the Empirical formula = CH_2O

Step 7: Find formula mass of empirical formula by adding all the atomic masses of all the elements in the formula together. C = 12.0, H = 1.0 (x2), O = 16.0 = 30.0

Step 8: Divide molar mass by empirical formula mass. 150.0 / 30.0 = 5

Step 9. Multiply empirical formula by that number obtained from the division of molecular mass.

The empirical number is CH_2O, multiply this by 5= $C_5H_{10}O_5$ this is the molecular mass.

Conclusion: Idenhtify and explain key words and what they meant. Molar mass, formula mass, empirical formula. Molecular formulas.

After T3's presentation, the CoP members revisited the objectives of this study.

6.4.2 Revisiting objectives of the study

Before I presented the model or LTSMs, we, as CoP members revisited the stoichiometry research objectives (see Section 1.7).

The following points emerged from the objectives when Physical Science teachers were deliberating on the model or LTSM development.

- Researching own practice;
- Designing and implementing models or LTSMs;
- Exploring SMK and PCK;
- Enhancing research skills; and
- Collaboration among the CoP members even beyond the workshop or study.

The revisiting of objectives was very crucial in this study because according to Zirar, Choudhary and Trusson (2017), revisiting the objectives in any study enhances the collection of evidence and derives fresh insights on the matter at hand. In the case of this study, revisiting objectives of the stoichiometry study guided us in deriving fresh insights into the teaching of stoichiometry. Sundaram and Inkpen (2004) opine that revisiting objectives might enhance the re-examining of usual arguments and develop a set of new arguments about why the preferred objectives function. Concurring, Zirar et al. (2017) state that during studies there is a need for revisiting the research objectives, which might generate new ideas for the study at hand. This drives home the point that revisiting objectives of this stoichiometry research study might be beneficial and strengthen the procedures of the teaching of stoichiometry concepts, which might enhance the models, or LTSMs development.

6.4.3 Development of models or learning and teaching support materials

From this third workshop it emerged that most teachers had problems with the development of teaching and learning materials. This was an opportunity to engage the CoP members on how to go about developing models or teaching materials. Bušljeta (2013) accentuates that the purpose and role of teaching and learning resources does not only consist of making the educational process more attractive and interesting, but also of encouraging active learning and the development of different skills for the learners. Bušljeta (2013) posits that developing teachers' skills in the conception of making models or teaching materials might enhance active learning when used in the classroom. This strengthens the CPD of Physical Science teachers as they learn how to make models and LTSMs for the teaching of stoichiometry.

6.4.4 Procedures of LTSMs making during the workshop

As agreed before, after T3's presentation I discussed with the CoP members how to make models or LTSMs. I quickly prepared a lesson plan on the methods of preparing models using available materials. The lesson was on how to make models of the electronic structure of an element.

Box 6.4.4.1: Highlights on exemplary lesson plan of electronic structure of element

Step 1 - Gather Information on a model of element to develop

Before you can build your model, you will need to know how many protons, **neutrons and electrons** your element has. Obtain this from the Periodic Table of Elements.

Step 2 – Materials to use

Cardboard, Bottle tops, threads, seeds, (any appealing available materials of your choices). Colour or paints, glue and ball pens

Step 3 - Build the Nucleus

Show that the nucleus, the central part of the atom is made from protons and neutrons. Define the protons and neutrons.

Step 4 - Placing the Electrons on the orbit.

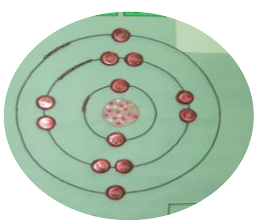
The electrons are found outside the nucleus on the orbit, place electrons there.

Step 5 – Model explanation

A model is a simplified representation of an object or element.

Step 6: Construct your own model now, pick an element of your choice

The Bohr Model



Below is a model of the electronic structure of Magnesium constructed by the participating CoP members during the workshop.

Figure 6.4.4.1: Model of the electronic structure of Magnesium constructed by CoP members group 1

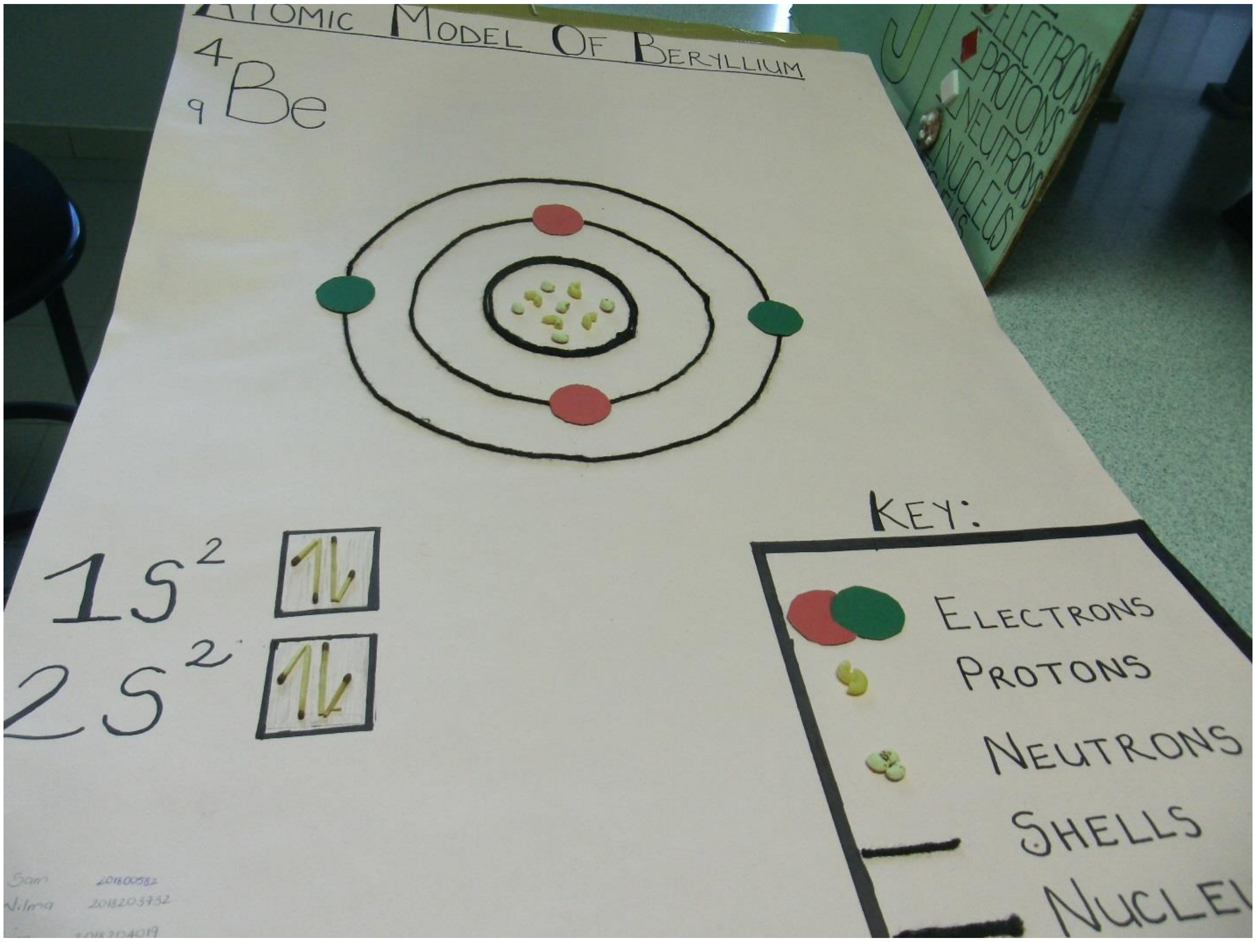


Figure 6.4.4.2: Model of the electronic structure of Beryllium constructed by CoP members group 2

6.4.5 Reflections on the model of electronic configuration construction

The Physical Science teachers enjoyed working together. When the construction of the electronic configuration started, T2 asked questions about the use of local materials. I said that it is central to analogues discussed, that locally available materials (Asheela, 2017) for the teaching or constructing models be used. During the discussion I made reference to the materials used when constructing the electronic configuration. For example, the matchsticks were used to show a pair of electrons in the orbit, coloured papers to beautify the model and cardboard to house the electronic configuration model. Bottle tops were used to show the position of electrons within the shell, marker pens were used for drawing, threads for making shells and seeds (to show the protons and neutrons). It was very busy, but l could see that participating teachers did a good job. Figures 6.4.4.1 and Figure 6.4.4.2 were constructed during the workshop. T3 asked if the model could be used in Biology as well. I responded that model construction can be used in any subject provided it is adequately relevant to the concept at hand. After the model of the electronic configuration construction teaching and reflection, the 3rd workshop came to an end and arrangements were made for the 4th workshop.

6.5 The Fourth Stoichiometry Intervention Workshop

The fourth workshop took place at School A, where we started with the first workshop. As explained earlier, meetings at these schools were on a rotational basis among the participating schools. T5 shared his lesson on percentage composition using analogies.

6.5.1 The percentage composition of substances

Below is the lesson plan on the percentage composition of substances. T5's domain of knowledge was shared to create common ground, inspire members, guide their learning and give meaning to their actions (Wenger et al., 2002), and this is a CoP. Below is the lesson plan prepared by T5 on percentage composition. T5 made use of analogy representation in teaching the percentage composition.

Box 6.5.1.1: Highlights on practical analogue on percentage composition procedures

Objective
To become familiar with the methods of calculating percentage composition of a substance or mixture.
Apparatus and Chemicals
Chemical balance, Bunsen burner, heat, Beakers, evaporating dish
Unknown mixture of iodine and Silicon dioxide
Discussion: Stoichiometry mixture's calculation
The mixture that you will separate contains two components: NH_4C1, and SiO_2. Their separation will be accomplished by heating the mixture to sublime the: NH_4C1 from SiO_2

Procedures:
Step 1: Carefully weigh a clean, dry evaporating dish.
Step 2: Then put the unknown mixture in the evaporating dish.
Step 3: Weigh the evaporating dish containing the sample and calculate the sample weight.
Step 4: Place the evaporating dish containing the mixture on a hot plate under the fume cupboard.
Step 5: Heat the evaporating dish until brown fumes are no longer formed. Heat carefully to avoid spattering and stir.
Step 6: Allow the evaporating dish to cool until it reaches room temperature and then weigh the evaporating dish with the contained solid. The loss in weight represents the amount of Iodine in your mixture.

Calculate the % composition of I2 (Iodine) = Mass of component in grams alone X 100

Mass of sample in grams

= % component of iodine

Teachers were excited with the analogy practical used by T5 and they commented that they had never thought of an analogy to explain this concept. The analogy practical seemed to be an eye-opener on the teaching of stoichiometry. One of the teachers (T4) said that if this workshop could be extended it would enhance their SMK and PCK. After the presentation and reflection by T5, I facilitated balancing of chemical equations during the workshop, and I used the generic method of balancing chemical equations.

6.5.2 Lesson plan on balancing chemical equations

In the box below is the lesson plan prepared on chemical balancing of equations.

Box 6.5.2.1: Lesson plan for the balancing of chemical equation

Topic: Balancing chemical equations
Stoichiometry describes the quantitative relationships between reactants and products in chemical reactions. Stoichiometric calculations depend upon balanced chemical equations. The coefficients of the balanced equation indicate the ratio of reactants and products taking part in the reaction.

Learning Objectives:

Learners should be able to:

- Balance chemical equation
- Identify the coefficient in the balanced chemical equations.
- Relate and compare stoichiometry in balancing chemical equations.
- Ratio of reacting substances (reactants and products)

Key words: stoichiometry, Reactants and Products, chemical equations, mole-mole problem, coefficients

Procedure:

Step 1: The teacher should outline the rules for balancing equations by inspection to Learners

a. Write a formula equation with correct symbols, formulas and subscripts
b. Count the number of atoms of each element on each side of the equation.
c. Balance atoms by using coefficients.
d. Check your work by counting atoms of each element.

Step 2: Explain what stoichiometry is.

- study of quantitative, or measurable, relationships that exist in chemical formulas and chemical reactions
- Connect importance of balanced equations with stoichiometry

3. Explain mole-mole questions: Q: How many moles of HCl are needed to react with 5.70 moles of Zn?

Step 1. Write balanced equation. $2HCl + Zn \rightarrow ZnCl_2 + H_2$

Step 2. Determine molar ratio. (2moles HCl for every 1 mole Zn)

Step 3. Cross multiply with given number of moles.

$$HCl / Zn = 2 / 1 = X / 5.70$$

$$X = 11.40 \text{ moles HCl}$$

Conclusion:

- Explain the relationship between stoichiometry and balanced equations; and
- Revise the mole-mole steps.

During the workshop, T1 brought about an equation that she failed to balance. The equation is written below.

$$\_\_\_\_ \ AlBr_3 + \_\_\_\_ \ K_2SO_4 \longrightarrow \_\_\_\_ \ KBr + \_\_\_\_ \ Al_2(SO_4)_3$$

Balanced equation:

$$\mathbf{2}\ AlBr_3 + \mathbf{3}\ K_2SO_4 \longrightarrow \mathbf{6}\ KBr + Al_2(SO_4)_3$$

The equation was balanced together at the workshop by CoP members. After the balancing I discussed the algebraic method of balancing equations below with teachers.

Box 6.5.2.2: Explanatory notes about algebraic method of balancing chemical equation

An Algebraic Method of Balancing Equations

In balancing equations, we require that the same number of atoms of each element appear on both sides of the equation. The problem is more mathematical than chemical. As you might expect, these equations can be solved by general mathematical methods.

Let us consider the following equation, writing it with the undetermined coefficients a, b, x, and y as shown by:

$$a\ C_2H_6 + b\ O_2 \longrightarrow x\ CO_2 + y\ H_2O$$

In order to determine the values of the four unknown coefficients, we must have four equations. These are supplied by the simultaneous balancing of each element. For example, we might start with the element carbon.

Carbon

One equation is obtained by equating the number of carbon atoms on the left side of the equation with those on the right. According to its formula each ethane molecule contains two carbon atoms. Therefore, there are 2a carbon atoms in ethane molecules. On the right side, each carbon dioxide molecule contains only one carbon atoms. Therefore, there are x carbon atoms on the right. Since these numbers must be equal at the end of our calculations we write

The equation

$$2a = x \quad \text{(Equation 1)}$$

Hydrogen

In similar manner, we can write an equation by algebraically balancing the number of hydrogen atoms:

$$6a = 2y \quad \text{(Equation 2)}$$

Oxygen

Doing the same for oxygen, we obtain

$$2b = 2x + y \quad \text{(Equation 3)}$$

This gives us three equations. For a simultaneous algebraic solution we need one more. Since all of the numbers representing atoms are relative, we can obtain our fourth equation by letting any one of the unknowns a, b, x, or y equal anything we wish.

.

Let us arbitrarily let a = 1 to set up our fourth equation. Then, from Equation 1, x = 2. Likewise, from Equation 2, y = 3. Placing these values for x and y into Equation 3, we get:

$$2b = 2(2) + 3 = 7$$

$$b = 3.5$$

To avoid fractions, we then multiply through by 2, getting a new set of values for the four coefficients: a = 2, b = 7, x = 4, and y = 6. If you plug in these numbers into the chemical equation you will find that it is correctly balanced.

Box 6.5.2.3 Using algebraic method to balance equation

Algebraic method of balancing the equation below

$NaCl + SO_2 + H_2O + O_2 \longrightarrow Na_2SO_4 + HCI$

Again, we put unknown coefficients in front of each molecular species:

$xNaCl + ySO_2 + zH_2O + wO_2 \longrightarrow uNa_2SO_4 + v\,HCI$

Writing down the balance conditions on each element gives:

Sodium balance:

$x = 2u$

Chlorine balance:

$x = v$

Sulphur balance:

$y = u$

Oxygen balance:

$2y + z + 2w = 4u$

Hydrogen balance:

$2z = v$

Setting u=1 arbitrarily, gives the immediate solution:
$x = 2 \quad v=2 \quad y= 1 \; z= 1$

and $2 + 1+2w = 4$, $2w = 4- 3$, $2w = 1$. $W = 1/2$.

In order to clear the fraction, we multiply all the coefficients by 2 and write down the balanced equation:

$2NaCl + SO_2 + H_2O + 1/2O_2 \longrightarrow Na_2SO_4 + HCI$

The algebraic method of balancing equations is the newest chemical equation balancing method and when fully understood, balancing of equations will be very easy.

6.5.3 Reflections on balancing of equations

T4 reflected that the algebraic method seemed to be good, but the Mathematics level of the learners might impede their understanding of this concept. T3 commented that even as teachers, we needed to practice very well before teaching our learners. After reflections, all the teachers requested the notes on the algebraic method of balancing equations to develop their SMK.

T3 concluded by repeating again that the method was good, but that CoP members needed to practice many examples in order to master it.

6.6 Challenges Encountered during Stoichiometry Workshop Activities

The first problem that manifested during one of the workshops was about T1 who could not participate well during the teaching and workshop activities. T1 said that she was not comfortable with Grade 11 and 12 Physical Science content, only Grade 9 and 10 content. She further said that she was forced to teach it because the Grade 12 Physical Science teacher was on sick leave. T1's view concurred with the results of the diagnostic test of school C where she teaches (see Table 5.2.2 and Figure 5.2.1) where learners did not do well in the test. Basing it on the results of the test and comments from her, I decided to go to T1 to motivate her and assist her with some other topics that we were not necessarily doing research on.

During one of my visits to the school, T1 opened up about her knowledge of Physical Science and other contributing factors. Below are the factors the teacher brought to my attention:

- Not enough teaching materials in their school;
- Her inexperience with experiments associated with Physical Science concepts;
- Lack of confidence in teaching the SCK in some areas of Physical Science;
- Overcrowded science classrooms;
- Absenteeism on the part of learners; and
- Learners not doing their homework.

The interesting part is that the issues raised by her were the core issues of my study as it sought to investigate and support the SMK and PCK of the teachers involved in the study. It therefore encompassed developing teaching materials (resources), and it also involved reflections that might enhance confidence among the teachers, improving CPD as the teachers worked with each other (Wenger et al., 2002). From these issues, it could be argued that things were indeed not working well with this teacher at her school, but she was keen to learn and would preferably like to teach a lower grade. Having occasional conversations with the Physical Science teachers seemed to be beneficial in the sense that I was able to get T1's perspective and context and get to know her better as an individual.

It would have been much appreciated if all the teachers would have opened up and discussed challenges they were facing at their respective schools. Consideration of their needs was and is valuable to the teaching and learning of concepts in the classroom. This approach of T1 in my view is a new knowledge about how Science teachers could open up during CPD workshop interventions for effective teaching delivery. This necessitates the need for intervention to uplift Science teachers from this dilemma, which Lave and Wenger (1991) regard as legitimate peripheral intervention.

The second challenge was the promotion and non-renewal of contract teachers. One of the teachers got promoted as an HOD to another school about 100 km from Katima Mulilo, making it difficult for him to come to the workshops. The new teacher that came as HOD to replace the one who left, volunteered to join the research team since he also teaches Physical Science. The teacher whose contract was not renewed was replaced by T6 who also joined the study.

6.7 Concluding Remarks

In this chapter, I presented, analysed and discussed the intervention workshops and some reflections that emerged as a result of these workshops. In the next chapter, I present, analyse and discuss data generated through observations and stimulated recall interviews.

CHAPTER SEVEN: OBSERVATIONS AND STIMULATED RECALL INTERVIEWS

> *A teaching observation is neither an evaluation nor an assessment: it's a way of sharing effective instructional practices, opening lines of communication, and informing professional development opportunities. Identifying instructors' areas of proficiency and areas for development will help all program faculty determine how to contribute to and sustain a programme culture of continual improvement in their teaching practice. Observations are a tool that plays a developmental role in the continuous improvement in the quality of teaching* (Kemp & Gosling, 2000, p. 1).

7.1 Introduction

In the previous chapter, I presented, analysed and discussed data generated from the intervention workshops. In this chapter, I present, analyse and discuss data generated from observations and stimulated recall interviews to address my research question three:

How do Grade 11 Physical Science teachers mediate learning of the developed stoichiometry exemplary lessons?

Three participating teachers teaching Grade 11 where observed teaching the exemplary lessons in their classrooms. The three teachers observed were also interviewed, after watching videos of their classroom teaching. This corresponds with Kemp and Gosling's (2000) view reflected in the epigraph emphasising that teaching observation is neither an evaluation nor an assessment, instead it is a way of sharing effective instructional practices, opening lines of communication, and informing professional development opportunities, which Trach (2014) also accentuates. This aligns with the objectives of this study to enhance CPD of the participating Physical Science teachers through participatory action research within the community of practice (CoP). For CPD to be engaged the observation of teachers are necessary in order to get information on their areas of need and identifying teachers' areas of proficiency and areas for development. This has implications for researchers when they attempt to use the participatory action research method so that the approach might be beneficial to the teachers and influence their SMK and PCK.

Reflections from teachers were then elicited through an interview on different aspects of their recorded interactions (Nguyen, McFadden, Tangen, & Beutel, 2013) after watching the videos, for effective data generation (Gass & Mackey, 2000). The purpose of using observations and stimulated recall interviews (SRI) in this study was to gain insight into teachers' methods of teaching and how it could be improved.

7.2 Procedure of Data Generation during Observation using Video-Recording

The procedure below was done with each of the three Grade 11 participating Physical Science teachers. Below is a diagrammatic representation of the SRI procedure.

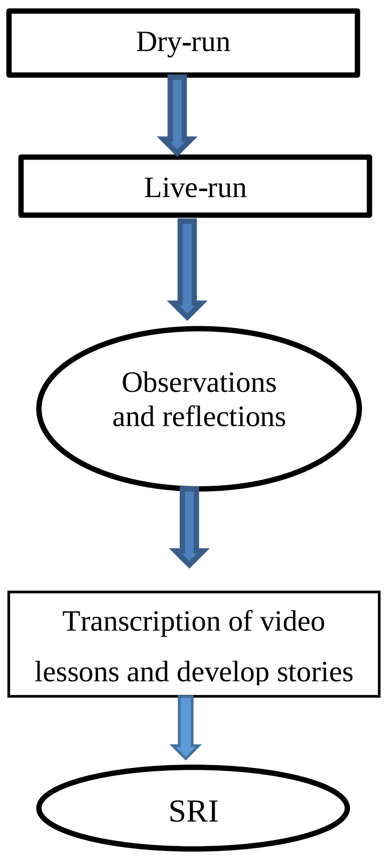


Figure 7.1.1: Diagrammatic representation of the video and SRI procedure (Nguyen et al., 2013, p. 7)

7.2.1 Camera setting in class

Due to limited resources, only one camera was used for recording lessons. The camera was handheld by an operator. Much attention was given to teachers in order to record the teachers' practices, and all the instructional resources such as slides, blackboard, textbooks and so forth.

7.2.2 Dry-run

A threat to validity is the possibility that individuals are creating 'explanations' about the links between prompted actions and intentions (Gass & Mackey, 2000), hence I conducted a dry-run session at the beginning of each stoichiometry lesson. A dry-run is defined in the English dictionary as a rehearsal of a performance or procedure before the real one, allowing learners to know the purpose of the visitor in their midst and why. The dry-run session also allowed learner participants to be more relaxed in my presence as they acclimatised to the new classroom environment with a known visitor in the classroom. The dry-run time was limited to allow more time for a live-run.

7.2.3 Live-run

A live-run was the video-recording of the real lessons in motion for a period of 40 minutes per lesson. Having acclimatised from the dry-run, lesson presentations began. In total, there were three classroom lesson observations, audio-video recorded for each of the three participating teachers; likewise, the three SRI sessions for the three teachers were tape recorded. The number of video lessons recorded was largely dependent upon the availability of resources, and time.

7.2.4 Observations and reflections

I watched the videos with each teacher so that they could reflect on their teaching behaviours and presentations. The main objective of the SRI was to address how Grade 11 Physical Science teachers mediate learning of the developed stoichiometry exemplary lessons. Watching the video also allowed the teachers to give their thoughts on their decision-making processes for their teaching behaviours as we observed their lessons (Nguyen et al., 2013). It was from these observations when watching the videos that I developed the SRI questions. I watched the videos at least twice on my own so as to draw up the SRI questions and transcribe the videos into written form. The three teachers teaching Grade 11 were observed purposely, as the focus of the study was how an intervention might enable Grade 11 teachers to mediate the teaching of stoichiometry. The three teachers for the SRI were coded as follows in the table below.

Table 7.2.4.1: Profile, qualification and school of teachers in the study for SRI.

T= Teacher, I= Interview and M= Male.

Teachers	Highest qualifications	School
T3IM	Bachelor of Theology.	**A**
T4IM	Diploma in Education	**B**
T6IM	Diploma in Education	**A**

7.2.4.1 Lesson observed at School A for T3

T3 started the lesson with a prayer given by one of the learners, and introduced me and the camera lady, this ties in with what I referred to as a dry-run (see Figure 7.1.1). This shared responsibility on the part of the learners made the learners feel relaxed. The teacher said learners should feel free to participate in the lesson.

Engaging in the live-run (Figure 7.1.1), T3 made copies of the periodic table for learners as learning and teaching support materials (LTSMs) and the concept 'Stoichiometry' was written on the chalk board. T3 asked learners to read the concept on the chalk board. Three learners simultaneously read the word and were all complemented with the word "*Beautiful". *T3's compliments are in line with Walker (2008) who posits that a good teacher must be able to give praise and recognition. It can be concluded that action enhances teaching and enables the learners to pay attention in the class. T3 explained the word stoichiometry in this way, "*Stoichiometry shows how elements react and the proportion or ratio of how they react*". T3 conceptualised this with hypothetical reactions (imaginary) saying, *"if one wants to prepare 'A', one needs to know the amount of 'B' needed"*.

T3 then introduced the word 'symbol'. He tried to build on learners' prior knowledge by referring to activities or class work done when they were in Grade 10 (Mavhunga & Rollnick, 2013). During the teaching, learners who did not get the periodic table indicated that and the teacher responded promptly by providing the periodic table. This talks to Walker, (2008) who emphasises that a good teacher should be compassionate, concerned about students' personal problems and relate to them and their problems. T3 also emphasised that the periodic table provides information that will be needed during the course of teaching and learning of stoichiometry.

The teacher started with a probing question asking what a symbol is. One learner responded by saying "*Symbols are a letter or letters which represent a name*". T3 reinforced the answer given, saying that, "*A short form of an element is the symbol*".

T3 conceptualised his teaching during the observation using my initials as symbols saying DD coming from Denuga Desalu. He further said that assuming a learner's name is Sapalo, his symbol will be S. He tried to put it in a manner so that learners could understand the term symbol. The teacher then asked the learners to give examples of symbols they knew. The following examples were given, Na for Sodium, Ca for Calcium and H for Hydrogen. The teacher further requested if there is a method used to identify the symbols so that there is no confusion, because scientists do not like confusion. One of the learners answered saying that names like copper get its symbol from Latin or Spanish or Greek. The teacher probed further with questions on how the symbols are abbreviated. One learner said that the letters used to represent an element for its symbols came from either the first letter or the first and second letters or, the first and third letters of the element. The teacher probed further asking about elements with first letters only. The following were the responses; H for Hydrogen, O for Oxygen and C for Carbon; 1st and 2nd letters: Li for Lithium, Ne for Neon. 1st and 3rd letters: Mg for Magnesium, Mn for Manganese, CI for Chlorine and Zn for Zinc.

T3 further asked for elements that do not have symbols that took the letters from their names. The following examples were given: Sodium is Na coming from Natrium, Copper is Cu coming from Cuprum, Iron is Fe coming from Ferium. Gold is Au coming from Augutum and Tin is Sn coming from Stannum.

T3 wrote the term 'formula' on the board and asked what a formula is. T3 moved around in the classroom to encourage full participation of the learners in the class activities (Sedlacek & Sedova, 2017). One learner said that she knows what a formula is, but she could not explain what it is. The teacher asked the learner to describe it, so that she could show that she knows what she is talking about. Then the learner said, "*a formula is a short form of getting a result or whatever*". The learner was complemented in an encouraging manner with a "*thank you for trying*".

T3 requested an example of a formula and NaCI was mentioned by one learner and chorused by the class as sodium chloride. T3 explained the term formula' saying that*, "Formula is a short form of a name of a substance. This name is made-up of symbols we are talking about, Na for Sodium and CI for chloride, [NaCI]".* T3 further posed questions on how a formula is written.

The teacher used prior knowledge of what learners learnt in Grade 10 by asking learners about the periodic table and what the word group in the periodic table stands for. Learners responded saying that group denotes the number of electrons in the outer shell of an element when the Bohr Neil orbital diagram is drawn. Group I elements have one electron, likewise, group II elements have two electrons, and so on. T3, responded and drew the diagram on the board.

Table 7.2.4.2: Showing, groups I- VIII, outer shell electrons and valence electrons

Group	**Number of e^- at outer shell**	**Valence electron**
Group I	1	1
Group II	2	2
Group III	3	3
Group IV	4	4
Group V	5	3 (8-5=3)
Group VI	6	2 (8-6=2)
Group VII	7	1 (8-7=1)
Group VIII or Group O	8	0 (8-8=0)

T3 then explained that when a reaction occurs it is the electrons that are involved in chemical reactions. The electrons are referred to as valence electrons, which are the combining power during chemical reactions. As you move to the right side of the periodic table, the determination of valence electrons changes (see Table 7.2.4.2). The procedure is still the same, but now the number of electrons that remain for the element to attain an inert gas structure are the valence electrons.

T3 gave a class activity on how to write formula and in trying to consolidate his teaching by using a learner-centered approach, he called on the learners to come and write the formula on the chalkboard. This corresponds to Walker's (2008) ideas that an effective teacher should be prepared all the time. That is, they do not waste instructional time and it is easy to learn in their class because they are always ready and support their teaching with activities.

T3 used an analogy to consolidate the formula of Na_2O explaining that if Na has one hand and O has two hands, for balancing purposes how many Na will oxygen need? The answer: Oxygen will need two sodium to balance.

T3 worked on an example for learners to clear up any misconceptions. One learner had written the charge as follows:

Ca^{-2} and O^{+2}, saying that when Ca loses $2e^{-}$s then it becomes Ca^{-2} and when O gains $2e^{-}$s it becomes O^{+2}.

This is a misconception that makes things difficult for learners to understand (Mavhunga & Rollnick, 2013). The teacher explained this misconception in order to make a difficult concept easier. When a metal loses electrons, the charges are always positive, so Ca will be Ca^{+2} and when O gains the charge will be O^{-2}.

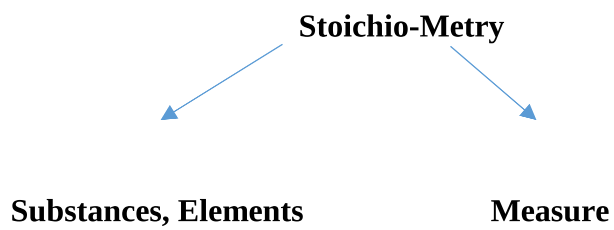
Reflections on the lesson by T3

From my own view, T3 is following the tenets of TSPCK, using curricular saliency when solving equations, and worked examples on the chalkboard to make difficult concepts easier to understand. Using all the tenets of TSPCK to enhance his teaching might result in more effective teaching.

7.2.4.2 Lesson observed at school C for T4

T4 introduced me and the camera lady to learners for them to be relaxed and participate in the teaching; this corresponds again to the dry-run used in T3's class. The class in question was Grade 11 A, a higher-grade class for the 2018 academic year.

After the brief introduction, T4 introduced the concept to be taught for that period. The teacher wrote the concept (stoichiometry) on the chalkboard and requested that the learners pronounce it. It could be argued that T4 wanted learners to identify the concept's spelling and its pronunciation. After the chorus answer the teacher unpacked the term 'stoichiometry' to learners. He also explained the concept, with the illustration below.



With this in mind, the teacher agreed with Mavhunga and Rollnick (2013) about one of the tenets of TSPCK, uncovering what makes a topic easy or difficult to understand. T4 further explained the stoichiometry concept as substances measurement. This concurred with T3's method of teaching because both attended the workshop intervention, which enhanced the participatory action research within a CoP approach that different teachers from different schools were concurrently using the same approach to teach.

T4 asked the learners about substances and where to get the substances or elements, learners responded saying the periodic table. The teacher distributed periodic tables to all learners and consolidated with the big periodic table on the chalkboard.

From the periodic table, T4 asked the question, "*What are the components that are there in the periodic table?*" Learners mentioned formulas of elements. He followed with the question, "*What is a formula?*" T4 tried to unpack the meaning of a formula and explained that, "*Formula in science is a group of symbols that makes up a word. Also, symbols are short words that denote an element. Symbols come together to form a formula*".

This explanation concurs with Mavhunga and Rollnick (2013) on the tenets of curricular saliency. That is, in my view there was a logical sequence in the explanation of a formula, symbols and how they constitute an element.

During teaching, T4 also gave learners a class activity, checking the periodic table and selecting symbols to generate formulas of their choice. This is in line with Chick's (2007) views that teachers are capable of giving correct and relevant questions to learners. T4 reflected on the topic 'formula' in the class, with a question "*Are you all hearing the concept formula for the first time*?"

Learners responded that symbols and formula were taught in Grade 8 and 9. From my own view, T4 brought in the prior knowledge of learners from Grade 8 and 9, to corroborate what he taught in the class. This prior knowledge is essential in transformation in TSPCK as explained by Mavhunga and Rollnick (2013) in their study, which necessitated why the intervention was necessary in this study.

From my observation during the learner activity, learners generated formulae that were real and imaginary. T4 engaged in a learner centered approach in the teaching which involved a variety of methods of teaching. This agrees with Dorgu (2015, p. 77) who states that "there are several teaching methods to use in the classrooms, it is left for the teacher to use the ones most appropriate for the lesson. These methods if properly used will enhance teaching and learning and bring about desired changes in the learners".

For formula writing, the teacher unpacked the formula writing procedures by using the periodic table. The teacher asked the learners to identify the zig-zag line in the periodic table. The teacher unpacked the periodic table, explaining that on the right side of the zig-zag line in the periodic table are metals and on the left side are non-metals. The teacher scaffolded the learners by writing examples of some formulae on the board and learners were asked to locate the symbols on the periodic table.

T4 explained that when non-metals combine together, covalent bonding is involved in binding the non-metals together. Electrons are shared between the two non-metals. On the other hand, when metals and non-metals are combined together, electrons are transferred from metal to non-metals. That is electrovalent or ionic bonding. This covers the curricular saliency (Mavhunga & Rollnick (2013) concept, where teaching should be in sequential order in order to understand formulae in stoichiometry.

Reflections on the lesson by T4

Learners were praised for their contributions during the teaching by the clapping of hands for them. The teacher also appreciated the learners with words like "*good*" or "*thanks for your contribution*" when answers were incorrect. This resonates with Walker's (2008) ideas that an effective teacher should be positive, by praising and recognising contributions from learners.

To conclude the lesson, T4 gave homework to his learners. This was a problem-solving approach. Learners felt motivated and happy to participate in the class.

7.2.4.3 Lesson observed at school B for T6

As the norm, the teacher introduced me and the camera operator to the learners and stated our purpose for being there, which I explained as a dry-run. T6 then introduced the topic of the lesson and wrote the term 'stoichiometry' on the chalkboard. He asked learners to read the term 'stoichiometry'. A learner responded with a loud voice reading the term 'stoichiometry.' Thereafter, T6 asked a question on what comes to the learners' minds when they see the term 'stoichiometry.' He also asked if they had seen the term 'stoichiometry' elsewhere to which the learners said no.

T6 broke down the term 'stoichiometry' into two, so as to explain it in a simple manner, for example: '*stoichio*' meaning substances/elements, and '*metry*' meaning measure. In a nutshell stoichiometry means substances or elements measuring. This process here talks to curricular saliency of TSPCK (Mavhunga & Rollnick, 2013).

T6 made copies of the periodic table for learners as learning materials. He explained the periodic table, highlighting that the periodic table consists of elements. On the periodic table there are two numbers, the bigger one and the smaller one. The bigger number is called a mass number. He further stated that mass numbers consist of the sum of protons and neutrons. He asked for one word that is used for both the protons and neutrons to which the leaners shouted "*Nucleus*". The teacher combined both representation and curricula saliency (Mavhunga & Rollnick, 2013) to enhance the teaching in the classroom.

After the introduction, T6 gave an example of going to a shop keeper and telling him or her that you need five million granules of sugar. He highlighted and concurred with the learners that the particles cannot be counted in that manner. That is why scientists have found a way to express this, as those particles are all the same, they are so tiny and indivisible. He then asked how sugar is measured and one learner said that sugar is measured in grams, and kilograms. The teacher wrote the learner's answers on the chalkboard and thereafter asked the learners to be specific. 100 grams, 200 grams and 500 grams were mentioned. The teacher then said there is 100 grams, 200 grams and 500 grams and also 1 kilogram. From my own view the teacher engaged representation or analogue in the teaching but according to De Jong and Treagust (2002), unguided analogue can provoke misconceptions which can influence the learning in a negative manner. T6 explained that in science there is a number known as a constant number which is known to be 6.022×10^{23} particles. T6 said the $6.022 \text{ X } 10^{23}$ will be dealt with at a later stage so that the learners understand it.

T6 explained that, the amount of mass on the periodic table symbolises the mass of each element, while the mole concept has to do with chemical reactions. At this stage, T6 asked, what are the components involving in chemical reaction? A learner responded it was consumable items. He asked, what are consumables items? At this point from my view, T6's mode of questioning was not done in a coherent manner. This resonates with Fitriati, Isfara and Trisanti's (2017, p. 217) views that,

> Teacher's questioning skills are crucial to successfully make students engaged in the classroom interaction, enhance student's verbal responses, and lead to the comprehension of the lesson. Therefore, it is suggested that teachers should be more aware of their questioning skills to assist students in the classroom.

In my point of view, T6 was trying to ask the question, what constitutes or makes up the consumable items? And the expected answer should be atoms. These are atoms that make up elements. Each atom has a specific mass, as shown in the periodic table.

T6 requested the learners to draw the combined structured of the reaction of hydrogen and oxygen on the chalkboard.

$$H_2 \quad + \quad O_2 \longrightarrow H_2O$$

T6 explained the chemical equation of the reaction between H_2 and O_2 atoms. He mentioned that on the left-hand side of the arrow are reactants and on the right-hand side of the arrow are products.

Reactants $\longrightarrow$ Products

"*Why are reactants called the name, reactants*? *They join together to make a new substance. The other side is the product, a new substance formed*," said T6.

T6 explained further to learners that, in the reaction, the number of both atoms of the reactants and products should be equal. The teacher brought in the terms such as 'conservation of mass' and 'balancing of equation'. The learners were then asked to count the number of O and H atoms in both reactants and products to check if the equation was balanced.

$H_2 + O_2 \longrightarrow H_2O$

Reactants $\longrightarrow$ Products.

"*Now lets us look at the number of atoms*," said T6.

Reactants	**Products**
H = 2, O = 2	H = 2, O = 1

One learner came to balance the equation on the chalkboard and T6 asked the learners to draw the atoms involved in the reaction in their exercise books.

2 moles of H_2 + 1 mole of O_2 $\longrightarrow$ 2 moles of H_2O

The learner showed how the equation balanced and the teacher stated that that is a chemical reaction and it tells you what will happen. From my own observation the teacher used a lot of teaching methods, such as being teacher centered, learner centered, and using representation and questioning methods. This is against Chick's (2007) view that teachers chose relevant examples which can also be applied to the choosing of relevant teaching methods.

T6 further gave practice examples on the concept discussed, for learners to do in the classroom. This goes along with Chick (2007) that teachers are in position to choose relevant and correct examples for learners to practice. The following were the examples given by T6:

1. Two make a pair, therefore, 2 shoes make a pair of shoes.
2. 12 make a dozen, therefore 12 eggs make 1 dozen eggs.
3. 144 make a gross, hence 144 eggs are 1 gross of eggs.

1 mole = 1 molecule of a substance can be represented in a chemical equation.

$2\ H_2 + O_2 \longrightarrow 2H_2O$. T6 asked for the ratio of moles in the reaction.

Ratio: $2:1 \longrightarrow 2$

$2H_2$ and 1 O_2 gives $2H_2O$

In concluding the lesson, the teacher asked for the mass of some elements, magnesium and carbon. The learners gave the following answers:

Magnesium (Mg) = 24, and carbon (C) = 12

T6 then told the leaners to always remember that every element in the periodic table represents 1 mole of the element e.g. 1 mole of Mg and 1 mole of C and thus the lesson ended.

The lesson was well presented, but incomplete concepts can affect learners in their studies. T6 failed to mention the units of Mg and C given by the learners, which is atomic mass unit (amu). This harmonises with Chick (2007, p. 1) that "it is clearly important for teachers to be able to choose or design suitable examples, to recognise what is offered (or afforded) by particular examples, and to know how to adapt an already existing example to better suit an intended purpose". From my own view this approach of not using or giving the correct concepts might affect the learning of the learners. As this was done by T6, one of the CoP members, a series of these mistakes might have happened before the workshop intervention, which might have affected learners' results on the stoichiometry questions.

Reflections on the lesson by T6

T6 explained the concept to learners using various teaching strategies and asked questions, but T6 had the problem of asking questions and immediately answering the questions himself. This is contradictory to the view of Bransford, Brown and Cocking (2000). Bransford et al. (2000) posit that, coming to know something requires learners to actively participate as they construct and progressively improve their understanding through the exploration of ideas. In my view, total involvement of learners might enhance the learning in the class and the intervention might be beneficiary to T6 in order to correct the tendency of asking questions and answering them himself.

7.2.5 Transcriptions of SRI after classroom observation of Physical Science teachers

Many qualitative studies collect audio of video data recorded from various sessions (e.g. interviews, focus groups etc.). These are usually transcribed for a closer study. Transcribing appears to be a straightforward technical task, but in fact involves judgment about what level of detail to choose (e.g. omitting non-verbal dimensions of interactions), data interpretation (e.g. distinguishing ‘I don’t, no’ from ‘I don’t know’) and data representation (e.g. representing the verbalisation ‘*hwarryuhh*’ as ‘how are you?’) (Bailey, 2008).

Audio and visual data representation in written form is an interpretive process and it is the first step in data analysis. Recordings are transcribed so that they can be studied in detail. After the classroom observation procedure with the participants, I made time to watch the videos over and over again so as to be able to transcribe the recordings into written stories.

Bailey (2008, p. 130) states that “transcribing is an interpretive act rather than simply a technical procedure, and the close observation that transcribing entails can lead to noticing unanticipated phenomena”. It is impossible to represent the full complexity of human interaction on a transcript and so listening to and/or watching the ‘original’ recorded data brings data alive through appreciating the way that things have been said, as well as what has been said (Bailey, 2008). Transcribed data from audio-visuals for each of the participating teachers was outlined immediately after the presentation of their classroom observation.

After the presentation of the lessons by the teachers at their respective schools, I watched the videos at least twice and came up with the transcriptions about the lessons. Transcriptions enhance the analysis of a study. Researchers need to take from the spoken text (structured, unstructured, or narrative interviews) to a written form for analysis (Stuckey, 2014). According to Powell (2005), stimulated recall discussions have been found to enhance reflection on one's teaching. The following are the transcriptions that emanated from the SRI after the classroom teaching video observations of T3.

7.2.5.1 Stimulated Recall Interviews (SRI) with all three teachers (T3, T4, T6)

A stimulated recall interview is considered by scholars in learning and teaching (Mackey & Gass, 2005) to be an inner-directed measure in which the teacher is provided with a stimulus and engaged in reflections of the thought processes in mind while teaching. It is "an information processing approach whereby the use and access to memory structures is enhanced, if not guaranteed, by a prompt that aids the recall of information" (Gass & Mackey, 2000, p. 17). The stimuli used were video and audio which served to stimulate the teachers' recollections of mental thoughts during teaching activities. In this section, the stimulated recall interviews with T3, T4 and T6 at different times, are discussed below. The videos were watched together with the three teachers individually at different times and later the interviews commenced and were audio recorded at different times.

The first question served as an introduction: **You have seen your own classroom teaching video. What do you think is useful and what do you think we need to improve on?**

T3 paused for few minutes and later reflected that

> *It is very interesting to see yourself and see some of the things you cannot even remember after the teaching. From the academic point of view is that learners are given freedom to bring out the answers themselves. Writing on the board is a way of encouraging learners to be free and contribute freely. Working out problems on the chalkboard are a positive way of teaching to enhance understanding of the concepts being taught.*

In my own view, T3 commented on his own self-observation saying that:

> *On the areas where I saw that things were not okay, we need a lot of time because they are supposed to have done some of these things in Grade 10, so we are spending a lot of time as if we are starting a new topic. In short, we wasted a lot of time. That is one of the*

> *weaknesses I observed. Maybe my voice also was not clear. We could have allowed learners to work out the problems without coming to the board to write.*

Desimone and Le Floch (2004) state that self-observation is a strategic process which can be verbalised by having respondents take their time attending to more specific bits and pieces of their thoughts and by researchers' providing respondents with prompts to elicit more specific information. It could therefore be ascertained that if questions from myself could stimulate T3, data would be generated not by coercion but voluntarily coming from T3.

T4 responded as follows: *"I need to use the periodic table chart in the classroom for the learners, to enhance proper teaching"*. T4 taught atoms and elements.

T6 responded to the same question about improvement on the teaching saying that:

> *I will say I'm satisfied, that it was ok. There is actually a lot of good stuff which I observed when I'm watching it than when I was teaching like, breaking down components and making simple things for learners to understand. I wish I could have done more on the aspect of illustrating using models of atomic structure, so they can see the objects which are constructed and the similarity of what I was teaching. Ordinarily, let me say that I'm happy because I was linking what I know. Unpacking difficult concepts like the word stoichiometry.*

T6 introduced the concept 'stoichiometry' to learners for the first time. One can infer that both teachers were happy seeing themselves after teaching in the class, which Walker (2008) emphasises as being a part of effective teacher, which is to be positive, by having optimistic attitudes about teaching.

The second question, about targeting challenges, followed: **What are the challenges you faced in the teaching of stoichiometry as seen in the video?**

T3 said that with the introduction so far there were no challenges on the teaching of stoichiometry, but challenges emerged on charges identification on elements.

> *What came so early is that learners are seeing negative charges for metals. Making Calcium charges -2 and Oxygen charges +2. That might be due to misconceptions that when elements lose, it's a minus and when they gain it's a plus. This might have made the learner come up with that statement.*

T3 was able to identify the challenge of misconceptions, similarly to Cox, Steegen and De Cock's (2016) view of awareness that teachers have of misconceptions and the possible strategies used to change the students' mental models. T3 further expatiated that he would use problem-solving strategies to correct the anomaly observed with charges identification on elements.

T3 was asked a follow up question about not writing the comments or answers of the learners on the chalkboard, T3 said,

> *That is a very good observation. It's a weakness on my part as a teacher. When learners are giving answers as short as they were, I need to write them on the chalkboard. For sure next time I will work on it and such kind of mistakes will not repeat themselves again. I will write the answers I get from the learners on the chalkboard.*

T3's comment agrees with Walker's (2008) view that one of the characteristics of a good teacher is the ability to admit mistakes, apologise for mistakenly written or unwritten text or verbal communications. Any teacher having this type of character has an indication of learning, and l can infer that this prompted T3 to partake in the study.

With question 2 focusing on challenges, T4 said *"Stoichiometry is a problem for most learners, and they fail"*. This is a challenge and solving this one perhaps needs a provincial visit to the groups, giving learners more problems to solve and giving extra classes as per the needs of the students.

Below is the response of T6 about the challenges learners face with stoichiometry:

> *Involvement of learners themselves to concentrate on particles of elements, for example more activities can be developed, so that learners do it practically in class in the form of a simulation. I have mentioned simulation earlier in my lessons so that at least learners can have a close inspection of what stoichiometry itself is all about, because it is a very difficult component for learners to understand.*

Focusing on the responses of these teachers, it can be inferred that responses differed because of the perspective or the angle of focus on the concept, which goes with Walker (2008) about different methods or approaches that a teacher needs to embark on when teaching.

To the question of self-observation about teaching methods used before the intervention and after the intervention, which were now to be compared, T3 posited that, *My complaint as a teacher, just looking at the syllabus, I thought there is a bit of disconnection between what we are supposed to do and where we are supposed to start from. That is why I would like to see what will make stoichiometry easier for learners to have as a stepping stone to build on as they do the other concepts that may be difficult concepts for learners.*

One could infer that T3 was able to see the missing gap in his teaching approaches. This confirmed or aligned to the point that the workshop intervention generated good teaching approaches for the CoP members. T3 made a comment on the exemplary lessons and learning and teaching materials produced during the study:

Research is simply saying, there is this problem, let's find out how best this problem can be dealt with. What are the solutions? So, if there is a research, for sure that should be the antidote for the problems we have had all these years. So, I will definitely use the models and LTSMs in my teaching.

From my understanding, T3 believed that if what was learnt at the workshop was better coordinated and implemented properly, the problem of poor performance in stoichiometry questions may be eliminated.

On the same question of self-observation about teaching methods used before and after the intervention, T4 had this to share,

Seeing myself also motivates me and l personally will be able to correct my mistakes which l may not be able to recall if not recorded. If l have the means this recorded video can also be used to teach a class in future. It enhances me to correct my mistakes and move forward.

T6 shared this about the question on self-observation,

I was nervous thinking that am I not exposing my mistakes now because the teaching is recorded but it is stimulating, and I believe that it exposed some of my goodness and short comings, which l can control in order to improve my teaching. In a nutshell it is a correcting strategy for me.

All these teachers saw the advantages of self-observation if they were to progress and be more effective teachers.

A follow up question for T3 was: **During the course of teaching you provided the periodic table for your learners, why did you do that?**

Immediately he responded and said that,

> *The periodic table is the nerve centre for the topic we were to discuss, so there was a need for the learners to have the periodic table, because through the periodic table we will know the charges. The periodic table helps in understanding of symbols, atomic number, mass number, valence and even chemical bonding and later helps in balancing of chemical equations. It makes life easy for learners.*

From T3's comment, it seems Mavhunga and Rollick's (2013) concepts of TSPCK were applied and these tenets were representation and curricular saliency.

T4 responded on periodic table distribution in the class, saying that, *"Periodic table is helping in understanding atomic number, mass number, valence and even chemical bonding and later helps in balancing of chemical equation"*.

This is similar with the reflection of T3 above. T6 did not distribute periodic tables, so there was no response from T6. I asked T3, if there was anything he wanted to share with me, that would help in this study and he voiced that,

> *I was just thinking that maybe the syllabus for Grade 11, as we continue, we look at infusing some of these ideas in the syllabus or scheme of work on how the topics should be tackled, so that we do it systematically in all the schools. When we do it systematically in schools, the challenges we are facing will surely be reduced.*

On the question of any issues that could be shared with me about this study, T4 said,

> *I believe that we should be motivated to do research as it enhances teaching, if management can be informed, research will benefit us. I hope the results of this study will be made known to the management and other stakeholders for the benefit of teachers.*

T6 added that:

> *I think it would work better to get information from the learners since they are the recipients of the learning process. Holding a discussion with them to find out the difficulties they have about stoichiometry. This will be getting information from the horse's mouth and by so doing, I'm sure you can work out ways to remedy their difficulties based on what they would have told you. You can get a clearer picture of how they better understand courage in the learners. This is something that we also lack in our schools. So, I think that approach will yield positive results.*

7.3 Concluding Remarks

In this chapter, I presented, analysed and discussed the interviews and the classroom observations of the teachers. This chapter sought to address research question 3 which looked at how Grade 11 Physical Science teachers mediated learning of the developed stoichiometry exemplary lessons.

In the next chapter, I present a summary of my findings, recommendations and conclusions.

CHAPTER EIGHT: SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSIONS

> *Reflective thinking is a multifaceted process. It is an analysis of classroom events and circumstances. By virtue of its complexity, the task of teaching requires constant and continual classroom observation, evaluation, and subsequent action. To be an effective teacher, it is not enough to be able to recognise what happens in the classroom. Rather, it is imperative to understand the "whys" "how's," and "what if's" as well. This understanding comes through the consistent practice of reflective thinking.* (McKnight, 2002, p. 1)

8.1 Introduction

The main goal of this interventionist study was to explore how to support Grade 11 Physical Science teachers' understanding and mediation of learning of stoichiometry concepts. The intervention was in the form of workshops for teachers' continuing professional development (CPD) and was conducted using participatory action research within a community of practice (CoP). Essentially, as proposed by Shulman (1986) the study was intended to enhance both the SMK and PCK of the teachers involved in this study. It was hoped that these teachers would be able to mediate learning of stoichiometry effectively in their science classrooms. This ideal resonates with Friedman and Phillips's view (2001) about CPD that,

> CPD is the systematic maintenance, improvement and broadening of knowledge and skill and the development of personal qualities necessary for the execution of professional and technical duties throughout the practitioner's working life. (p. 4)

This caveat is relevant to my study as its focus was on professional development of science teachers to broaden their knowledge and skills in order to enable them to systematically mediate learning of stoichiometry. It is recognised, however, that to achieve this involves lot of multifaceted processes during teaching and learning as proposed by McKnight (2002) in the epigraph.

In the previous chapter, I presented, analysed and discussed data generated from the classroom observations and stimulated recall interviews. In this chapter, I thus present an overview of my study, a summary of the research findings, new knowledge generated in this study, some recommendations, limitations of the study, areas for future research and reflections. Finally, I present the conclusion of the study.

8.2 Overview of the Study

The primary emphasis of this study was an intervention on supporting teachers' understanding and mediation of learning of stoichiometry in selected schools in the Zambezi region. The rationale was to understand and support Physical Science teachers on how to effectively mediate learning of stoichiometry.

To achieve this goal, the following research questions were posed:

1. What are Grade 11 Physical Science teachers' understandings of teaching stoichiometry prior to the intervention?
2. How does an intervention in the form of workshops support Grade 11 Physical Science teachers in developing exemplary lessons for teaching stoichiometry? and
3. How do Grade 11 Physical Science teachers mediate learning of the developed exemplary lessons?

In Chapter One, an overview of the study was discussed focusing on the background of the study, problem statement, and significance of the study, research design and methodology, research goal and research questions and a brief overview of the thesis chapters. Chapter Two concentrated on the relevant literature on the teaching of stoichiometry. Chapter Three discussed the theoretical framework informing this study. That is, constructivism, namely, Piaget's cognitive constructivism and Vygotsky's social constructivism were discussed. Additionally, Shulman's (1986) PCK was also discussed. Within PCK, the TSPCK was used as an analytical lens (Appendix L) (Mavhunga & Rollnick, 2013).

Similarly, to Ngcoza's (2007) study, it could be argued that this study adopted an emancipatory research approach since its purpose was to develop understanding and knowledge about the nature and root causes of the problem in order to develop strategies to solve this problem. This was the case with the stoichiometry intervention workshops; to help the Physical Science teachers to develop relevant strategies to solve stoichiometry problems. Essentially, the subject matter knowledge, pedagogical content knowledge encouraged by emancipatory learning are formed within Wenger's CoP as a framework to enhance the CPD of Physical Science teachers through PAR.

In Chapter Four, I discussed the research paradigm underpinning the study. That is, the interpretive paradigm, which located the methodology within the qualitative research, employing the participatory action research approach (as discussed in Section 4.4.1) as a way to understand and promote the Science teachers' CPD within a CoP. The interpretive research paradigm views reality and meaning making as socially constructed and it holds that people make sense of social realities (Cohen et al., 2011). This is the reason why interpretive research was used in this study to assist me to understand my research participants' opinions on how stoichiometry concepts should be taught. The interpretivist character of this study manifested when TSPCK, an analytical lens (Appendix L), was used to support the theories and concepts discussed. This served as a useful precursor to the participatory action research approach used in this study within the CoP, allowing the participants to work together collaboratively during the intervention workshops to construct and transform SMK and PCK of CoP members.

This descriptive qualitative study in which cycles of stoichiometry participatory action research (see Figure 4.4.2.1) was used employed four phases to generate data. In Phase One, the data generated came from survey questionnaires, semi-structured interviews and document analysis. In Phase Two, data were generated through workshop discussions, while in Phase Three data were generated from workshop discussions, observations, videotaped lessons and stimulated recall interviews. In Phase Four, data were generated from reflections on the implementation of exemplary lessons (see Table 4.3.2.1).

Six teachers participated in all the phases and the research sites were schools in the Zambezi region. The data generated were then presented and analysed in Chapter Five, Six and Seven. Some discussion of the summary of research findings are discussed in this chapter. I now present my summary of findings below.

8.3 Summary of Findings

The focus of this study was about an intervention to support teachers' understanding of and mediation of learning of stoichiometry, but my summary of findings will also include what transpired before and after the workshop intervention. From my experience, social constructivism, PAR, and CoP have become some of the most influential forces in Science teaching. This study gave me an opportunity to observe and understand constructivist theory and its application in teaching and learning. My findings before the intervention were amazing; the teachers were feeling reluctant to be part of the study and were shy to talk or answer questions during the study (anti-social). I presumed all this to be a lack of confidence or fear of the unknown about the project. At the commencement of the workshop there was a shift in teachers' behaviour. The teachers were now volunteering to do things willingly during and after the workshop. T3 volunteered to facilitate mapping of stoichiometry during the workshop. Teachers now opened up about the research project. T4 publicly asked me if I could assist him in some other topics in Physical Science – this had never happened before. That is the main reason why I stated that subject matter knowledge and pedagogical content knowledge skills had shifted as a result of their participation in the workshop. During the workshop intervention, data generated were analysed to answer my three research questions (see Section 8.1). I thus present the summary of my findings in relation to these research questions.

8.3.1 Research question 1

What are Grade 11 Physical Science teachers' <u>*understandings*</u> *of teaching stoichiometry prior to the intervention?*

The aim of the data generated during pre-intervention was to find out how teachers mediated the learning of stoichiometry before the intervention. This served as baseline data on how to understand and plan the intervention workshops to improve the teachers' SMK and PCK in relation to the teaching and learning of stoichiometry, using participatory action research within a CoP. Questionnaires and interviews were used to generate data to answer this research question.

Interviews were conducted with teachers prior to the intervention and during the analysis of the interview transcripts, themes emerged and were linked to the theory (see Table 5.4.1). Below are some of the teachers' responses during interviews. Below are the responses from T3, T4 and T6 on themes about LTSMs and practicals for effective teaching (representations).

T3's responses on LTSMs was as follows: *"Use of worksheets or tests or do some written exercise to help those that are still lagging behind with the concept that is being taught*".

T4's views on LTSMs were: "*The use of a practical approach. I use a practical approach, and wherever possible I need to demonstrate. My work was more of hands on experiments, practicals and the results facilitate learning*".

T6's responses on LTSMs went like this: "*I like to prove things. Whatever I do I really want to prove because it is based on reality. Stoichiometry should be taught in a standard laboratory and demonstrated, carry out experiments where possible*".

From these excerpts, it is evident that T3, T4 and T6 were all in favour of LTSMs for the teaching of stoichiometry. This could be the reason why in all the schools, question 1 in the diagnostic test was answered by learners (see Section 5.2). This question was about moles using diagrams or representations to generate questions (Appendix J).

The teacher research questionnaire covered all the tenets of TSPCK, namely, learners' prior knowledge, curricular saliency, understanding of what makes a topic easy or difficult to understand, representations (including analogies or models) and conceptual teaching strategies. It emerged from this study that three teachers (T2, T5 & T6) failed to answer questions on conceptual teaching strategies, what makes a topic easy or difficult to understand and questions on the representation. In contrast, only T1, T3 and T4 answered the question in the questionnaire correctly. It could be argued that this justified the need for the intervention workshops for the teachers.

The findings revealed that the use of a diagnostic test on learners made the Physical Science teachers aware of the learners' challenges in stoichiometry – what is difficult to understand (Mavhunga & Rollnick 2013) – something which necessitated the need of workshop interventions to assist them. It also helped in the use of prior knowledge, one of the tenets of TSPCK, to access what learners already knew about stoichiometry.

8.3.2 Research question 2

How does an intervention in the form of workshops support Grade 11 Physical Science teachers in developing exemplary lessons for teaching stoichiometry?

The aims of the workshops were to analyse the learners' diagnostic tests and curriculum documents, co-develop exemplary lessons and worksheets, as well as learning and teaching support materials (LTSMs) with the aim of improving the teaching and learning of stoichiometry.

Furthermore, the workshops were intended to generate data about how teachers mediate the learning of stoichiometry during stoichiometry teaching, to understand and improve the teachers' SMK and PCK in relation to the teaching and learning of stoichiometry. For all the above to be achieved we held a total of four workshops within a period of eight weeks (see Sections 6.2 to 6.4).

The first workshop documents such as diagnostic tests, textbooks, schemes of work, Physical Science syllabus, Examiners' Reports and Namibian senior secondary certificate higher/ordinary (NSSC (H)/(O)) past examination question papers, were analysed for this study. Furthermore, recommended textbooks for teaching of stoichiometry emerged from this workshop. My reflections and impressions of our first workshop was that the Physical Science teachers worked together collaboratively as a team (Lave & Wenger, 1991; Wenger, 1998). For instance, the science teachers involved in this study indicated that it was the first time they had come together to analyse examination question papers, examiners' reports or even looked at relevant textbooks for the teaching of stoichiometry. Teachers were motivated by the setting of the adapted diagnostic test and textbook identification during the workshop. From my own view, this strengthened their confidence in this study and they were fully involved.

The second workshop started with basic mathematics and mapping out of stoichiometry (see Boxes 6.4.2 and 6.4.3 for Basic Mathematics Operations 1 and 2 respectively). Croteau et al. (2007) argue that in the beginning of teaching Chemistry, learners are taught a variety of Mathematics involving balancing of equations. Paying some attention to Mathematics during our workshops thus resonates with Croteau et al.'s (2007) idea – teaching of Mathematics in this study was needed for learners' understanding of the stoichiometry concept. As CoP members, we agreed that we should collaborate with Mathematics teachers to assist with stoichiometry Mathematics concepts prior to teaching.

Mapping out of stoichiometry was facilitated by T3 who volunteered to do it at the workshop. Stoichiometry mapping is a procedure that shows which concept comes before the other and it aligned with curricular saliency of the TSPCK (Mavhunga & Rollnick, 2013).

In the same workshop, lesson presentation on the calculation of mole conversion (see Box 6.4.1.2) was done with representations or models to explain the mole concept for ease of understanding (Evagorou et al., 2015). Furthermore, examples of mole calculations were solved during the workshop. During this representation, a game was used and Ersoz (2000) argues that games are highly motivating in teaching because they are amusing and interesting and learners can practice with them. Concurring, Wang (2010) suggests that using games to explain concepts creates an atmosphere that might enhance the learners' desire to learn. That is, learners learn better when they have the feeling that they are making progress and games provide an opportunity for them to practice and overcome their fears.

According to Jana, Arui, Dutta, and Sar (2016) in their studies about teachers' views about game-based learning, they discovered that teachers experienced problems about time planning, learners' non-cooperative behaviours, and teachers' insufficient background knowledge about organising and designing games. In my own view, if some of these points are not carefully monitored and controlled, games might hinder effective learning and teaching in the classroom. In this study the intervention workshop for the teachers might have helped to control some of these negative experiences about games, as teachers collaboratively worked together and constructed knowledge (Vygotsky, 1978).

The third workshop was about the empirical and molecular formulas respectively (see Boxes 6.5.1.1 and 6.5.1.2), revisiting the objectives of the study, and development of exemplary lessons on empirical, molecular formula and LTSMs. As proposed by Zirar et al. (2017), after the presentation, CoP members revisited the objectives of the study (see Section 1.7). Zirar et al. (2017) state that revisiting the objectives in their study was so that they could gather evidence and derive fresh insights or ideas. In the context of this study, revisiting objectives of the stoichiometry study was done to help the participants in the areas that needed improvement for the teaching of stoichiometry.

From this workshop it emerged that most teachers had problems with the development of teaching and learning materials (LTSMs). This intervention workshop for teachers on model development was seen as a need to enhance mobilisation plans for LTSM development. To Bušljeta (2013), the purpose and role of LTSMs, not only consists of making the educational process more attractive and interesting, but also encourages active learning and the development of different skills for learners. Teaching on how to make models or LTSMs to strengthen the Physical Science teachers' CPD was facilitated by me (researcher). Box 6.5.4.1 outlined the procedure of making a model of an electronic structure of an element. Electronic structures of Magnesium and Beryllium were constructed by the participating CoP members during the workshop (see Figures 6.4.4.1 and 6.4.4.2 respectively). Materials used were locally available materials as espoused by Asheela (2017). These activities marked the end of the third workshop and preparations were subsequently made for the fourth workshop.

The fourth workshop started with the percentage composition of substances and balancing of chemical equations. The exemplary lessons on the percentage composition of substances were summarised in Box 6.6.1.1. Teachers were excited with the practical analogy and it was an eye-opener to them. As a result, T2 and T5 indicated that it was the first time that they were exposed to the use of analogies as a teaching strategy. Most importantly, they reflected that this lesson enriched their SMK and PCK.

Balancing of chemical equations using the algebraic method (see Boxes 6.6.2.2 and 6.6.2.3) was facilitated by me. The CoP members were happy with the lesson presentation on balancing of equations and they took notes on it. These notes might help to develop their SMK when engaging themselves in the practice.

My research question 2 was thus adequately answered, as evidenced in the teacher responses and active participation during the workshops (Sedlacek & Sedova, 2017). The participants acquired knowledge in making models or LTSMs. As a result, it could be argued that their SMK and PCK were strengthened. Overall and similarly to Ngcoza's (2007) study, it could be argued that the workshop intervention was a beneficial CPD programme for them. Also, it aligns with Eun (2008), that for this social interaction to lead to development, it has to be situated in activities that have a clear goal, such as joint problem solving. This is what my study was all about – having a clear goal on how to mediate the learning of stoichiometry, resulting in CPD of the teachers.

All the teachers observed used representations during the course of teaching. T3, for instance, who also teaches Biology proclaimed how he used representations or models in his Biology class and subsequently a plant cell model was made by his learners as a project. One can infer from this that the intervention workshops were successful and should be on-going. According to Eun (2008), on-going infers continuous follow-up support which is similar to mediation. This mediation had three types of mediators: tools (material resources); signs (newsletters and journals); and other humans (professional networks).

The findings of this study further indicated that the CoP members acquired the professional transformations which were important breakthroughs in their careers. Transformation is defined in the Vygotskian framework as those forms of behaviour that are used between people in concrete social interactions (i.e. intermental plane to the forms of individual mental processes i.e. the intramental plane (Eun, 2008). The internalisation process does not occur automatically from a direct transformation of the intermental plane to the intramental plane, but through the use of mediators. The intervention workshops in my study were framed with activities serving as material mediators (artefacts) that aimed to solve stoichiometric problems. So, the collaborative working together of CoP members might lead to their CPD. The CoP members in my study also were the human mediators enhancing transformation that resulted in higher forms of mental functions leading to their CPD.

The findings of this study revealed the ZPD of participating teachers, coming from different backgrounds and having the ability to do certain skills before the intervention. ZPD is not only for learners, but it can be applied to teachers as well. In this study the ZPD enabled teachers to define their immediate needs and the shifting developmental status, which necessitated the need for the workshop intervention.

The findings also revealed the total involvement of teachers during the workshop. Teachers were actively involved in the study, volunteering willingly to partake in any task without coercion. T3 volunteered to facilitate stoichiometry mapping during the workshop intervention.

8.3.3 Research question 3

How do the Grade 11 Physical Science teachers mediate learning of the developed stoichiometry exemplary lesson?

To answer my research question 3, data were generated using observations and video recordings. The procedure of the video recordings was as follows; dry-run, live-run, observations and reflections, and stimulated recall interviews (SRI). The dry-run was an acclimatisation process; the live-run was the recording of the lesson in motion; observations and reflections were the watching of the video with each teacher; followed by the SRI. According to Powell (2005), SRIs have been found to enhance reflection on one's teaching.

In the context of this study, the stimulated recall interviews assisted the Grade 11 Physical Science teachers to reflect on the way they mediated learning of stoichiometry exemplary lessons. My study helped the teachers to keep their professional knowledge and skills updated which concurs with the view of Hyatt (2017).

During the classroom observations, I noticed that T3, T4 and T6 used LTSMs during their lesson presentations. For instance, T4 clearly illustrated with relevant diagrams the meaning of the stoichiometry concepts (see Section 7.2.4.2) while T3 and T6 used the periodic table as the LTSM. The classroom observation established that CPD and LTSMs can play important roles in the mediation of learning of stoichiometry.

The findings in this study revealed significant changes in the teachers' subject matter knowledge and pedagogical-content knowledge as a result of being engaged with the participatory action research approach within our CoP. For example, during interviews and classroom observations, the teachers were able to explain the use of TSPCK, tenets both in their lesson preparation as well as classroom teaching.

The findings of this study further revealed that developing exemplary lessons and LTSMs, collaboratively boosted both the science teachers' subject matter knowledge and pedagogical-content knowledge. The LTSMs made during workshop interventions were used in their classrooms for effective teaching of stoichiometry during the observation follow-up visits.

In summary, the findings of the study recognised that the teachers' subject matter knowledge and pedagogical content knowledge skills had shifted as a result of their participation in the workshop intervention. These findings corroborated the findings of Tshiningayamwe (2015), who said that teachers in professional learning communities share successful teaching strategies, develop new approaches to shared problems and share specific subject matter knowledge.

8.4 New Knowledge Generated in this Study

The findings in this study suggested ways of closing the gap widened by not implementing TSPCK tenets in the classroom by Physical Science teachers. As an attempt to address this gap, learners were given questionnaires in order to assess their understanding of stoichiometry.

T3 and T5 commented about some concepts such as Avogadro's and limiting reagents that they found problematic during the compilation of difficult stoichiometry concepts. From literature accessed so far, none talked about this approach of using learners to access teachers' SMK (BouJaoude & Barakat, 2003; Fach, de Boer & Parchmann, 2007; Opara, 2014). So, it could be concluded that it is a new knowledge in the research of teachers. This approach might make research *with* teachers (Ngcoza & Southwood, 2015) friendlier, when implemented.

In the context of Namibia, with new innovation in the field of education, CPD for updating is intended as a new mode of collaboration in the teaching of concepts. However, how to foster such collaboration among teachers needs support. Nevertheless, the findings of this study suggested that creating opportunities for teachers to collaborate within updating CPD, enhanced the effectiveness of classroom teaching. This is a new approach and new knowledge for learning, if well implemented.

The use of TSPCK tenets, contributed to the theory of CPD. TSPCK during the workshop intervention promoted the professional development of teachers; the TSPCK tenets were used to analyse documents (Appendix L) during the workshop. This might be regarded as a new knowledge. However, even as a lecturer with many years of experience, it has never occurred to me that TSPCK could be used in document analysis and in classroom teaching during lesson preparation and presentations. This is a new approach in the context of my study as a theoretical contribution to TSPCK.

Another new knowledge in my study is the integration of knowledge and skills across subjects. In my study, one of the CoP members (T3) was able to transfer the knowledge learnt about model development in stoichiometry to Biology. T3 instructed the learners to make a model of a plant cell during a Biology practical activity in the class. This is a new knowledge. CoP member should know that their need to learn new skills means learning from CoP members, learners or professionals in order to use these in their classroom teaching (Gilakjani & Sabouri, 2017). T3's learning of model development that was integrated into Biology, took place during the workshop intervention for stoichiometry.

The formation of the CoP in my study was an acceptable approach that produced new thinking on how to teach stoichiometry. The members were Physical Science teachers, a Science subject adviser, a university lecturer and me. Through this approach, teachers were able to develop LTSMs for the teaching of stoichiometry. One of the teachers also experimented with this approach in the teaching of Biology. The new knowledge from working with members in a CoP with different backgrounds was that members came with knowledge from a wide spectrum. When this knowledge from different CoP members was summed up, it developed solutions to teach stoichiometry.

8.5 Recommendations

The study focused on the influence of the intervention workshops (see Section 6) with the view to improving the six Physical Science teachers' practice within a CoP in the Zambezi region. The results illuminated the fact that the role and importance of the workshops and CPD cannot be overstated within a CoP.

Arising from this study, I thus offer the following recommendations for consideration by lecturers, teachers (curriculum implementers), school principals, inspectors, CPD initiators and educational policy developers.

- Teachers should develop effective teacher professional development activities such as study teams, cluster teaching, and peer coaching where teachers are expected to examine their assumptions and practices continuously;
- Teachers should engage in hands-on practical activities to put more emphasis on the concepts 'to be innovative' and 'to be critical', during classroom teaching of stoichiometry;
- The use of relevant teaching materials in the teaching and mediation of learning stoichiometry might be associated with a shift towards the use of TSPCK tenets for the teaching of stoichiometry concepts;
- This study afforded learning opportunities for Physical Science teachers (see Section 6.2 to Section 6.6) and such experiences resulted in positive learning experiences for their learners in the long run as well. I therefore recommend that Physical Science teachers should promote CPD updating from the bottom-up, for school management to enhance their professional development;
- From my own perspective, it is my contention that while engaging teachers in CPD using participatory action research within a CoP, it should be done with care. I therefore recommend that university lecturers, senior education officers such as inspectors or subject advisers, who are knowledgeable about CPD, should be part of a CoP;
- I recommend that teachers develop LTSMs for any academic or non-academic classroom presentations for their CPD, provided it enhances learning.
- The implication of my study is that the developed exemplary lessons during the workshop intervention by CoP members should be encouraged to be used in the teaching of stoichiometry in all the schools in the Zambezi region;
- Finally, this study recommends school-based CPD programmes for schools. This could serve to empower the principals and Head of Departments to engage with the CPD implementation process in a simple manner that will motivate the participants to be fully involved and be cost effective.

8.6 Limitations of the Study

The focus of this study was how an intervention supported Science teachers' understanding and mediation of learning of stoichiometry in selected schools in the Zambezi Region. That is, the participants in this study were Physical Science teachers teaching within the Katima Mulilo urban area in the Zambezi region. Due to financial, time and geographical constraints, the study was only carried out in three schools. As a result, the findings of this study cannot be generalised. Nonetheless, it provided some insights into how Physical Science teachers collaborated with each other during the workshops. The intervention also enabled teachers in these specific schools to make sense of stoichiometry concepts and the challenges that confronted them.

In this study another limitation experienced was that only six Physical Science teachers were used as the unit of analysis in this study, leaving out other Physical Science teachers in the Zambezi Region.

One other limitation observed in my study was the absence of the subject adviser and my critical friend, the university lecturer, both of whom could not carry on until the end of the research project. The subject adviser left because of the expiration of his work contract. The university lecturer, my critical friend, left because of other assignments from his university.

Another limitation in this study was that I did not ask these teachers to write reflections throughout this research process and instead they just reflected as a group. In research, reflections are critical especially when a participatory approach is employed. According to Ryan (2013), reflection is one means of encouraging deeper and richer understandings during the learning process and is a form of purposeful thinking that can be used to explore complex problems and anticipate outcomes. Also, Ash and Clayton (2009) posit that reflection allows the learners to seek out personal meanings and identifications with the learning material and create connections with the ideas and content already known. From literatures, I found reflection appropriate in any study. It enhanced the importance of workshop discussions and this might inspire participants to consider reflective practices in their own teaching. I will emphasise daily reflection in any future projects.

In light of these limitations, if I were to do the study again, I would still foreground teachers as the unit of analysis but reduce the number to four teachers and encourage reflections to be written down daily during the research period. This would generate more insights into the teaching of stoichiometry. I would also look for funding so that the scope of the study can be extended to more regions within Namibia to make a comparative study, which might enhance generalisations.

8.7 Areas for Further Research

Other studies could engage with CoPs using students as the unit of analysis. Students from different neighbouring schools could work collaboratively together to solve issues on scientific concepts.

More research studies could be carried out on stoichiometry, focusing on how teachers mediate the learning of stoichiometry.

It might be more appropriate to conduct more research studies based on the teaching of Chemistry using local materials for conceptual understanding of Chemistry concepts in the laboratory or classroom.

Another study about Chemistry hands-on practicals could foreground learners as the unit of analysis and encourage reflections to be written by all the research participants as the study progresses.

Finally, research could be carried out on teaching and learning of chemical equilibrium, as it involves balancing of chemical equations as in stoichiometry, using students as the unit of analysis.

8.8 Reflections

"How is our project going?" (T4)

I was humbled by this question by T4, one of my research participants, which he asked at a shopping centre in Namibia. This shows that *ownership* was developed in our CoP. I could infer that our project has given teachers the confidence and developed their passion for science. It gave me the confidence that the workshop intervention, along with the interactions of the CoP members, had developed their SMK and PCK and also equipped the teachers with confidence in future science projects. T4 demonstrated this when he stated that the project was not mine as the researcher, but for all the CoP members in which he was one of them. The project was ours.

The topic 'stoichiometry' is a challenge in Namibian schools and I came to realise this when I was with the Rössing Foundation as a science coordinator. When I gained admission to the PhD programme with Rhodes University, I thus decided to research what the problem could be with stoichiometry concepts. Through a successful written proposal, assisted by my supervisor, I came up with the main research problem – how an intervention could support teachers' understanding and mediation of learning of stoichiometry in selected schools in the Zambezi region.

Being a part-time PhD student was not an easy thing due to other crucial commitments such as work, family, friends and many others. For me to be able to make any progress during this time, I had to spend some sleepless nights, limit the time spent with my family, friends and others. For me not to quit the programme needed God's intervention as I had two major operations during this journey.

At Rhodes University when l was presenting my research proposal for the first time, the first question was: *Unpack the term stoichiometry*? I managed to respond to the question by explaining the meaning of stoichiometry (see Section 7.1.4.2). *Stoichio* is a Greek word meaning substances or elements and *metry* meaning measure. Literarily combining the two words means substances or elements measuring.

After the proposal presentation at the Department of Education of Rhodes University, I went back to the Zambezi region in Namibia and I started negotiating with the local teachers to participate in my study. One thing that I learnt during my study with Rhodes University is that you do not give up and with the support of your supervisor, you will overcome any situation; there is always a way out.

From my research participants, three out of six Physical Science teachers in this study were taught by me at a teacher's college in the Zambezi region. I also worked with these teachers during science week or science fairs, school-based studies and during career talks in schools in a positive way, as colleagues. Regarding ethical considerations, I presented myself as a colleague so that the issue of positionality would not interfere with my study (see Section 4.7).

In this study, I worked with teachers using a participatory action research approach within a CoP (Wenger, 1998). In addition, I found the TSPCK theoretical analytical framework to be suitable as an analytical lens (Appendix L) for understanding stoichiometry concepts, as proposed by Mavhunga and Rollnick (2013).

In this study, it was difficult at times to follow the schedule, and that affected the nature of participatory action research as proposed in the literature (see Section 4.4). Nonetheless, during the workshops, all the six Physical Science teachers demonstrated their empowerment and growth through taking control of the process due to their willingness to do any assigned tasks. In view of these recognised changes among the Physical Science teachers, I can confidently say that the participatory action research approach within the CoP led to our empowerment to develop LTSMs.

I would contend that a lesson from this experience is that diversity is a fact of life that cannot be ignored. That is, our CoP consisted of teachers that came from different ethnic backgrounds who brought different perspectives to the team. This infers that CPD creators should develop positive strategies for addressing diversity of participants, focusing on their contexts and needs, a point reiterated by Babikwa (2003) in his study.

I also learnt that the participatory action research approach is very slow and time consuming and what needs serious attention is power sharing. Notwithstanding, there was no power sharing tussles in this study because participants voluntarily participated, and ethics were explicitly discussed before the commencement of the study. As a result, some Physical Science teachers were keen and confident enough to take leadership positions during workshops at their schools. I can thus infer that there was a shift in professional development of the teachers involved in this study. This resonates with Lave and Wenger's (1991) assertion that learning is an "integral part of a generative social practice in the lived-in world" (p. 35).

8.9 Conclusion

The study highlighted an intervention programme to improve Physical Science teachers' understanding and mediation of learning of stoichiometry in selected schools in the Zambezi region. This intervention was in the form of workshops aimed at developing CPD of Physical Science teachers through a participatory action research within a CoP.

The diagnostic test given to learners were marked by the participating teachers and the data generated was used as the baseline data for this study (see Appendix N). The findings necessitated the intervention workshops to assist the teachers as most learners failed questions 11, 14, 17, 18, 19 and 20 (Appendix J). These questions were on stoichiometry calculations, balancing of equations, % yield calculations, empirical and molecular calculations. T5, one of the participating teachers reflected that: "I *have never taught limiting reagent and percentage yield*". The fact that T5 does not teach concepts in the curriculum he mentioned, is evidence that there is a lack of TSPCK and SMK.

In my view, it could be surmised that this was a justification as to why learners were failing stoichiometry concepts, as some concepts had not been properly taught to them.

On a positive note, learners did well in questions that used representations or models (Mavhunga & Rollnick, 2013). These were questions 1, 3, 8 and 10 (Appendix J) and it could be inferred that using representations or models in the teaching of stoichiometry might enhance effective mediation of learning of stoichiometry (Vygotsky, 1978).

The study revealed that teachers can mediate lessons through the TSPCK tenets. It emerged that such TSPCK tenets enhance learning, promote the teaching of hands-on practical activities (representation), as well as their learners' prior knowledge. The study has established that Physical Science teachers' participation in CPD activities within a CoP enabled them to learn how they could improve instructional practices. This requires teachers to be empowered professionally, as Guskey's (1986) model of teacher change expects teacher development programmes to result in changes in teaching approaches and achievement of the learners.

The study thus recommends that Physical Science teachers should be afforded opportunities to participate in CPD activities using participatory action research to share ideas on how to mediate the learning of stoichiometry. It is recognised, however, that there is a need for more intervention workshops to be conducted on how the teaching and learning of Science could be improved by engaging CPD updating, within a CoP. Finally, this study has provided some insights on how to go about advocating for the use of CPD updating and construction of models or LTSMs, in the teaching and mediating of stoichiometry using the participatory action research approach.

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APPENDICES

Appendix A: Ethical clearance

RHODES UNIVERSITY
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PROPOSAL AND ETHICAL CLEARANCE APPROVAL

Ethical clearance number 2017.7.03.01

The minute of the EHDC meeting of 5 October 2017 reflect the following:

2017.7.03 ***CLASS A RESTRICTED MATTERS***
DOCTOR OF PHILOSOPHY RESEARCH PROPOSALS

To consider the following research proposal for the degree of Master of Education in the Faculty of Education:

Denuga Desalu Dedayo (15D7489)

Topic: A model for professional development and collaboration workshops to improve teacher understanding of- and the mediation of learning of stoichiometry in selected schools in Zambezi Region.

Supervisors: *Professor K Ngcoza*
Ms J Sewry

Decision: *Approved*

This letter confirms the approval of the above proposal at the meeting of the Faculty of Education Higher Degrees' Committee on 5 December 2017.

The proposal demonstrates an awareness of ethical responsibilities and a commitment to ethical research processes. The approval of the proposal by the committee thus constitutes ethical clearance.

Sincerely

Prof Marc Schäfer
Chair of the EHDC, Rhodes University
28 March 2018

Appendix B: Director Permission letter

Ministry of Education, Arts and Culture

REPUBLIC OF NAMIBIA

ZAMBEZI REGIONAL DIRECTORATE OF EDUCATION, ARTS AND CULTURE

OFFICE OF THE REGIONAL DIRECTOR

Zambezi Regional Council

Tel No.: (066) 261962/261931
Fax No.: (066) 253187

Private Bag 5006
Katima Mulilo

Enquiries: Adrenah K Mukela
Reference No:

08 June 2016

University of Namibia
Katima Mulilo Campus
Namibia

Attention: Mr Desalu Denuga

RE: PERMISSION TO OBSERVE SOME PHYSICAL SCIENCE LESSON PRESENTATIONS AT NGWEZE SSS, CAPRIVI SSS, KIZITO SS RESEARCH STUDY

Your letter dated 18 May 2016 in the subject context above bears reference.

The Ministry of Education, Zambezi Region hereby would like to thank you for willingness to conduct lesson observations in our schools. Kindly be informed that approval is granted to you to conduct lesson observations as requested, but let me draw your attention to the following aspects:

<u>NOTE!</u>

a) The granted approval should not disrupt the normal teaching and learning at those schools you intend visiting.

b) Ministry of Education, Zambezi Region hereby would like to request you to share your findings with the Directorate.

By copy of this letter the Inspector of Education is notified accordingly of your presence at the school.

I trust and hope you will find this in order.

MR AUSTIN M SAMUPWA
REGIONAL DIRECTOR OF EDUCATION

Office of the Director
Private Bag 5006 - Katima Mulilo

Appendix C: Request permission to observe some physical science lesson presentations

P O Box 1629,
Ngweze,
Katima Mulilo
Namibia

The Director
[redacted]
Directorate of Education
Private Bag 5006
Katima Mulilo

Dear Sir

Re: Permission to observe some Physical Science lesson presentations at School A, School B and School C (Research Study)

I am hereby requesting for permission to conduct a research study at the above-mentioned school as from 5th February to 30th of June 2018.

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

Should you give me permission; I will interview the teachers, look at lesson plans, observe learners' written work and videotape their lessons presentations during Physical Science class.

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

All participants in my study will be treated with respect and dignity. Confidentiality and anonymity will be upheld. Where participant wants to withdraw, she/he will be free to do so.

Your co-operation in this regard will be highly appreciated.

Yours Sincerely

Mr. Desalu Denuga

Appendix D: Inspector request permission letter

P O Box 1629,
Ngweze,
Katima Mulilo
Namibia
[redacted]

[redacted]
Directorate of Education
Private Bag 5006
Katima Mulilo Circuit.

Dear Sir,

Re: Permission to observe some Physical Science lessons presentations at School A, School B and School C (Research Study)

I am hereby requesting for permission to conduct a research study at the above-mentioned school as from 5th February to 30th of June 2018.

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

Should you give me permission; I will interview the teachers, look at lesson plans, observe learners' written work and videotape their lessons presentations during Physical Science class.

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

All participants in my study will be treated with respect and dignity. Confidentiality and anonymity will be upheld. Where participant wants to withdraw, she/he will be free to do so.

Your co-operation in this regard will be highly appreciated.

Yours Sincerely

Mr. Desalu Denuga

Appendix E: Subject adviser request permission letter

P O Box 1629,
Ngweze,
Katima Mulilo
Namibia
[redacted]

[redacted]
Directorate of Education
Private Bag 5006
Katima Mulilo Circuit.

Dear Sir,

Re: Permission to observe some Physical Science lesson presentations at Schools A, B and C (Research Study)

I am hereby requesting for permission to conduct a research study at the above-mentioned school as from 5th February to 30th of June 2018.

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

Should you give me permission; I will interview the teachers, look at lesson plans, observe learners' written work and videotape their lessons presentations during Physical Science class.

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

All participants in my study will be treated with respect and dignity. Confidentiality and anonymity will be upheld. Where participant wants to withdraw, she/he will be free to do so.

Your co-operation in this regard will be highly appreciated.

Yours Sincerely

Mr. Desalu Denuga

Appendix F: Request permission for physical science lessons presentations at school a (research study)

P O Box 1629,
Ngweze,
Katima Mulilo
Namibia
Jan18, 2018

The Principal
[redacted] School A
Katima Mulilo.

Dear Sir,

Re: Request permission to observe Physical Science lesson presentations at School A. (Research Study)

I am hereby requesting for permission to conduct a research study at the above-mentioned school as from 5th February to 30th of June 2018.

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

Should you give me permission; I will interview the teachers, look at lesson plans, observe learners' written work and videotape their lessons presentations during Physical Science class.

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

All participants in my study will be treated with respect and dignity. Confidentiality and anonymity will be upheld. Where participant wants to withdraw, she/he will be free to do so.

Your co-operation in this regard will be highly appreciated.

Yours Sincerely

Mr. Desalu Denuga

Appendix G: Request permission to observe physical science lessons presentations at school b (research study)

P O Box 1629,
Ngweze,
Katima Mulilo
Namibia
[redacted]

The Principal
[redacted] School B
Katima Mulilo

Dear Madam

Re: Permission to observe some Physical Science lesson presentations at School B. (Research Study)

I am hereby requesting for permission to conduct a research study at the above-mentioned school as from 5th February to 30th of June 2018.

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

Should you give me permission; I will interview the teachers, observe at their free time, look at lesson plans, observe learners' written work and videotape their lessons presentations during Physical Science class.

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

All participants in my study will be treated with respect and dignity. Confidentiality and anonymity will be upheld. Where participant wants to withdraw, she/he will be free to do so.

Your co-operation in this regard will be highly appreciated.

Yours Sincerely

Mr. Desalu Denuga

Appendix H: Permission to observe physical science lessons presentations at school c (research study)

P O Box 1629,

Ngweze,
Katima Mulilo
Namibia
[redacted]

The Principal

[redacted] School C

Katima Mulilo.

Dear Sir,

Re: Permission to observe some Physical Science lesson presentations at School C (Research Study)

I am hereby requesting for permission to conduct a research study at the above-mentioned school as from 5th February to 30th of June 2018.

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

Should you give me permission; I will interview the teachers, observe at their free time, look at lesson plans, observe learners' written work and videotape their lessons presentations during Physical Science class.

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

All participants in my study will be treated with respect and dignity. Confidentiality and anonymity will be upheld. Where participant wants to withdraw, she/he will be free to do so.

Your co-operation in this regard will be highly appreciated.

Yours Sincerely

Mr. Desalu Denuga

Appendix I: Request permission letter for physical science teacher as my research participant

P O Box 1629,
Ngweze,
Katima Mulilo
Namibia
[redacted]

Dear Sir,

Re: Requesting you as my research participant teacher

I am hereby requesting you to be my research participant during the study to be conducted at your school as from 5th Feb to 31st of June 2018

I am currently doing my Doctor of Philosophy (PhD) Degree in Science Education with Rhodes University. My research topic is: Exploring the possibilities for an intervention on how to improve the teaching and learning of stoichiometry in selected schools in Namibia

The outcome from this study will be published in a thesis form and will be available to the decision makers in education, curriculum developers, teacher educators and Science teachers in order to bring about improvement in the teaching of stoichiometry.

Should you give me permission; I will observe and videotape four lessons presentations during your Physical Science class.

I will be most grateful if you will allow me to work with you.

Yours Sincerely

Mr. Desalu Denuga

Appendix J: Concepts covered in the diagnostic achievement test

1	Mole visualization question
2	Definition of moles
3	Grams / mole calculations
4	Gas stoichiometry
5	Atoms / moles calculations
6	Application of moles
7	Grams to grams calculations
8	Solutions and moles calculations
9	Concentrations calculations
10	Gas volumes stoichiometry calculations
11	Concentrations gas stoichiometry calculations
12	Molarity concentration calculations
13	Dilution stoichiometry calculations
14	Balancing of equations
15	Limiting reagents
16	Limiting reagent
17	% Yield calculations
18	Empirical formula calculation
19	Molecular formula calculations
20	Empirical formula & Molecular formula calculations

Appendix K: Interview schedule questions for physical science teachers

Introduction

My name is Mr. Denuga D, a PhD student with Rhodes University and also a lecturer at UNAM Katima Mulilo Campus. I thought it would be a good idea to interview you as a Physical Science teacher about the challenges and constrains in the teaching of stoichiometry. My questions will focus on your background, your experiences in teaching stoichiometry and mediating strategies used to correct anomalies that emerged during the teaching. The information you will provide will assist in my research and also of help to other colleagues teaching Stoichiometry. The interview might take about 10 to 20 minutes. Is the time schedule appropriate for you to answer my questions?

Stoichiometry interview questions

1. How long have you been teaching physical science?

2. How many schools you have thought physical science before coming to this school?

3. What are your experiences during the teaching of stoichiometry concept?

4. What methods do you engage when presenting the concept of stoichiometry to students?

5. How do you see the students' reactions when the stoichiometry concept is introduced?

6. When do you present the concept of stoichiometry during the chemistry course?

7. How do you certify that the objective for teaching a particular stoichiometry concept is accomplished?

8. What obstacles from your own experience are preventing the students from mastering stoichiometry concepts?

9. What are the tactics that you use to help students learn stoichiometry concepts?

10. What teaching methods are not useful in teaching the stoichiometry concepts?

11. Do you engage any modern strategy or technology when teaching stoichiometry concept?

12. What methods do you use to assess students' learning stoichiometry concepts?

Closing remarks

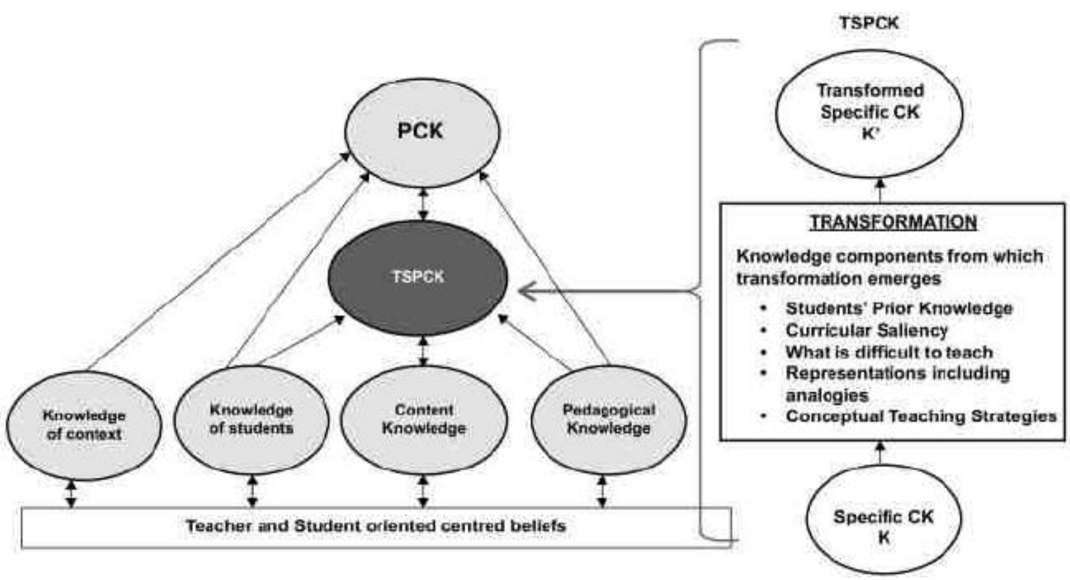
I appreciate the time you took for this interview. Is there anything else you think would be helpful for me to know that will enhance my research work? Would it be alright to call you if I have any other questions about stoichiometry concept?

Thanks again. I look forward to having you.

Appendix L: Colour coded interviews responses for data analysis (Using TSPCK)

Data analysis is described as a process of bringing order and reducing a large amount of data to make sense of it (Bertram & Christiansen, 2015). For qualitative data I used an inductive approach to data analysis, as the categories, themes and patterns emerged from the collected data, unlike deductive data where theory are imposed on data.

The qualitative data analysis used was content analysis. Mayring (2000) contends that ''content analysis is a method for summarizing any form of content by counting various aspects of the content'' (p. 5). Content analysis was used to analyse qualitative data from the documents, teachers interviews, coded, which transformed data into patterns, categories and themes. These themes were used to form analytical statements.



- Learner prior knowledge Yellow
- What is easy or difficult to understand? --red
- Representations--purple
- Curricular saliency- light green
- Conceptual teaching strategies- green

R: Which methodological background do you suggest when teaching stoichiometry?

T1: As for me as a teacher there is no bad teaching methods. Teaching methods are fine but after teaching you check, are my learners did or did not get anything from the concepts. Then you need to apply another method that will enhance them understanding stoichiometry concept taught.

T2: I engage learners centered methods, for example l will group them in group of five and I introduce the concept to them and tell them to go and research and build on what they will bring.

Lost opportunity by the researcher, the researcher could have developed a follow-up question

T3: Firstly, l go to the very basic of introducing or revising the periodic table, from the periodic table we go to symbols, formula writing. Exchange of valences or charges, then when we come to balancing of equations. Then we can now go to any other things after the foundation has been built.

T4: The approach l normally used is practical approach, in fact all my teaching l use practical approach, wherever possible l need to demonstrate where not possible.

R: How successful is the practical (follow-up for T4)

T: It is successful, but you need to combine it with theory., background is necessary from atoms, element, compound and then when necessary learners must understand both, in short, we in-cooperate both.

Coding- colour coded, with inductive approach, the theory is emerging from the data, unlike deductive approach theory is impose imposed on data.

Patterns, Categories → group together to form the **themes**

<u>R: Which problem of understanding did your students encountered to assist them in the teaching of stoichiometry?</u>

<u>Theme: Challenges (sck speaks to Curriculum knowledge, salient and what is difficult to teach)</u>

T1: The first one is chemical equations and the second one is mastering formula, as said earlier student get confused with formulas, in terms of compounds. Students

T2: It is background, the students lack background information on the concept atomic structure, they don't have sufficient information, also at home they don't have that support to accomplish their idea of learning stoichiometry, in other word they lack background and also lack resources and most of them only rely on the teachers as source of information.

(*Lack of resource, no prior Knowledge, background content knowledge) SCK*

T3: the main problem is abstractness of the subject. If it is accompany with issue of titration and reacting masses to see that this is so much that has been used. so, it becomes so much of a challenge for kids to conceptualize the notion attached to stoichiometry.

What is difficult to teach, SCK

T4: The biggest challenge is the formula, they cannot write formula, when I try to go deeper l came to understand that they don't understand valence, start with the valence from the periodic table, how to get valence and then write formulas, in the same concept the find it difficult to understand, they struggle with writing formulas and if they cannot write formula they cannot balance and write equations. If this part of writing formula is not very clear in stoichiometry, they will face problem, and other calculations associated with stoichiometry**.**

(Curricular saliency),

R: How do you assist them with the balancing of equations? (follow-up question for T4) (Semi- structured interview)

T4: Very difficult we use the common method, because you need to explain that for an equation to be balanced the number of atoms, of course looking at the equation the number of atoms of the elements on the reactants should be same with the product, we used the basic method of drawing a line and we try to check the number of atoms on the left is same as the number on the right. Me l see that balancing is not really a big challenge, because the equation is not balance properly and the formula are not written correctly and then they seem to struggle with the balancing because that equation will never balance, because **the formula** is wrong. Because the formula is wrong so it could not balance the child will struggle, struggle and at the end he or she will say balancing is a problem. Yet is not really a bigger problem.

R: What do you find frustrating when teaching stoichiometry?

T1: After teaching and you think you have taught and at the end of the day you gave them work to do, and students are not performing it is very frustrating.

T2: When the learners don't understand, you exhaust all your resources, strategies and yet nothing good comes out, is very frustrating.

T3: The part that actually have problem is the Avogadro's, when teaching learners that science is about proving or showing that this thing is there and know you need to show the particles in moles is frustrating on my part.

T4: What is frustrating is that learners seems not to grasp whatever you are teaching, right from the beginning as l said in writing formulas you know you take slowly and then you explained this concepts, Is very unusual the learners cannot even use periodic table to extract the symbols of the elements and they cannot even write the symbols of the elements correctly, yet they are looking at them on the periodic table. It becomes a problem from writing symbols from the periodic table, writing the formula and when you are repeating these things it becomes frustrating.

Theme: Lack of learners' understanding and poor performance

R: What makes you to teach chemistry?

T1: In terms of carrying out experiments. Is more of hands on experiments, practical and the result facilitate learning

T2: for me is the manipulation of terms involved and to measure the moles, which is the theoretical concepts of the substances, to me l find it very amazing.

T3: Is a very interesting to chemistry, playing around with numbers and things, the percentage of substances particular element in certain substance, those are so great so that this is what happen in the industry.

T4: It is my passion, l enjoyed it, when you love something you will always like to do it. If it is me l will live in the lab, just try to mix chemicals and so on because l like to proof things whatever l do l really want to proof it because it is based on reality.

R: What can we do to help students in stoichiometry?

T1: Periodic table, student should understand periodic table and how to balance chemical equations. They need to know the balancing factors of chemical equations. Students need to know how to determine the number of moles. Teachers need to emphasis those concepts for effective teaching of stoichiometry.

T2: The first one is, l made them to master periodic table that is when they need to know the mass of elements and also, they need to know how to write formulas and l made them to do that and also be able to balance chemical equations.

T3: The main methods are firstly, we are making sure that the foundational concepts, formula writing, equations are done and understood. And others simply, everything we move around these basics things. I spent time to make sure that the learners capture the basic concepts that is formula writing and balancing of equation.

T4: Career guidance, l think in my view, you asked them what they want to become, they pause a bit, they are blank, they don't know what they want to become. but if they are motivated to become doctors for example and they really understand that to become a doctor or an engineer you really need chemistry, you start to love the subject, now they think that physical science is a lot of work, yet they are doing it and they don't seem to enjoy it. But they need to be driven by the career if they want to do it. They don't have choice they have to do mathematics, physical science so that they become whom they want to be in life. Then it motivates them to work hard so that they can be successful.

Loss of opportunity on the researcher's side. The researcher supposed to probe further on how the students should be motivated, because the teacher was focusing on career

R: What is your greatest strength, weakness, opportunity and threat during the teaching of stoichiometry?

T2: I think my great strength is done, because of the experiences l have taught the concept I am used to it and master all the tricks, weakness may be some leaners may not grab the concept very easily.

T3: The greatest strength is the knowledge and the desire to make these kids be like me and even better. The weakness, l get frustrated when l don't see the desired results from the learners, sometimes it may be pushed and this is not good. The system to make sure that you carry the learners along.

R: Do you think there is anything you think l should know that will enhance my research work,

T1: Yes. What l want to see in your research is a simplified module involving methods of teaching stoichiometry which teachers can use during the course of teaching.

T2: In terms of stoichiometry may be just to engage view learners and see how they perceive the concepts.

T3: The topic is going to be taught and learners have sufficient understanding. In your research there must be enough time allocated for the stoichiometry, this allocation of two lessons is insufficient. And that is why we continue having problems with stoichiometry. The depth of stoichiometry is not taught in most schools.

T4: I think l have said almost everything, but l think, l am going to mention one thing. I will like to mention something that through the use of your research **results, may be recommendations** that can be passed to the Regional office, at least we need to train more teachers in chemistry, physics especially now that we are towards introducing new curriculum, we are going to face problems of teachers if you can have a report that can be directed to the source, but at least l know the problem of finance but at least if they could do inductions they can use lecturer from UNAM and have like in-service training for the teachers that we have based on the syllabus so at that l inducted through that syllabus a little bit intensively so that the result can improve in the Region.

R: What methods do you use to assess the learning and teaching of stoichiometry?

T1. By given students test on stoichiometry and using classwork, class activities. You need to give questions on each concept you taught them. In term of stoichiometry gases, in terms of liquid and solutions. Students need to be told about standard solution, which seems confusing.

T2: I used worksheets, and assessment test.

T3: I discovered that if l give the leaner homework, everybody may be forced to write the right thing. When you give a test, you discovered that people who wrote things that they claimed they understood performed badly. I prefer given small exercise and questions on the topics you have done. and also engage students to write on the board and solve this problem those are the things that l do.

R: Do you engage any modern technology in the teaching of stoichiometry.

T1: Yes, l do. I use power-point and internet to teach the concept. Ask questions in different ways and this will enhance them to understand the concept stoichiometry

T2: I engage you-tube, video lessons, prepared lessons on the concept stoichiometry.

T3; Yes, dual method kind of, students during teaching can watch you-tube or any video tape about the concept taught

R: What teaching method is not useful for the teaching of stoichiometry?

T2: Teacher's centered is one of them because the students are not fully involved. Because the learners are already having negative notion about stoichiometry been a difficult concept, they take it as teachers' topic, so they need to be involved, let them own the idea themselves.

T3: Every other method depending on the part we are dealing with; we cannot say that this is the method that may not be required. Because when we look at the different component of concepts, Once in a while one or two may be depending on the same method.

R: Under what condition do you study stoichiometry or preferred to teach or feel better to teach stoichiometry?

T1: Stoichiometry teaching is in term 2 and best to be taught in a standard laboratory where practical's can be carried out enhance learning and also involve learners.

T2: I preferred to teach stoichiometry and demonstrate, hands on experiment, so that the learners will have a better understanding rather than just write equation for the learners to memorize.

T3: I prefer to teach stoichiometry I enjoyed teaching it when I have learners who are excited to learn, with the best equipment to carry out necessary experiment for examples qualitative analysis. Here we have this number of moles of acid so when we have all theses we can, Here the kids relate this number of moles and concentration and the like is a marvellous they enjoy, they want to do more and more just like that.

R: How do you satisfy that the objective of teaching stoichiometry concept is accomplished?

T1: We need to come up with a simple way in which to find out what are the problem. Loss of opportunity on the part of researcher

T2: I confirmed this with a worksheet or tests by after marking l will be able to know the level of understand and if they perform below average l have to intervene and bring in meditation techniques of extra mural classes on the concept taught.

T3: We look at the objective of the particular aspect of the concept and introduce some work to do and when we reverse, we do some exercise to help those that are still lagging behind.

TSPCK components	Categories	Themes	Theory	Research questions
Learner prior knowledge	l will group them in group of five and I introduce the concept to them and tell them to go and research and build on what they will bring. Then we can now go to any other things after the foundation has been built the students lack background information on the concept atomic structure, they don't have sufficient information,	Building on what learners already know	Theory that talks about prior knowledge. Constructivism. Vygotsky (1978) Cognitive Constructivism is a learning theory that uses prior knowledge as the main factor in learning. The idea behind constructivism is that we actively construct, or create,	R 1
What is easy or difficult to understand? --	chemical equations and the second one is mastering formula is abstractness of the subject. challenge is the formula, they cannot write formula because the equation is not balance properly and the formula are not written correctly and then they seem to struggle with the balancing because you think you have taught and at the end of the day you gave them work to do, and students are not performing it is learners don't understand, you	Lack of understanding of concepts	Cognitive, TSPCK Theory that talks about easy or difficult to understand of concepts	R1

	exhaust all your resources, strategies and yet nothing good comes out, is very seems not to grasp whatever you are teaching, right from the beginning as l said in writing formulas you know you take slowly and then you explained may be some leaners may not grab the concept very easily. l get frustrated when l don't see the desired results from the learners, sometimes it may be pushed We continue having problems with stoichiometry. The depth of stoichiometry is not taught in most schools.			
Representations	used is practical approach, in fact all my teaching l use practical approach, wherever possible l need to demonstrate where not possible. Is more of hands on experiments, practical and the result facilitate learning l like to proof things whatever l do l really want to proof it	Learning and teaching support material and practical for effective teaching	Cognitive, TSPCK Theory that talks about practical and LTSMs	R3

	because it is based on reality. teach stoichiometry and demonstrate, hands on experiment to be taught in a standard laboratory where practical's can be carried out enhance learning and also involve , with the best equipment to carry out necessary experiment for examples qualitative analysis with a worksheet or tests by after marking do some exercise to help those that are still lagging behind.			
Curricular saliency	Then you need to apply another method that will enhance them understanding stoichiometry concept taught Firstly, l go to the very basic of introducing or revising the periodic table, from the periodic table we go to symbols, formula writing. Exchange of valences or charges, then when we come to balancing of equations start with the valence from the	Periodical sequential teaching procedure building on acquired knowledge.	Topic specific pedagogical content knowledge. (TSPCK) Theory about sequential teaching processes	R 3

	periodic table, how to get valence and then write formulas, in the same concept the find it difficult to understand, they struggle with writing formulas and if they cannot write formula they cannot balance and write equations. If this part of writing formula is not very clear in stoichiometry, they will face problem, and other calculations associated with stoichiometry. manipulation of terms involved and to measure the moles, which is the theoretical concepts of the substances, to me l find it very amazing. Periodic table, student should understand periodic table and how to balance chemical equations. They need to know the balancing factors of chemical equations. Students need to know how to determine the number of moles l made them to master periodic table that is when they need to know the mass of elements and also, they need to know how to write formulas			

	formula writing, equations are done and understood. And others simply, everything we move around these basics things. I spent time to make sure that the learners capture the basic concepts greatest strength is the knowledge and the desire to make these kids be like me and even better.			
Conceptual teaching strategies	my learners did or did not get anything from the concepts successful but you need to combine it with theory., background is necessary from atoms, element, compound and then when necessary learners must understand both, in short, we in-cooperate both challenge for kids to conceptualize the notion attached to stoichiometry. common method, because you need to explain that for an equation to be balanced the number of atoms, of course looking at the equation the number of atoms of the elements on the reactants should be same with the product, we used the basic method of drawing a line and	Successful intervention to mediate learning.	Theory about intervention., CPD, participatory action research CoP	R 2

	we try to check the number of atoms on the left is same as the number on the right interesting to chemistry, playing around with numbers and things, the percentage of substances particular element in certain substance, those are so great so that this is what happen is done, because of the experiences I have taught the concept I am used to it and master all the tricks be just to engage view learners and see how they perceive the concepts. topic is going to be taught and learners have sufficient understanding. In your research there must be enough time allocated for the stoichiometry to the Regional office, at least we need to train more teachers in chemistry			

Appendix M: Stoichiometry topic specific pedagogical content knowledge tool

STOICHIOMETRY TOPIC SPECIFIC PEDAGOGICAL

CONTENT KNOWLEDGE TOOL

The purpose of this research is to find the difficulties associated with the teaching of Stoichiometry. The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

Please write your responses directly into the response boxes.

Thank you for your valued input and assistance.

PCK / SCK Research on Stoichiometry

Contact Person: Dr. Kenneth Ngcoza

E-mail: k.ngcoza@ru.ac.za

Researcher: Mr. Denuga Desalu Dedayo.

Email: denuga.denuga77@gmail.com

For any queries please feel free to contact us.

NB

Adapted with permission from Mr. Stephen Andrew Malcolm. University of the Witwatersrand

E-mail: stephen@moolman.co.za

DEMOGRAPHIC INFORMATION

CODE:	

NAME:		
GENDER	Male	Female
CURRENT SUBJECTS TAUGHT		
NUMBER OF YEARS TEACHING SCIENCE		

QUALIFICATIONS

Degree / Diploma	Where Obtained	Main Subjects	Year

Have you taught stoichiometry?	YES		NO	

If yes, please indicate the grade and the number of years for each Grade.

Grade	Number of years	Years (e.g. 2008, 2009)

CATEGORY A: LEARNER'S PRIOR KNOWLEDGE

1. Before starting the section on reaction stoichiometry you give the learners a diagnostic test. One of the questions in the diagnostic test is reproduced below.

Each cube represents a volume of 22,4 dm^3 at STP. In which of the three pairs of cubes, Set A, Set B or Set C, is there 1 mole in each cube and in which of the three pairs cannot contain 1 mole in each cube?

N_2 (g)	H_2 (g)	O_2 (g)	Hg (l)	SO_2 (g)	S (s)
Set A Cubes		Set B Cubes		Set C cubes	

How would you respond verbally to learners who state that all the cubes contain one mole?

Response A	At standard temperature, or 0°C and standard pressure, or 101,3 kPa one mole of any gas at STP occupies a volume of 22.4dm^3. This is called the molar volume, but it only applies to gases at STP. Hence cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain 1 mole. The pair of cubes in Set B contains a liquid in one cube and the pair of cubes in Set C contains a solid in one cube. So, one of the Set C pair of cubes and the Set B pair of cubes contain other substances that are not gases. So, Set B and Set C pairs do not contain one mole in each cube.
Response B	That is incorrect. All three pairs of cubes cannot contain one mole of substance. One mole of a gaseous substance occupies a volume of 22.4dm^3 at STP. So only the cubes of Set A contain one mole. The pairs of cubes in Set B and Set C do not have cubes that all contain one mole of substance since only one of the substances in the cubes of Set B and Set C are gaseous substances at STP.
Response C	It is important to check the phases of the substance. Molar gas volume only applies to substances in the gaseous phase. One mole of any gas at STP occupies 22.4dm^3. So, the cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain one mole. There are exactly the same number of gas molecules, approximately 6 ,02 x 1023 particles in these cubes. The other substances in the pairs of cubes, Hg and S, are not in the gaseous phase. You would need to know the masses of mercury and sulphur in order to calculate if the cubes with these substances in Set B and Set C contain one mole of these substances. So, only in Set A is there one mole of substance in each cube in the set.
Response D	None of the above. I have another response which is

Choose your response and indicate the reason(s) for your choice in the space below.

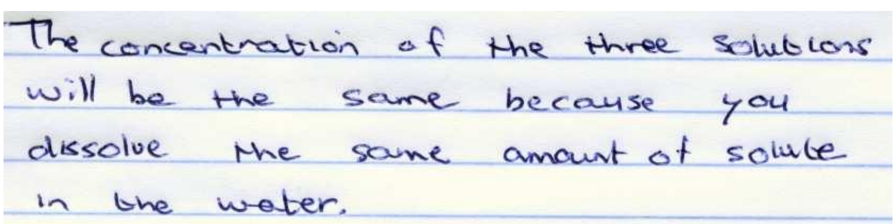
My choice is Response _

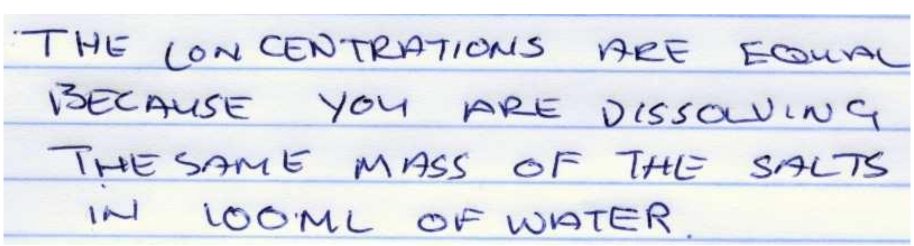
2. After teaching the learners about concentration you give them an exercise to do for homework. In one question you ask learners the following question.

During a practical lesson you have to make up molar solutions. You are provided with 10 g of sodium chloride, sodium bromide and sodium iodide. You dissolve each of these salts in a 100 ml volumetric flask.

Do these solutions have the same or different molar concentrations? Explain your answer.

How would you respond in writing when giving feedback to the homework exercise to learners who provide the following answers?


The concentration of the three solutions will be the same because you dissolve the same amount of solute in the water.


THE CONCENTRATIONS ARE EQUAL BECAUSE YOU ARE DISSOLVING THE SAME MASS OF THE SALTS IN 100ML OF WATER.

Response A	The mass of the salts does not mean that the number of particles is the same. The ions of the different salts have different relative atomic masses and therefore the molar mass of each salt is different and so the concentration of solutions will be different. Referring to the periodic table you can, by inspection, see that sodium chloride has a smaller molar mass than sodium iodide, and would therefore have a greater number of ions. Therefore, the amount of salt, measured in moles, will also be different. Remember that just because the mass of each salt is the same the amount of salt, measured in moles will be different. Since concentration is the amount of substance per unit volume, the concentration of the sodium chloride solution will be greater than that of the sodium bromide, which would be greater than that of the sodium iodide. If you add ten grams of the salt to the same volume of solvent, you are not adding the same number of ions for the different salts.
Response B	Concentration mathematically is the number of moles per unit volume. You need to calculate the number of moles for each of the three salts. This is done by dividing the mass of the sample by the molar mass of each salt or using the formula $n = m / M$. You need to refer to the periodic table to calculate the molar mass of each salt by adding the atomic mass of each element in the salt. So, firstly calculate the number of moles of each salt in 10 grams of the salt. Once you have calculated the number of moles of each substance then use the formula $c = n / V$ to find the concentration of each solution. The concentration of the solutions will be different.
Response C	You need to understand what concentration is before you answer a question like this. So, you were asked to dissolve three different salts in a given volume of water. Then you were asked if the concentration of these three solutions was the same or different. You must remember that concentration mathematically is the number of moles divided by the volume. So, you need to work out how many moles of each salt and divide this by the volume of water you dissolved the salts in. The concentration of the three solutions cannot be same even if the mass of these salts is the same and the salts are dissolved in the same volume of water.
Response D	None of the above. I have another response which is

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response

CATEGORY B: CURRICULAR SALIENCY

3. The following questions relate to planning and sequencing of concepts.

3.1. What concepts in stoichiometry at Grade 11 do you believe are the main ideas[1] for understanding by students at the end of the instruction of this topic?

Choose at least three concepts from the provided list and place them in a sequence that depicts the best order of teaching. Provide reasons for both your choice and suggested sequence.

Theoretical yield is the amount of product that is formed when a reaction goes to completion based on the stoichiometry of the reaction.		Molar ratios can be used to determine the number of reactants used or the yield of product formed.
Molar Mass of an element or compound expresses the equivalent relationship between one mole of a substance and its mass in grams.		Balanced chemical equations provide the combining ratios of reacting substances and their products in a chemical reaction.
Stoichiometric calculations combine balanced chemical equations and the concept of the mole to calculate the masses of all reactants required and products formed in a chemical reaction.		Molar Volume of a gaseous substance expresses the equivalent relationship between one mole of a gas and its volume of 22,4dm^3 and standard temperature and pressure.
Conservation of mass is a chemical law that allows quantitative relationships to be established in chemical reactions.		Dilution is the process of decreasing the concentration of a solution by addition of solvent to a solution.
Concentration is a property of a solution and relates to the number of solute particles per unit volume.		The amount of substance in a given mass or volume can be expressed as a constant number of elementary particles.
Limiting reagent is the reactant that used up in a chemical reaction and determines the amount of product formed.		The mole is the SI unit for amount of substance and allows us to connect the macroscopic scale of matter with the microscopic scale of matter and can used to help count elementary particles that make up substances.
Concentrated solutions have more particles per unit volume than dilute solutions.		
The actual yield of product formed depends on the reagent that limits the amount of the other reactant that reacts.		Gravimetric and volumetric analysis are quantitative analysis methods to determine the amount of substance.
Reaction stoichiometry involves the determination of molar ratios of the number of reactants and products in a chemical reaction through balanced chemical equations.		Avogadro's number expresses the equivalent relationship between one mole of a substance and the number of entities it contains. Avogadro's number has been experimentally determined to be 6,02 x10^{23} particles
Volume is the amount of space occupied by a sample and from the volume of a gaseous substance the amount of substance can be determined.		Mass is the amount of matter contained in a sample and from the mass of a chemical substance the amount of substance can be determined.

[1]Main ideas are statements describing key understanding that must be learnt in a topic.

	Suggested concepts and sequence	Reasons
1.		
2.		
3.		

3.3. What topics/concepts must have been covered in chemistry before you can teach stoichiometry?

List of Topics/Concepts to be taught before Stoichiometry

3.4. Why is it important for learners to learn about stoichiometry? Identify reasons.

CATEGORY C:
INVESTIGATING THE CONCEPT THAT MAKES STOICHIOMETRY EASY OR DIFFICULT TO COMPREHEND

4. What concepts do you find difficult to teach in stoichiometry? Select your choice and provide reason(s) in the table below.

Concept		Why is it difficult for learners to understand?
Amount of substance/mole		
Molar mass		
Molar volume		
Avogadro's number		
Concentration		
Dilution of solutions		
Molar ratios		
Stoichiometric calculations		
Limiting reagent		
Theoretical yield and actual yield		
Percentage composition		
Empirical formula		
Molecular formula		
Molarity		

CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

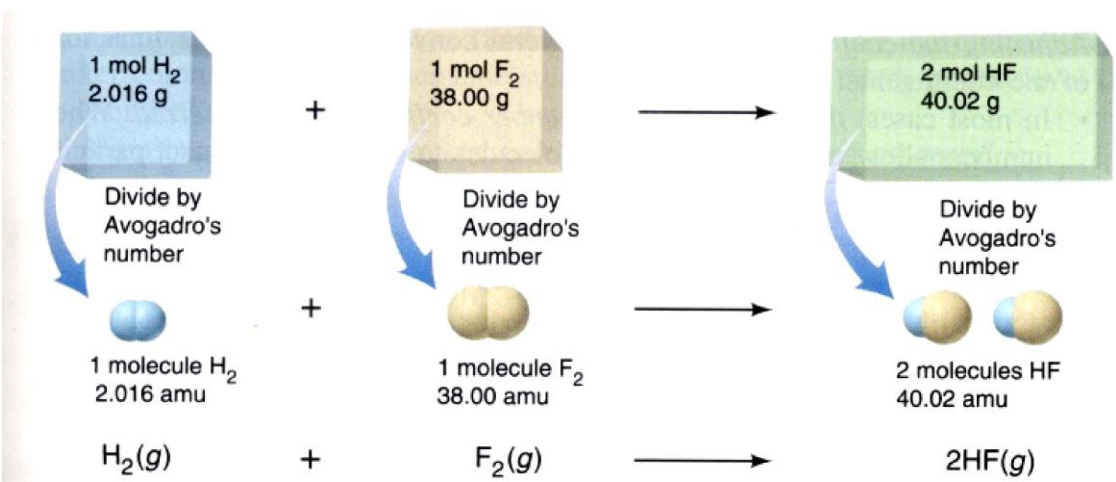
5. Below are possible representations for teaching the relationship between mass, mole and number of elementary particles.

Representation 1

Items	Kind of Set	Number in Set
Socks, dice Eggs,	Pair	2
oranges Bottles,	Dozen	12
cans Brushes,	Case	24
pencils Sheets of	Gross	144
paper Atoms,	Ream	500
molecules	Mole	$6{,}02 \times 10^{23}$

Representation 2

Representation 3



5.1. Complete the table below by providing as many details as possible about each representation.

Representation No.	What I like	What I do not like

5.2. Which representation do you like most?

5.3. How would you use the representation that you like most in a lesson?

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES

6. Learners are given the following question in the mid-year examination.

> About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:
>
> $$TiC\ell_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgC\ell_2(\ell)$$
>
> In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.
>
> Source: Department of Education (2007). Grade 11 Chemistry Paper, November Examination

The learners are asked to determine the limiting reagent of the reaction, giving reasons for their answers. The learners provide the following answers.

Extract 1:	Extract 2:
Titanium (IV) Chloride Limiting reagent is the reactant with the least number of moles in the equation	Magnesium This is the reactant present in the least amount according to mass.

Explain how you would assist these learners to move towards the correct answer, explaining what their errors are and highlighting the strategy you will use.

In your response:

(1) Explain why you think your strategy will work.

(2) Indicate what you consider as important in your strategy.

THANK YOU. Your assistance is really appreciated in the development of this Instrument.

Appendix N: Stoichiometry diagnostic achievement test

STOICHIOMETRY DIAGNOSTIC ACHIEVEMENT TOOL TEST

The purpose of this research is to find the difficulties associated with the teaching of Stoichiometry. The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

Please write your responses directly into the response boxes. Thank

you for your valued input and assistance.

PCK / SCK Research on Stoichiometry

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Researcher: Mr. Denuga Desalu Dedayo.

Email: denuga.denuga77@gmail.com

For any queries please feel free to contact us.

NB

Adapted with permission from Mr. Stephen Andrew Malcolm. University of the Witwatersrand

E-mail: stephen@moolman.co.za

CODE:	

NAME:	

Instructions

1. Please fill in the demographic information on the TSPCK instrument.
2. Please answer all the questions.
3. Please write your responses directly in the spaces provided.
4. You may use a calculator to answer some of the questions and use scrap paper for any rough work in answering the questions.
5. A periodic table and useful data is provided for your use if necessary.

Table 1: Physical Constants

NAME	SYMBOL	VALUE
Avogadro's constant	N_A	6,02 x 10^{23} mol^{-1}
Molar gas constant	R	8,31 $J.K^{-1}.mol^{-1}$
Standard pressure	p	1,013 x 10^{6} Pa
Standard temperature	T	273 K
Molar gas volume at STP	V_m	22, 4dm3.mol^{-1}

Table 2: Periodic Table of Elements

KEY: Atomic number (29); Symbol (Cu); Approximate relative atomic mass (63,5)

1 (I)	2 (II)	3	4	5	6	7	8	9	10	11	12	13 (III)	14 (IV)	15 (V)	16 (VI)	17 (VII)	18 (VIII)
1 H 1																	2 He 4
3 Li 7	4 Be 9											5 B 11	6 C 12	7 N 14	8 O 16	9 F 19	10 Ne 20
11 Na 23	12 Mg 24											13 Aℓ 27	14 Si 28	15 P 31	16 S 32	17 Cℓ 35,5	18 Ar 40
19 K 39	20 Ca 40	21 Sc 45	22 Ti 48	23 V 51	24 Cr 52	25 Mn 55	26 Fe 56	27 Co 59	28 Ni 59	29 Cu 63,5	30 Zn 65	31 Ga 70	32 Ge 73	33 As 75	34 Se 79	35 Br 80	36 Kr 84
37 Rb 86	38 Sr 88	39 Y 89	40 Zr 91	41 Nb 92	42 Mo 96	43 Tc 99	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	*	72 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 Tℓ 204	82 Pb 207	83 Bi 209	84 Po 209	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	**	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 264	108 Hs 265	109 Mt 268									

57 La 139	58 Ce 140	59 PR 141	60 Nd 144	61 Pm 147	62 Ms 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 17	71 Lu 175
89 Ac 227	90 Th 232	91 Pa 231	92 U 238	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lro 262

1. Which of these three sets in Figure 1 contains 1 mole of tin, 1 mole of magnesium, and 1 mole of sulphur in each tube?

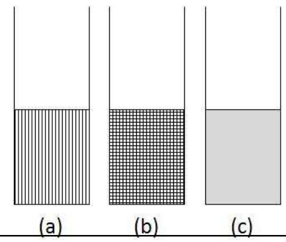
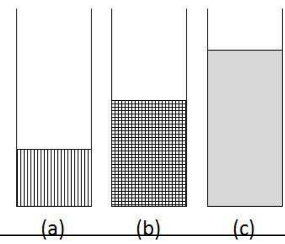
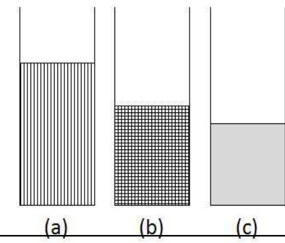
Set 1	Set 2	Set 3
		
Key:	(a) Tin (b) Magnesium (c) Sulphur	

Figure 1.

(a) Cannot tell by inspection as more information is needed.
(b) Set 1 as they contain equal volumes.
(c) Set 2 as they contain equal masses of substances. My choice is: ______

Give a reason for your choice.

____

____

____

____

____

____

2. Explain in your own words what a mole in chemistry is.

____

____

____

____

____

3. How many grams of calcium carbonate are in 6 moles of calcium carbonate, $CaCO_3$? (Molar mass 100 $g.mol^{-1}$)
(a) 0,06 g
(b) 0,6 g
(c) 6 ,0 g
(d) 60 g
(e) 600 g My choice is: _____

4. One gram of hydrogen gas at STP occupies:
(a) 44,8 dm^3.
(b) 22,4 dm^3.
(c) 11,2 dm^3.
(d) 5, 6 dm^3.
(e) 2, 8 dm^3. My choice is: _____

5. How many atoms of hydrogen are in 3 moles of ammonia, NH_3?
(a) 3 atoms
(b) 9 atoms
(c) 6.0221 x 10^{23} atoms
(d) 1.8066 x 10^{23} atoms
(e) 5.4199 x 10^{24} atoms My choice is: _____

6. During a practical a group of learners produced 50 grams of the following five gases. Determine in which experiment the least number of gas molecules were produced.
(a) Ammonia
(b) Chlorine
(c) Carbon dioxide
(d) Nitrogen
(e) Hydrogen My choice is: _____

7. How many grams of magnesium oxide (M = 40 $g.mol^{-1}$) will be formed by the combustion of a small strip of magnesium in 16 grams of oxygen according to the following balanced reaction?

$$2\ Mg + O_2 \quad 2\ MgO$$

(a) 8 g
(b) 16 g
(c) 20 g
(d) 40 g

(e) 80 g My choice is: _____

8. Which solution is the most concentrated?
(a) 1 mole of solute dissolved in 1 litre of solvent
(b) 2 moles of solute dissolved in 1 litre of solvent.
(c) 2 moles of solute dissolved in 3 litres of solvent
(d) 6 moles of solute dissolved in 4 litres of solvent
(e) 4 moles of solute dissolved in 8 litres of solvent My choice is: _____

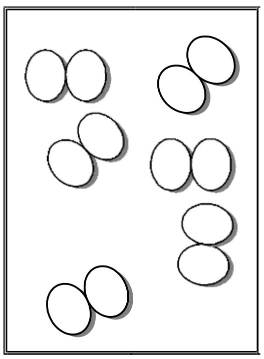
9. What is the concentration of a solution prepared by dissolving 238 grams of potassium bromide, KBr (M = 119 $g.mol^{-1}$), in water to make a total of 500 millilitres of aqueous solution?

(a) 0.476 $mol.dm^{-3}$
(b) 476.00 $mol.dm^{-3}$
(c) 4.00 $mol.dm^{-3}$
(d) 0,004 $mol.dm^{-3}$
(e) 56.6 $mol.dm^{-3}$

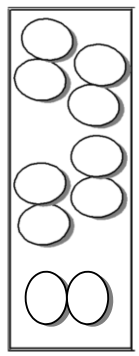
My choice is: _____

The following diagrams represent different volumes of H_2 under standard conditions of temperature and pressure. Questions 10 and 11 are based on these diagrams in Figure 2.

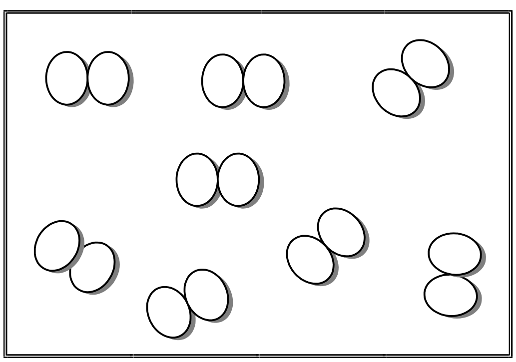
(a) Vol = 2 litres



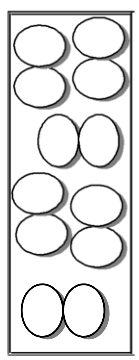
(b) Vol = 1 litre



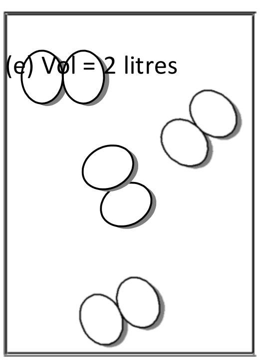
(c) Vol = 4 litres



(d) Vol = 1 litre



(e) Vol = 2 litres



(f) Vol = 1 litre

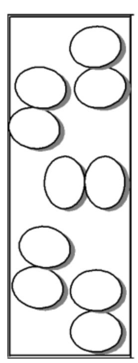


Figure 2.

10. Which diagrams represent the same amount but different concentrations of gas?

____

11. Which diagrams represent different amounts but the same concentration of gas?

____

12. What is the final molar concentration of a sodium hydroxide (NaOH) solution if 25 millilitres of a 0.350 $mol.dm^{-3}$ NaOH solution is diluted to 1.00 litre?

(a) 7.1×10^{-2} $mol.dm^{-3}$
(b) 14 $mol.dm^{-3}$ (c)
1.4 $mol.dm^{-3}$ (d)
8.75 $mol.dm^{-3}$
(e) 8.75×10^{-3} mol.dm-3

My choice is: _________

13. Figure 3 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram, the water molecules have not been shown.

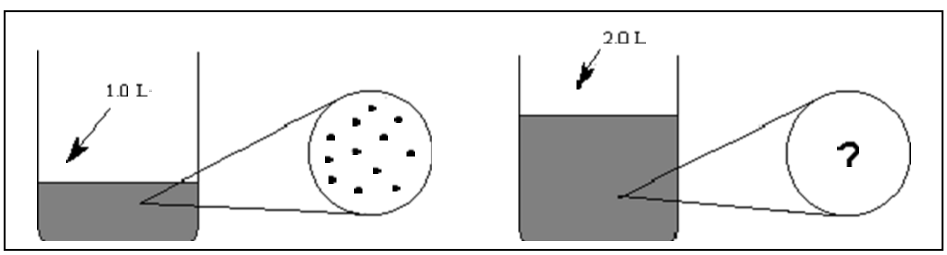
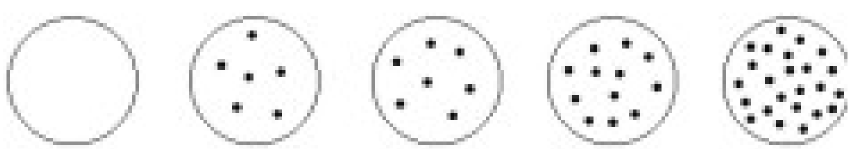


Figure 3.

Which response represents the view of the same magnification circle after 1.0 L of water was added.



(a) (b) (c) (d) (e)

My choice is: _____

B_2 reacts with AB_2 as shown below in Figure 4. "B" atoms are the lighter colour and "A" atoms are darker in colour. Questions 14 and 15 refer to this reaction depicted in Figure 4.

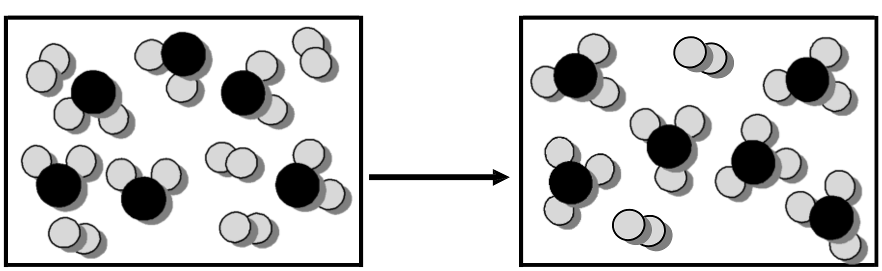


Figure 4.

14. Write a balanced equation for the reaction.

____

15. Reactant AB_2 is the limiting reagent in this reaction. In your own words, explain why it is important to determine the limiting reagent of a reaction.

____

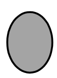
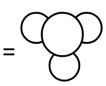
____

____

____

____

KEY: K^+ =  Pb^{2+} = 

I^- =  NO_3^- = 

<u>TesttubeA:</u> At the instant of mixing
7 ml of 1 mol.dm^{-3} of lead nitrate (aq) + 3 ml of 2 mol.dm^{-3} of potassium iodide (aq)

<u>TesttubeB:</u> At the instant of mixing
3 ml of 1 mol.dm^{-3} of lead nitrate (aq) + 7 ml of 2 mol.dm^{-3} of potassium iodide (aq)

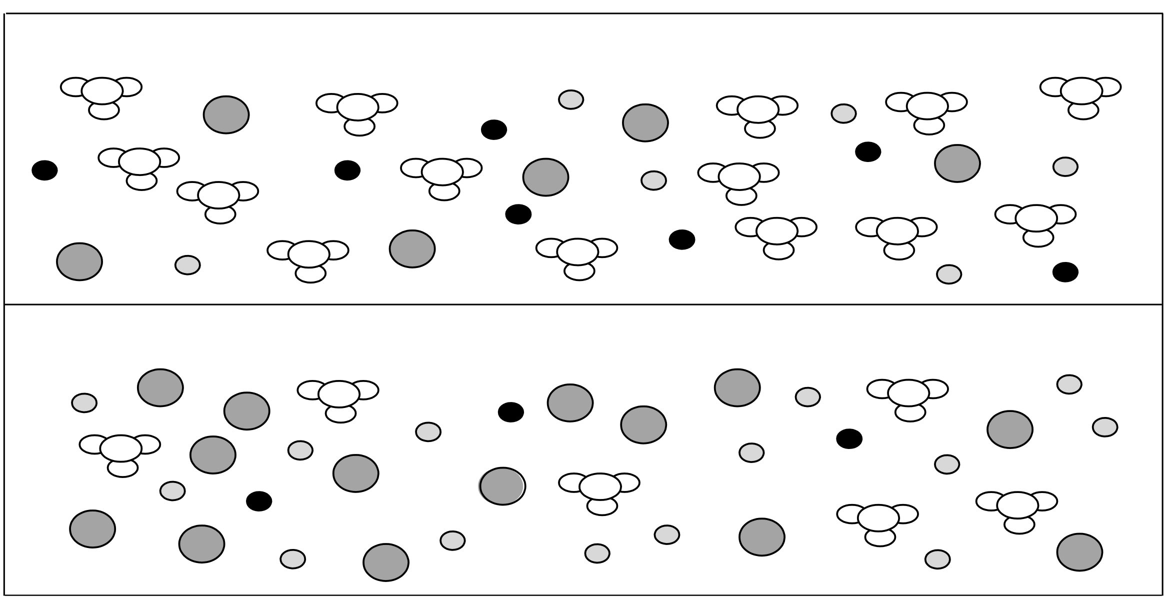


Figure 5.

The diagram in Figure 5 above shows a sub-microscopic representation of the contents of a set of two test tubes (A) and (B) which contain the results of mixing solutions of 1 mol dm^{-3} lead nitrate and 2 mol dm^{-3} potassium iodide. Note: water molecules have been omitted so there are spaces between the ions. The relative sizes of ions are not shown accurately. Questions 16 to 17 are based on the diagrams in Figure 5.

16. Which substance is the limiting reagent in each case?

____

____

17. Calculate the actual amount of precipitate formed in moles in test tube A.

____

____

18. Write the empirical formula for the following compounds.

a) C_6H_6 ________________________

b) C_8H_{18} ________________________

19. A compound with an empirical formula of CFBrO and a molar mass of 254.7 grams per mole. What is the molecular formula of this compound?

____

20. A compound containing 5.9265% H and 94.0735% O has a molar mass of 34.01468% g/mol.

Determine the empirical and molecular formula of this compound.

____

THANK YOU. Your assistance is really appreciated in the development and transition stage of this Instrument

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