The development of teachers' pedagogical content knowledge (PCK) in the mediation of chemical equilibrium: A formative interventionist study

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Declaration of Originality

I, Tasara Manamike (19M9106), hereby declare that this thesis is my own original work and has not been previously submitted in any form for assessment or for a degree in any other higher education institution. Where I have used work from other scholars, such ideas have been acknowledged by means of quotations and references according to Rhodes University Education Department Guidelines.

________________________ 3 March 2022

Signature Date

Dedication

I dedicate this thesis to my family, my colleagues at school and Rhodes University as well as my many associates and friends, especially my cheerleader-in-chief, Sandra, and her two supporting acts Victor and Alex.

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I express profound gratitude to my supervisor, Prof. K. Ngcoza for the countless hours he spent reading my work, the corrections, guidance and the encouragement.

I give special thanks to my wife Sandra and the two boys, Victor and Alex for their support and understanding.

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Abstract

Persistent student errors in understanding chemical equilibrium as shown by poor student achievement in national examinations reflect student difficulties in learning and deficiencies in teaching methodologies. Studies which have been conducted in Namibia have explored the teaching of chemical equilibrium and revealed that teachers seem not to have adequate pedagogical content knowledge (PCK) for mediating chemical equilibrium and therefore there is a need for continuing professional development (CPD). However, it seems the CPD facilitators also find this topic difficult and are unsure of which methods are really effective owing to the disagreements among teachers and researchers. In addition, current CPD practices ostensibly fail to address the teachers' needs because the facilitators have their own commitments and accountabilities and may ignore teachers' contexts. It is against this backdrop that I conducted this formative interventionist study to improve teachers' PCK for mediating chemical equilibrium through expansive learning (learning something that does not yet exist).

A blend of the interpretivist and critical paradigm underpinned this study, which assumed a transactional epistemology. The qualitative case study research design was used to gather in-depth information about the multiple realities of the participants, bearing in mind that teaching is idiosyncratic, and the teaching approaches or strategies employed heavily depend on the contexts. Accordingly, the cultural historical activity theory was used to guide the teachers' activities during the intervention for generating the data which were analysed using the topic-specific pedagogical content knowledge.

The study revealed that the participants faced challenges in their teaching, namely: (i) students' difficulties with comprehension and (ii) teachers' instructional problems or deficiencies in instructional skills. The findings also revealed that the intervention enabled the participants to collectively transform their practices and therefore address the major challenges in their practices, that is, they expansively learnt how to effectively teach chemical equilibrium.

Keywords: Chemical equilibrium, pedagogical content knowledge, professional development, professional learning communities, formative intervention, expansive learning, cultural historical activity theory, topic-specific pedagogical content knowledge

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List of Abbreviations and/or Acronyms

A level	– Advanced level
AS	– Advanced Subsidiary
CHAT	– Cultural Historical Activity Theory
K_c	– Equilibrium constant in terms of concentration
K_p	– Equilibrium constant in terms of pressure
LCP	– Le Chatelier's Principle
LTSMs	– Learning and teaching support materials
PAR	– Participatory Action Research
PCK	– Pedagogical Content Knowledge
PLC	– Professional Learning Community
RCM	– Refined Consensus Model
RUEC	– Rhodes University Ethics Committee
TPD	– Teacher Professional Development
TSPCK	– Topic-Specific Pedagogical Content Knowledge

CHAPTER ONE: SITUATING THE STUDY

1.1 Introduction

This study aimed to investigate how a formative intervention can facilitate (or not) an improvement of the teaching and learning of chemical equilibrium in Namibia, targeting teachers' subject matter knowledge (SMK), pedagogical content knowledge (PCK), and skills (Shulman, 1987). This study is pertinent because students seem to habitually fail questions on chemical equilibrium as recounted in examiners' reports that are produced annually by Namibia's Department of National Examinations and Assessments (DNEA). For instance, the topic was singled out in the 2014 Examiner's Report as one of the topics "centres had not covered in sufficient detail" (Ministry of Education, Arts & Culture [MoEAC], 2014, p. 223). Thus, I assumed that the Chemistry teachers might be culpable for students' errors in learning chemical equilibrium and the consequent poor results. In this regard, García-Lopera et al. (2014) argue that the existence of error in student understanding of chemical equilibrium indicates problems in the teaching methodologies.

A study by Chani et al. (2018) explored the mediation of chemical equilibrium to high achieving students in Namibia. The study revealed that Namibian students and teachers consider the topic of chemical equilibrium as one of the most difficult topics to teach and learn. Moreover, teachers seem to lack adequate PCK and skills for properly mediating learning of the topic. Consequently, these scholars recommended CPD for Chemistry teachers but seemingly failed to provide details on how to execute the CPD. Thus, this study can be considered a response to that call; to present formative intervention as a methodology for executing continuing teacher professional development using a small-scale intervention as an example.

In this chapter, I thus introduce this study. Initially, I articulate the background of the study in which I expose the teachers' plight, particularly the difficulties that we face in mediating learning of chemical equilibrium, the ontological and epistemological contestations on the topic, and how these may impact teacher professional development (TPD) programmes. Then, I discuss my personal experiences as a student and as a Chemistry teacher which include the interactions that I have had with Grade 12 Chemistry students, other educators, and various stakeholders. Thereafter, I clarify the statement of the problem, the essentials on the significance of the study, and brief descriptions of the theoretical framework, the data gathering methods, and definitions of key concepts used in the thesis. Finally, I present a summary that highlights all the main elements in the chapter.

1.2 Background of the Study

Chemistry is considered an important school subject and a part of the highly regarded Science, Technology, Engineering and Mathematics subjects. This is because Chemistry teaches important skills such as reasoning, being objective as well as problem solving. In addition, students get to learn ideas that enable them to understand everyday concepts such as global warming, the workings of engines, technological advancements and limitations thereof as well as the environment.

However, the teaching of Chemistry is no easy feat. Hackling and Garnett (1985), almost half a century ago, identified chemical equilibrium as one of the topics in Chemistry that teachers and students alike find difficult to teach and learn, together with mole concept, stoichiometry, and redox reactions. Chemical equilibrium is especially daunting because the proper conceptions of stoichiometry and the mole concept are mandatory prior knowledge (Mavhunga & Rollnick, 2013). More recent studies by Hanson (2020), de Berg (2021), and locally by Chani et al. (2018) corroborate these findings.

In Namibia, Chemistry teachers seem to lack PCK for effectively mediating their students' meaning making of chemical equilibrium. As mentioned earlier, the examiners' reports seem to indicate that teachers lack the ability to teach chemical equilibrium (MoEAC, 2014; 2019; 2020). I speculate that this ineptitude might be exacerbated in part by the changes in the school curriculum. In this regard, the Namibia Senior Secondary Certificate Higher level (NSSCH) is currently being replaced by a more demanding Namibia Senior Secondary Certificate Advanced Subsidiary (NSSCAS) qualification (MoEAC, 2015).

Based on my experience as a facilitator of TPD in Namibia, I have found that chemical equilibrium is a difficult topic for facilitators because every teaching strategy seems to have shortcomings or engender difficulties. In addition, "predictions based on the LCP may conflict with experimental facts" (Cheung, 2009, p. 514) subsequently compelling teachers to choose between theories and empirical findings or between hands-on practical activities (Asheela et al., 2021) and traditional teaching methods. In the same vein, I find it difficult, as a chief examiner, to provide reasonable advice in examiners' reports on how one can best mediate the learning of chemical equilibrium because I also do not know the best teaching methodology to use for the topic.

In addition to the above, TPD interventions in Namibia generally fail to address teachers' concerns. Instead, they focus on addressing the deficiencies in teaching and learning based on the opinions of stakeholders in education, such as principals and education inspectors. Correspondingly, Lieberman and Pointer-Mace (2008) found that teachers in the USA perceived TPD as "idiosyncratic and irrelevant" (p. 226), that is, TPD "is fragmented, disconnected, and irrelevant to the real problems of classroom practice" (p. 227). Closer to home in South Africa, Pretorius et al. (2014) asserted that TPD interventions "do not always address teachers' needs or necessarily result in better realisation of the outcomes in science education" (p. 553). From my own experience too, Science workshops rarely address the teachers' needs and the facilitators' advice and suggestions on how to teach are not enacted; the teachers tend to revert to the old ineffective methods when they return to their classrooms.

In Namibia, it seems that the TPD facilitators decide on how and what to teach beforehand without any input from the participants. For instance, current TPD programmes that are intended to help teachers with the new curriculum are focused on pedagogical knowledge (PK), with an emphasis on constructing schemes of work and lesson plans, instead of SMK that the teachers need and request. To the facilitators' defence, it seems this problem is due to an "inherent divergence of commitments and accountabilities" between them and the participants (Mbekwa & Julie, 2019, p. 16).

1.3 My Personal Experience

I completed my secondary school education at a well-resourced school in Chinhoyi, Zimbabwe. The school had well-equipped Science laboratories and most Science lessons were conducted in these laboratories. My teachers, in the lower levels, used numerous demonstrations in their teaching and occasionally they gave us hands-on practical activities. I vividly remember the test for starch using an iodine solution that I performed more than a quarter of a century ago. The teacher gave the class the chemicals that we needed and a few instructions. We were required to design the experiment and carry it out. We all executed the experiment very well.

I excelled in Science and Mathematics in the early years of secondary school where we covered fewer abstract concepts and our teachers could find real-life examples of situations where we would need the ideas they were teaching (Gwekwerere, 2016; Mizzi, 2013). But, as the Science concepts became more abstract and the preferred teaching method became the lecture method, comprehension became elusive. I usually joke with my students that I was good in Mathematics when it was about numbers, that I was fine when letters were introduced but, like Adam, I left when sin was introduced.

My Advanced level (A-level) Chemistry teacher can be equated to a priest or pastor of a conventional church, for he religiously followed their routines to the letter. He would read a passage from a book, add a few words of his own, and repeat the process until the bell rang. At times, we had a copy of the book, in which case he would give us the page numbers so we could read along. On his best days, he dictated notes from an old, worn-out notebook and we wrote those notes in our own notebooks. It was torture! As a consequence, I struggled to understand most topics and relied on memorisation, including answers to past examination questions. I only persevered because we had been convinced that a pass in Science subjects was a gateway to a life of prosperity and abundance. I avoid similar methods in my own teaching. Or do I?

I studied for my first degree, a Bachelor of Technology in Textile Technology with Honours at the National University of Science and Technology in Bulawayo, Zimbabwe. I worked briefly as Production Manager for the Technical Textiles division of Kadoma Textiles in Kadoma, Zimbabwe. I left the industry and moved to the classroom, with a view to teach A-Level Textile Design. Later, I studied pedagogy with Rhodes University, South Africa and completed a Bachelor of Education with Honours degree.

I commenced my teaching career at a poorly resourced school in Gweru, Zimbabwe, over a decade ago. I was deployed to teach A-level Textile Design, Chemistry and Mathematics but found myself teaching more Chemistry than the other two. My experiences at this school informed my approach towards teaching, TPD as well as my worldview about education.

In the time I taught there, the school was located in the [1]township and its demographic was comprised of students with poor backgrounds, most of whom were unable to pay fees on time. A significant number of students relied on bursaries and scholarships, such as the government's Basic Education Assistance Module for vulnerable children and the Capernaum trust scholarship for orphans. Even so, it was not all doom and gloom; most of the students in the school were academically gifted, particularly those who enrolled for the A-level.

Notwithstanding, teaching resources were scarce, and the infrastructure was inadequate. For instance, we had one laboratory, modified from a woodwork workshop, for the three A-level Science subjects that we offered, namely Biology, Chemistry, and Physics. This laboratory was also used as a venue for non-laboratory (theory) lessons as well as a register classroom. We did not have adequate chemical reagents or equipment and students were required to share the equipment or carry out group work for tasks designed for individual work. Learning Science proved very difficult for most students, particularly practical skills, and I tried to mitigate the challenges by having laboratory sessions after school hours.

The staff complement at the school consisted mostly of experienced teachers who were very supportive. For instance, Mr Dube stood out as the most helpful teacher. He taught A-level Physics and he was one of the teachers with whom I shared the solitary laboratory. Mr Dube helped me develop into a teacher, but he did not always make it easy. As a case in point, he refused to help me identify laboratory apparatus that were unfamiliar to me. As a consequence, I intensely studied catalogues and developed very sturdy knowledge about equipment and apparatus necessary in a school laboratory. Such knowledge proved valuable in our circumstances because I could re-purpose a lot of equipment and apparatus.

The most valuable lesson that Mr Dube taught me was to be resourceful; that teaching Science demanded a knack for improvising as reiterated by Asheela et al. (2021) in their study conducted in Namibia. I learnt to be pragmatic and could run laboratory sessions, otherwise impossible, with the available equipment and chemicals. For instance, I assigned numerous different titrations using hydrochloric acid and sodium hydroxide by simply changing their

[1] A low-income neighbourhood

concentrations or by using different indicators. I also used distilled water, labelled 'aqueous silver nitrate', for analysing substances without halide ions.

I involved the students, whenever possible, in modifying Science experiments to suit available equipment and in making reagents such as red cabbage indicator to use for titrating. That really helped the students to understand the main ideas and made the mediation process easier. In consequence, most of my students performed very well in external examinations and that earned me passage to Namibia.

In Namibia, I started at a well-resourced rural school before moving to another well-resourced private school in the capital Windhoek, where I am currently teaching. Both schools enrol high achieving students and examination results are almost always very good. However, the students find some topics, such as chemical equilibrium, extremely difficult despite their innate ability (Chani et al., 2018).

During my time at the rural school, I voluntarily ran TPD workshops for Science teachers and despite being the facilitator, I learnt a lot from the participants (fellow teachers). We formed a vibrant professional learning community (PLC) (Brodie, 2013; Chauraya & Brodie, 2018; Ngcoza & Southwood, 2019) for sharing ideas, challenges, and experiences as well as learning and teaching support materials (LTSMs). I am still part of that community four years after leaving the region.

I have been a marker of national examinations for the past seven years and chief examiner for Chemistry since December 2017. One requirement for a chief examiner is to compose an examiner's report at the end of each marking session. The report spotlights the topics and ideas students found difficult and suggests teaching strategies. As alluded to earlier, I have been experiencing difficulties in providing meaningful suggestions for some topics, such as chemical equilibrium, because every teaching methodology engenders problems. I also do not know the best method or combination of methods for effectively teaching chemical equilibrium. For instance, hands-on practical activities as advised by Asheela et al. (2021) are not always successful in mediating learning of chemical equilibrium because the main ideas are abstract and are at a microscopic level. In general, the students focus on their observations, which are at the macroscopic level, and thus inadequate for understanding corpuscular ideas.

The privilege of looking at students' scripts at the national level, coupled with the task of providing suggestions that potentially improve the teaching of Chemistry, has been invaluable to my teaching practice as well as that of my peers. However, making suggestions on teaching chemical equilibrium has not been easy and is part of the problem this study sought to pursue.

1.4 My Positionality and Reflexivity

The general structure of PD consists of a facilitator and participants, which as indicated earlier can be problematic. Thus, in this study, it was important for me to reflect on my positionality and how this may have influenced the research process.

Bertrand and Demps (2018) provided some further insight on positionality and insisted that every researcher inherently carries assumptions and biases into their work and that these influence the interpretation and representation of the participants' *voices*. Concurring, Holmes (2020) explained that, as a researcher, I cannot separate myself from the social reality that I live in to study it objectively. In light of these arguments, I hereby provide "an open and honest disclosure and exposition [to] show where and how" I think my beliefs may have influenced the study (Holmes, 2020, p. 3). In addition, I divulge that I used a reflexive approach throughout the research process aimed at understanding the influence of my positionality on the research design, conduct, and output (Holmes, 2020).

Firstly, I recognise that in this study I might have been considered a TPD facilitator and therefore a more knowledgeable other (Vygotsky, 1978). This might have been exacerbated by the participants' awareness that I am the chief examiner for Chemistry responsible for setting and marking external examinations as well as generating the examiners' reports that they use to guide their teaching. I mitigated some of these challenges by presenting myself as a co-learner and made it clear that the project intended to create something new and learn something that does not yet exist (Sannino et al., 2016).

Secondly, as alluded to in Section 1.2, I am a Zimbabwean male while the research participants were all non-Zimbabwean females. Therefore, I assumed that there were differences in our social and cultural backgrounds, and that these might have restricted access to comprehension of the nuances used in the participants' responses (Galam, 2015). In particular, I could have missed metaphors and figures of speech. In other words, it is possible that I did not fully understand the participants' social and cultural contexts. Moreover, I recognise that the use of

English, which is the first language for neither the participants nor myself, might have ameliorated or exacerbated this problem. Furthermore, the current research practices did not permit me to function at my full potential. In this regard, Chilisa (2012) critiqued "current academic research traditions" and argued that the methodologies therein "exclude from knowledge production the knowledge systems of formerly colonized, historically marginalized, and oppressed groups" (p. 21).

In the context of outsider/insider positionality for this study, I assumed an insider position. I am a Chemistry teacher who also struggles with teaching chemical equilibrium and had a genuine desire to learn how best to teach it. The research participants were all colleagues, with whom I frequently shared teaching resources. In fact, I was teaching at the same school as two of the research participants. Thus, I had "priori knowledge of the group [and concept] under investigation" and relished the advantages of an insider position, such as "being able to ask more meaningful or insightful questions (due to possession of priori knowledge)" (Holmes, 2020, p. 6). Disadvantages of the insider position, for instance, the participants' assumption that I was more knowledgeable (Holmes, 2020) was mitigated, as explained earlier, by establishing the research group as a PLC and conducting a formative intervention. Hence, I was part of the collective that "conducts a formative intervention on themselves to address unsustainable contradictions and transform their activities" (Sannino et al., 2016, p. 2). The next section thus details the problem.

1.5 Statement of the Problem

Teachers in Namibia, just like in other places around the world, seem to find chemical equilibrium a very difficult topic to teach (Van Driel & Gräber, 2002) and it is no small wonder why there are persistent student errors in understanding (MoEAC, 2014). In other words, teachers are complicit in their students' poor performances. This suggests that there is a need for effective professional development for teachers to improve their knowledge for mediating learning of chemical equilibrium (Chani et al., 2018).

However, the TPD workshops that are organised for teachers by Namibia's MoEAC seem ineffective, and as a result, student achievement on chemical equilibrium in national examinations remains poor (MoEAC, 2019; 2020). These TPD interventions "do not address teachers' needs or result in better realisation of the outcomes in science education" (Pretorius et al., 2014, p. 553) and teachers find them "fragmented, disconnected, and irrelevant to the real problems of classroom practice" (Lieberman & Pointer-Mace, 2008, p. 227).

In general, "designing and conducting TPD experiences … that promote deep and lasting pedagogical change is difficult" (Beatty & Feldman, 2012, p. 283) and is especially so for chemical equilibrium. In this regard, Mbekwa and Julie (2019) suggested that TPD interventions fail because the teacher educators have their own commitments or accountabilities and may ignore the teachers' needs and contexts. Although this may be true, I believe that the main reason why TPD interventions aimed at improving teachers' PCK for mediating learning of chemical equilibrium fail could be that the TPD facilitators simply do not know how to effectively support teachers in learning how to teach it. This is exacerbated by seemingly irreconcilable ontological (relating to reality or truth of concepts and ideas), such as LCP, and epistemological (relating to nature of knowledge and its acquisition) contestations among teachers and researchers about chemical equilibrium. In addition, it seems literature does not provide decisive practical details on how to conduct TPD interventions nor any means to address the contestations mentioned above.

It is against this backdrop that I implemented a formative interventionist study for the development of teachers' PCK for mediating learning of chemical equilibrium in which *we* learnt something that does not yet exist (Sannino et al., 2016).

1.6 Purpose and Significance of the Study

The primary purpose of this study was to improve the teaching and learning of chemical equilibrium concepts by Grade 12 Chemistry teachers to their students. Extending on Sannino et al.'s (2016) study, this study was envisaged or conceptualised as a formative intervention to avoid the pitfalls associated with conventional professional development programmes. For instance, current professional development practices fail because the trainers bring preconceived ideas to the training, "implanting an alien bubble in an unknown territory" (Engeström, 2009, p. 25). Thus, the ideas are reasonably ignored or rejected by the trainees. As a consequence, this study had a secondary purpose of improving or suggesting a possible method for professional development.

Furthermore, it was hoped that this intervention might culminate in the formation of a formal professional learning community (PLC) (Brodie, 2013; Chauraya & Brodie, 2018; Ngcoza &

Southwood, 2019). That is, I had hoped that after our workshop, the teachers involved in this study would continue to share experiences, merge ideas and practices, and collectively develop tools such as topic-specific pedagogical content knowledge (TSPCK) for teaching (Mavhunga & Rollnick, 2013). Finally, I had hoped that the interactions from the workshops would have a positive impact on my own teaching practice to benefit my students.

1.7 Research Goal, Objectives, and Research Questions

The main goal of the study was to work *with* Grade 12 AS teachers on how to improve our PCK to understand and mediate learning of chemical equilibrium. To achieve this goal, the following objectives and research questions were addressed:

1.7.1 The research objectives

- To determine the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and the remedial strategies they employ in their classrooms.
- To determine how the implementation of a formative intervention facilitates (or not) the development of Grade 12 Chemistry teachers' PCK for mediating learning of chemical equilibrium.

1.7.2 Research questions

- What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?
- How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 Chemistry teachers' PCK for mediating learning of chemical equilibrium?

1.8 Theoretical and Analytical Frameworks

A theoretical framework is considered paramount to a research process because it undergirds the thinking processes in research. Grant and Osanloo (2016) averred that a theoretical framework guides research, and helps others understand the principles used to establish the approaches and ideas in the research process. In this regard, a theoretical framework is understood as a lens that a researcher uses to view the world, in particular aspects that are ostensibly invisible (Collins & Stockton, 2018).

This study was guided by a theoretical framework derived from two well-established theories, namely, Shulman's (1987) PCK, in particular, Mavhunga and Rollnick's (2013) topic-specific grain of PCK and Engeström's (1987) third generation Cultural Historical Activity Theory (CHAT). Pedagogical Content Knowledge (PCK) is a construct that recognises that Science teachers possess specialised knowledge which sets them apart from professional scientists on one hand and people who are good with students on the other (Liepertz & Borowski, 2019). This knowledge permits them "to pedagogically restructure and package difficult and abstract content in formats accessible for student understanding" (Mavhunga, 2019, p. 130). Put differently, PCK is considered the "knowledge of translating CK or SMK to become knowledgeable to students" (Nind, 2020, p. 188).

CHAT is a theory for analysing and understanding human action and enables researchers, particularly those who undertake action research, "to analyse complex and evolving professional practices" (Foot, 2014, p. 329). The CHAT was used to analyse the intervention, primarily to answer the second research question that was concerned with checking the efficacy of the intervention for professional development, while PCK was used to analyse teachers' skills the intervention engendered.

1.9 Data Gathering Methods

Four data collection methods were selected for use in this study, based on ideas for data collection in formative interventions by Morselli (2019), namely:

- Semi-structured interviews;
- Document analysis;
- Workshop discussions, including participatory observation and videotaping; and
- Journal reflections.

1.10 Definitions of Key Concepts Used in the Thesis

Chemical equilibrium: A state of balance in a reversible chemical reaction in which the forward and reverse reactions occur but the amounts of the reactants and products remain constant.

Le Chatelier's Principle (LCP): A (controversial) principle in Chemistry that is used to predict the effects of changing external conditions (such as temperature and pressure) on a system at equilibrium.

Pedagogical content knowledge (PCK): Specialised knowledge possessed by teachers for making content understandable to their students (Mavhunga & Rollnick, 2013).

Cultural Historical Activity Theory (CHAT): A theory for analysing collective human activity (Sannino, 2011).

Formative intervention: An approach to research that has a transformative agenda in which the researcher collects data aimed at helping the participants understand their practices (Sannino et al., 2016).

Teacher professional development (TPD): Specialised training of teachers that is aimed at improving their skills, competences, and effectiveness.

1.11 Thesis Outline

This thesis is made up of six chapters as follows:

Chapter One: Situating the Study: In this chapter I gave details of the study, the context of the study, the research goals, research objectives, and research questions as well as an overview of the theoretical frames guiding the study and the proposed data collection methods.

Chapter Two: Literature Review: This chapter details related research in the field of this investigation. The chapter focuses primarily on studies that support the approaches that I undertook. However, it will also point out other studies that were done differently and articulate the reasons why those ideas were not considered in this investigation.

Chapter Three: Theoretical and Analytical Framework: In this chapter, I give details of the two theoretical frames that guided this investigation, namely the CHAT and PCK.

Chapter Four: Research Methodology: In this chapter, I give details of the research paradigm and research design of this study as well as details of data collection methods. It is in this chapter that I enunciate my worldview, the justification of the sampling employed and the approaches to data analysis.

Chapter Five: Semi-structured interviews: In this chapter, I present and discuss my findings, using interview data. Enough data is made available to support the claims made.

Chapter Six: Intervention workshops: In this chapter, I present and discuss my findings, using data obtained intervention workshops. Enough data is made available to support the claims made.

Chapter Seven: Summary of Findings and Conclusion: In this chapter, I make clear the implications of the research and point out areas for further studies.

1.12 Chapter Summary

This chapter was aimed at enticing the reader to be invested in this investigation. The chapter started with a description of the background and context of the study. Here, the circumstances that the Namibian Grade 12 Chemistry teachers find themselves in, in the context of mediating learning of chemical equilibrium, were laid bare. The aim was to justify the investigation. Next, the chapter detailed my personal experiences as a student and as a teacher, spotlighting the subject matter of this investigation, namely the teaching of chemical equilibrium and continuing professional development (CPD). Thereafter, a statement of the problem, the purpose and significance of the study, and the research goals, objectives and questions were provided. These were succeeded by a brief account of the theoretical framework and the envisaged data gathering methods. The chapter ended with a glossary of terms used in the study and an outline of the thesis. The next chapter presents a review of relevant literature.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In the previous chapter, I elucidated the context of this study by referring to some research findings. I established the relevance of the current study, in which I worked *with* fellow Grade 12 Chemistry teachers to collectively improve our PCK in chemical equilibrium, while simultaneously analysing the entire process. Thus, this study employed participatory action research (PAR) approach.

In this chapter, I review various literature relevant to my research. I begin by explaining the main ideas related to chemical equilibrium, such as reversible reactions, incomplete reactions, the equilibrium law, and LCP. Thereafter, I highlight teachers' challenges related to teaching chemical equilibrium from literature. These challenges were used to inform the intervention workshops that we ran as mirror data, that is, the research participants looked at them to see if they reflected their own practices or not.

Finally, I discuss the main ideas around TPD or PLCs and direct the reader to a few studies that describe why and how current TPD programmes fail as a means to validate the use of formative interventions to carry out this transformative exercise (Sannino et al., 2016). Relatedly, I also present the successes that other researchers reported when they employed this type of research intervention in carrying out professional development.

2.2 Chemical Equilibrium – The Main Ideas

Chemical equilibrium refers to a state of balance in a chemical reaction in which the rate of the forward reaction is equal to the rate of the reverse reaction. The ideas in chemical equilibrium were initiated by empirical studies of incomplete and reversible reactions in the 1860s (Van Driel & Gräber, 2002). Reversible reactions are chemical reactions that can progress in both directions; reactants combine to form products (forward reaction) and products break down to form reactants (reverse reaction). Reversible reactions never reach completion where all reactants are converted into products because at equilibrium, the amounts of products and reactants do not change even though the reaction continues (Ryan & Norris, 2020).

The amounts of each species at equilibrium for any reversible reaction at a given temperature fit a simple law known as the equilibrium law.

> If a reversible reaction is allowed to reach equilibrium, then the product of the concentrations of the products (raised to appropriate powers) divided by the product of the concentrations of the reactants (raised to appropriate powers) has a constant value at a particular temperature (Ramsden, 2000, p. 222)

This law can be expressed mathematically for a hypothetical reaction between W and X to form Y and Z as follows:

$$\mathrm{aW + bX \leftrightharpoons cY + dZ}$$

$$\mathrm{K_c} = \frac{[\mathrm{Y}]^{\mathrm{c}}\,[\mathrm{Z}]^{\mathrm{d}}}{[\mathrm{W}]^{\mathrm{a}}\,[\mathrm{X}]^{\mathrm{b}}}$$

where [Y] stands for concentration of Y.

K_c is constant regardless of the amounts involved, provided the temperature is kept constant. K_c is used to quantitatively describe the equilibrium position (Ryan & Norris, 2020). For instance, a high value of K_c means the equilibrium position is to the right.

The position of equilibrium can also be described using K_p: the equilibrium constant in terms of partial pressure. K_p is used for reactions involving gaseous substances, where measuring the pressure may be easier (or more convenient) than measuring the concentration. For the hypothetical reaction between W and X to form Y and Z above and all the substances are gaseous, K_p is given by:

$$\mathrm{K_c} = \frac{p\mathrm{Y}^{\mathrm{c}}\,p\mathrm{Z}^{\mathrm{d}}}{p\mathrm{W}^{\mathrm{a}}\,p\mathrm{X}^{\mathrm{b}}}$$

where pY stands for partial pressure of Y.

Changes occur to the equilibrium position when external factors, such as temperature, are altered. To predict the new equilibrium position two concepts are used: LCP and the reaction quotient, Q. In Namibia, students are required to learn LCP and use it to make predictions and Q is not indicated in the syllabus. It seems, though, that some teachers teach Q to improve their students' understanding.

La Chatelier's principle is a quick qualitative method (Kousathana & Tsaparlis, 2002) while Q is a calculated value (García-Lopera et al., 2014). For instance, LCP states that "when an equilibrium system is subjected to a change in temperature, pressure, or concentration … the system responds by attaining a new equilibrium that partially offsets the impact of change" (Cheung, 2009, p. 514). Q is calculated exactly like K. When $Q > K$, indicating the numerator is bigger in the ratio than it should be, the reverse reaction is favoured, and equilibrium shifts to the left. The reverse also holds true: when $Q < K$ the forward reaction is favoured, and equilibrium shifts to the right (Kousathana & Tsaparlis, 2002).

2.3 Problems Associated with Understanding Chemical Equilibrium

Chemical equilibrium has been considered a difficult topic since its inception in the late 19th century (Van Driel & Gräber, 2002). Consequently, literature is replete with findings that detail the problems that students face in understanding it, challenges that teachers face, and suggestions on how to best mediate learning of the topic. This section reviews the literature intended to form a basis for answering the first research question: *What challenges do Grade 12 teachers face in mediating learning of chemical equilibrium in their classrooms?* This study was limited to challenges in the context of teachers' TSPCK (Mavhunga & Rollnick, 2013), using CHAT to illuminate teaching as a complex activity system (Sannino et al., 2011).

Numerous challenges are reported in the literature on mediating learning of chemical equilibrium to secondary school students. In particular, almost two decades ago, Van Driel and Gräber (2002) provided an extensive description of the concepts in chemical equilibrium that students from across the world and over a few decades faced and how these make its teaching difficult. A study conducted by Chani et al. (2018) in Namibia, closely resembles the context of the current study, and corroborated Van Driel and Gräber's (2002) findings. For instance, these scholars found that teachers face three main challenges in teaching chemical equilibrium: (i) student misconceptions (or alternative conceptions), (ii) Le Chatelier's Principle, and (iii) chemical equilibrium calculations. These challenges informed our workshops as mirror data, but the participants were encouraged to carefully reflect on their own practices as they sought to describe their own challenges. TSPCK is known to be very context specific (Mavhunga & Rollnick, 2013) and thus empirical generalisations will not work in this study as they tend “to hide the cultural and historical specificity of the activity system” (Morselli, 2019, p. 42).

2.3.1 Students’ prior knowledge and misconceptions

Modern learning and teaching theory, particularly constructivist approaches that are derived from Piaget’s theory of cognitive development, deem students’ prior knowledge key to learning. Prior knowledge is rated highly and is considered influential to new learning (Van Riesen et al., 2018). While accurate students’ prior knowledge aids teaching and learning, inaccurate prior knowledge, known as misconceptions, act as barriers to learning (Morales, 2017).

Literature is replete with misconceptions that students develop in learning chemical equilibrium. For instance, a literature review by Üce and Ceyhan (2019) outlined the following student misconceptions that make chemical equilibrium difficult to teach:

- “While reaction is about to be at equilibrium, the velocities of forward and reverse reaction increase evenly”.
- “When reaction is at equilibrium, concentrations of reactants are equal to the concentrations of products”.
- “When reaction is at equilibrium, the concentrations of reactants and products change in time”.
- “When reaction is at equilibrium, the concentrations of reactants and products constantly change as they go between reaction products and reactants”.
- “When reaction is at equilibrium, velocity of forward and reverse reaction are equal to each other and change”.
- “When reaction is at equilibrium, velocities of forward and reverse reaction are not equal to each other”.
- “When reaction is at equilibrium, in the case when equilibrium is disturbed by the temperature increased, the velocity of forward reaction is higher than the velocity of reverse reaction”.
- “When reaction is at equilibrium, in the case when equilibrium is disturbed by the volume decreased, the velocity of reverse reaction immediately decreases; when reaction is at

equilibrium again as a result of increasing temperature, the velocities of forward and reverse reaction are equal to the value at the first equilibrium".

- "When reaction is at equilibrium, in the case when catalyst is added into reactor, the fact that velocities of forward and reverse reactions do not change or increase is related to reaction affinity of catalyst with forward or reverse reaction" (p. 204).

Secondary school students find these misconceptions very difficult to relinquish unless teachers address them directly (Morales, 2017). Thus, in the context of TSPCK, misconceptions can be considered "what is difficult to teach". Morales (2017, p. 85) argued that these misconceptions develop over time and "are sourced from adults, media, other educators, misunderstandings from what students heard, and from inconsistent figures and texts in textbooks". This makes the misconceptions social and historical and thus important in this study in the context of the CHAT framework.

Van Driel and Gräber (2002) focused on the misconceptions students espouse when they arrive in the classroom to learn chemical equilibrium. For them, misconceptions have their origins in prior learning such as the learning of chemical changes and the balancing of chemical equations. The students develop the understanding that all reactions go to completion, that is, all reactants are converted into products. García-Lopera et al. (2014) also revealed that the way balancing chemical equations is taught, in particular, the emphasis placed on ensuring that the quantities of each element on the reactant side should equal the quantities on the product side, leads to students' misunderstanding of the reversibility of reactions and leads to students holding a "compartmentalised view of equilibrium" (Van Driel & Gräber, 2002, p. 280). Thus, we can also consider misconceptions as students' prior knowledge in Mavhunga and Rollnick's (2013) TSPCK framework.

García-Lopera et al. (2014) weighed in on this idea of students' prior learning as a source of misconceptions in learning that spawn difficulties for teachers in mediating learning of the topic. Specifically, they found the use of physical analogies by teachers, which encourage students to mobilise ideas already learnt, as a key source of misconceptions. For instance, some teachers use the idea of static equilibrium learnt in mechanics which promotes an understanding of equilibrium in terms of everything being equal. In addition, this idea compels students to visualise the concept of reversibility as physical movement (García-Lopera et al., 2014). Now, I turn to LCP.

2.3.2 The problems of Le Chatelier's Principle

Le Chatelier's Principle (LCP) presents two main challenges to the Chemistry teacher. First, LCP uses vague language that is difficult to understand (Chani et al., 2018; García-Lopera et al., 2014; Quilez, 2004). This leads to a plethora of difficulties for the teacher as they try to mediate learning of chemical equilibrium and for the students, who tend to "learn the principle by heart and then try to apply it without understanding" (Van Driel & Gräber, 2002, p. 279). Because of a lack of understanding, students seem to apply the principle in areas where the principle is not valid, such as when a solid solute is added to a saturated solution (Van Driel & Gräber, 2002). In this regard, Chani et al. (2018) averred that even high achieving students in Namibia who are proficient in the English language struggle with understanding the language of LCP. Indeed, Science is a language in its own right. These scholars seem to concur with Quilez (2004), who also argued that it is "difficult to explain the precise meaning of the *words* used in" LCP (p. 283, my emphasis).

Secondly, LCP is scientifically inadequate (Cheung, 2009), is amorphous in nature (Quilez, 2004), "it is hard to state LCP unambiguously" (Cheung, 2009, p. 514), and many variations exist (Cheung et al., 2009; Quilez, 2004; Van Driel & Gräber, 2002). In fact, Quilez (2004, p. 282) refuses to call LCP a principle and instead refers to Le Chatelier's rules because "textbooks use many similar statements, which, in turn, may express divergent and even contradictory ideas". This study, however, focused on the challenges brought about by the language used rather than ontological concerns of LCP because the learning of LCP is a requirement in Namibia's school curriculum. We recognise, however, that its amorphous nature may be the cause of serious challenges for teachers.

Cheung (2009) posited that in Hong Kong, teacher misconceptions about LCP are prevalent and the reason why students struggle to understand chemical equilibrium is that "teachers cannot help their students understand what they themselves do not understand" (p. 514). In the context of PCK, this suggests that the teachers might be lacking SMK (Shulman, 1987). To Shulman, SMK precedes PCK. Teachers understand LCP "as an infallible principle without limitations" (Van Driel & Gräber, 2002, p. 275) and are unaware of the scientific inadequacy of LCP (Cheung et al., 2009). Thus, this study hoped to develop teachers' SMK around LCP and its limitations so that the teachers would be able to use the principle more carefully and minimise their students' confusion which is evident in calculations in particular.

2.3.3 Problems with calculations

Namibian students seem to find chemical equilibrium difficult (Chani et al., 2018), in particular, the calculations because of the abstract nature of chemical equilibrium as well as the need for mastery in several other topics (Özmen & Naseriazar, 2018). That is, students should have the correct knowledge of several subtopics before they can attempt chemical equilibrium problems (Özmen & Naseriazar, 2018), which as indicated earlier are usually not properly learnt. For instance, students who do not understand the ideas of concentration, ideal gases, and partial pressures as well as the mole concept and stoichiometry always struggle with calculations in chemical equilibrium.

Difficulties with undertaking stoichiometry were singled out by García-Lopera et al. (2014), particularly when dealing with equilibrium concentration. They realised that students' erroneously concluded: "equal stoichiometric coefficients should correspond to equal concentrations" (p. 450). In addition, students omitted coefficients of the reaction stoichiometry in the expression for the equilibrium constant, a challenge that Chani et al. (2018) and Van Driel and Gräber (2002) also identified. García-Lopera et al. (2014) argued that most errors in stoichiometry have their origins in previous concepts such as "the law of conservation of mass or mathematical calculations involving proportionality" (p. 450).

Kousathana and Tsaparlis (2002) were more thorough in their investigation of the errors students make in chemical equilibrium calculations. They classified the challenges into random errors and systematic errors. They defined random errors as those caused by haste, carelessness, or the overloading of the working memory and systematic errors as those due to misconceptions or failure by the students to understand the underlying concepts. In general, their findings corresponded to the problems that I have described above, particularly the difficulties that students have with stoichiometry, the gas law, and the equilibrium constants. However, I found their classifications of students' errors fascinating and imagined they might be relevant to this investigation.

2.4 Possible Teaching Strategies

Chemical education literature contains a plethora of teaching strategies, considered in this study as indicators of TSPCK (Chani et al., 2018), aimed at helping teachers overcome the challenges they face in the teaching of chemical equilibrium. However, these strategies appear unsuitable for direct assimilation by teachers because each seems to have its own insufficiencies. In addition, when each method is used in isolation, this “may in fact result in new learning difficulties because students may become bored, reducing their motivation to learn” (Özmen & Naseriazar, 2018, p. 123). Furthermore, each of these strategies does not adequately consider the specificity of the teachers’ contexts or the novel teaching difficulties brought about by the Covid-19 pandemic (Thomas & Rogers, 2020). Thus, teaching methods discussed in the following paragraphs were not taken as prescriptive but instead were used as a foundation in formulating our own techniques as well as to decide how best to blend them in our quest for a blend suited for our contexts.

2.4.1 Hands-on practical activities

The use of hands-on practical activities is effective in aiding students to comprehend chemical equilibrium (Asheela et al., 2021, Xian & King, 2019), in particular the idea of reversibility (Rudd et al., 2007; Van Driel & Gräber, 2002). Van Driel and Gräber (2002) argued that simple chemical experiments have the potential to challenge students’ conceptions. However, Rudd et al. (2007) emphasised that traditional ‘cookbook’ laboratory sessions do very little to improve students’ understanding and only work if the students are asked “questions in corpuscular terms” (Van Driel & Gräber, 2002, p. 282). In other words, poorly planned hands-on practical activities might not address, or could even exacerbate, students’ misconceptions caused by “macroscopic/microscopic disconnect”. For instance, once chemical equilibrium is attained, macroscopic properties (which the students observe) stop changing and students may incorrectly think the reaction has stopped yet processes continue at the microscopic level (Özmen & Naseriazar, 2018). In addition, teachers find using hands on practical activities in their teaching difficult because they lack the resources and have time constraints (Boakye & Ampiah, 2017) or fail to manage the time allotted for science lessons (Teig et al., 2019).

2.4.2 Analogies, metaphors, and visualisation

Analogies, metaphors, and visualisations have been found to be effective in teaching Science (Guerra-Ramos, 2011; Guzey & Roehrig, 2009; Maharaj-Sharma & Sharma, 2015) as well as helping students understand abstract ideas in chemical equilibrium (Raviolo & Garritz, 2009; Üce & Ceyhan, 2019). For instance, I use a person walking the wrong way on an escalator to teach dynamic equilibrium. I ask students to visualise a person going down an escalator that is going up. The person has to move faster than the escalator to get to the bottom. If their speed is equal to that of the escalator their position does not change, even though it can be seen that both the person and escalator are moving. This is what is called dynamic equilibrium. Thus, analogies enable students to draw parallels between what they know and the new knowledge (Chani et al., 2018) or make "conceptual links with familiar objects, scenarios or events" (Maharaj-Sharma & Sharma, 2015, p. 558). Computer simulations (Guzey & Roehrig, 2009), YouTube videos and similar multi-media resources (Koto, 2020) provide the teacher more powerful tools for helping students visualise the concepts.

The analogies, although powerful in teaching, do not work well for all students (Guerra-Ramos, 2011) because they rely on the students generating "their own meaning based on their backgrounds, attitudes, abilities and experience" (Canpolat et al., 2006, p. 218). In addition, analogies can result in the transfer of incorrect information (Chani et al., 2018) because students have to make conceptual links which may lead to the formation of misconceptions (Chani et al., 2018; Raviolo & Garritz, 2009). For instance, the analogy may reinforce the idea that reagents and products are separate and distinct (Van Driel & Gräber, 2002). Therefore, teachers need to be wary of "where the analogy breaks down in order to avoid misunderstanding, inappropriate comparisons or oversimplification of the new concepts" (Guerra-Ramos, 2011, p. 37).

Raviolo and Garritz (2009) found that analogies expressed by teachers in classrooms are similar to those found in textbooks, indicating that textbooks are the sources of the analogies. A potential problem of textbook-based analogies is that the analogies that should be familiar to the students may be unfamiliar. Thus, the analogy may just create two unknowns instead of being an "analogical comparison between two fields: a known field and the conceptual field" (Raviolo & Garritz, 2009, p. 5). Consequently, in the intervention workshops, we had the task of generating analogies appropriate for our students, a feat Raviolo and Garritz (2009) discovered is difficult for teachers.

2.4.3 Conceptual change approach

The conceptual change approach is a novel teaching strategy within the constructivist theory (Üce & Ceyhan, 2019) based on "Piaget's construct of disequilibrium and Zeitgeist change" that targets students' misconceptions (Canpolat et al., 2006, p. 219). The approach involves the use of refutational texts or conceptual change text, whereby a common theory or idea is presented, and its shortcomings explained. Thereafter, a more plausible alternative theory is then presented (Özmen, 2007). For the approach to work, it is important that (i) the students must become dissatisfied with their existing concepts; (ii) the new concept must be intelligible; (iii) the new concept must appear plausible and (iv) the new concept must be fruitful (Canpolat et al., 2006).

There are challenges associated with the conceptual change approach. An obvious problem is that it requires teachers to have a good understanding of their students' misconceptions. In addition, the preparation of the refutational texts that have the potential to cause cognitive conflict (Canpolat et al., 2006 Le Grange, 2007) requires expertise that the teachers may not possess. Furthermore, Canpolat et al. (2006) contended that cognitive conflict alone may not be enough to produce conceptual change and requires that the new conceptions are intelligible. We have already established that this is difficult to achieve in the context of chemical equilibrium.

Teachers tend to use of past examination questions in their teaching, particularly those that test higher order thinking skills, to help their students develop a deeper understanding (Turner, 2018) of the chemical equilibrium concepts. Although this technique is not truly the conceptual change approach, I think it shares some features of the conceptual change approach and we may use it as a means for creating refutational texts.

2.5 Professional Development

Teacher CPD is considered paramount in schools to ensure that a high standard of teaching is maintained as well as to retain high-quality teachers in the profession. This section reviews the literature on professional development as a basis of answering the current study's second research question:

> *How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 teachers' PCK for mediating learning of chemical equilibrium?*

The Teaching and Learning International Survey (Talis) defined professional development as "activities that develop an individual's skills, knowledge, expertise and other characteristics as a teacher" (Organisation for Economic Co-operation and Development [OECD], 2009, p. 49).

The main goal of such activities is "to enhance teacher effectiveness as professionals, in order to improve students' learning progress and achievement" (Stoll, 2013, p. 227). In other words, the object of teacher learning, however it is implemented, is to achieve maximised student experiences that translate into better student outcomes.

Research on professional development interventions reports alarming findings. For instance, Lieberman and Pointer-Mace (2008) found that teachers in the USA perceived professional development as "being idiosyncratic and irrelevant" (p. 226); that "it is fragmented, disconnected, and irrelevant to the real problems of classroom practice" (p. 227). Closer to home, in South Africa, Pretorius et al. (2014) reported that professional development interventions "do not always address teachers' needs or necessarily result in better realisation of the outcomes in science education" (p. 553). These findings on professional development, which is always well-intentioned, begs the question: What is wrong with how TPD is conducted that provokes indifference among teachers or fails to generate agency in teachers to learn and improve their practices?

Based on my personal experiences, I submit that professional development workshops seldom address the areas that teachers need help in. For instance, since the introduction of the new curriculum in Namibia, the workshops organised by NIED have focused on PK and the construction of the scheme of work and lesson plans. Teachers voiced their concerns and desperate need for content knowledge, but no change was made to the programme. Mbekwa and Julie (2019, p. 16) supported my experiences, arguing that professional development is usually set to fail because the teacher educators from organisations, such as teacher education institutions, have their "own commitments and accountabilities" and ignore the teachers' contexts. Consequently, their offerings rarely address the teachers' immediate needs and are rejected by the teachers. As a result, after the workshops, the teachers revert to their old ineffective ways of teaching. Similarly, Lieberman and Pointer-Mace (2008) criticised this approach of professional development because all that teachers learn is "how to follow a script that presumably they will use in hopes of raising their students' test scores" (p. 228), arguing that it ignores the specific needs of the students and the particular experiences of the teacher.

Considering that professional development is time consuming and costly (Stoll, 2013), it is important to embark on a process that really makes a difference. Beatty and Feldman (2012) warned that creating a professional development programme that promotes deep and lasting pedagogical change is difficult. Thus, this study recognises these and that professional development "needs an appropriate set of descriptive mechanisms to capture its complexity" (Mbekwa & Julie, 2019, p. 17). Research identifies two methods that have the potential to improve professional development: (i) working within the CHAT framework and (ii) professional learning communities. This study was conceptualised as a PLC, central to which was co-learning how to mediate learning of chemical equilibrium.

A PLC is considered effective for TPD because it significantly impacts teacher learning (Brodie, 2013; Chauraya & Brodie, 2018). According to Lieberman and Pointer-Mace (2008), learning is social, that is, "learning is situated in a community of practice" (Chauraya & Brodie, 2018, p. 2). Therefore, PLCs enable "teachers to teach each other, support their peers and deepen their knowledge" (Lieberman & Pointer-Mace, 2008, p. 227).

A PLC has three characteristic properties that promote collaborative learning, namely joint enterprise, mutual engagement, and a shared repertoire (Lave & Wenger, 1991; Wenger, 1998).

Joint enterprise refers to the common problem to be solved by collective action; mutual intervention refers to a collaboration among members that facilitates engagement; and the sharing of knowledge and mutual engagement refers to collective solutions or tools that are generated by the PLC (Chauraya & Brodie, 2018). These three characteristics thus provide cohesion to the community or their activities and enhance the members' morale (Chauraya & Brodie, 2018).

For this study, the participants and I formed a PLC, which I define as an "inclusive and mutually supportive group of people with a collaborative, reflective and growth-oriented approach towards learning more about their practice" (Stoll, 2013, p. 226), to enable all participants to learn *from* and *with* each other (Lieberman & Pointer-Mace, 2008; Ngcoza & Southwood, 2019). In other words, this intervention allowed all the members to share ideas about their practices and critically interrogate those practices in an ongoing reflective manner (Chauraya & Brodie, 2018), from a position of equality without the researcher, or any other participant, being considered 'a more knowledgeable other'. In addition, I mobilised the concept of a PLC for this study because it fosters shared beliefs and understandings, which in turn nurtures trust (Lieberman & Pointer-Mace, 2008) that may facilitate learning. Thus, the PLC was used "as part of the overall strategy of TPD [because] PLCs promote and sustain the learning of all teachers through collaboration" (Turner et al., 2018).

2.6 Working within the CHAT Framework

This study was couched in the CHAT framework because CHAT has the potential to capture the complexities associated with human interactions (Yamagata-Lynch, 2010). Thus, the problems endemic in professional development such as suggesting ideas that may or may not be relevant to teachers or their particular classrooms were avoided (Lieberman & Pointer-Mace, 2008). In addition, the CHAT framework enabled participants to link "the activity systems of professional development and teachers' classroom practice" (Beatty & Feldman, 2012, p. 283). This meant that the professional development programme encouraged the participants to always reflect on their own teaching practices and engage in ways that would directly benefit their students.

The CHAT has been used in numerous teacher education initiatives and significant successes have been reported. For instance, Wilson (2014, p. 28) examined several teacher educational programmes that used CHAT and concluded that "CHAT has much to offer teacher education, both as a method of analysis and as a stimulus for change" despite its shortcomings. For instance, he criticised CHAT's context specificity arguing that this limits the applicability of findings in different contexts (which CHAT is designed to avoid) and CHAT's silence on racial, class, or gender-equality issues.

More recently, Morselli (2019) carried out Change Laboratory interventions, a form of formative interventions that engage participants in CHAT analysis of their own practices intending to improve them, for training teachers in entrepreneurship education. Similarly, she reported that positive results were accomplished. More researchers have experimented with the use of CHAT and also had positive results (Beatty & Feldman, 2012; Mbekwa & Julie, 2019; Teras & Lasonen, 2013; Trust, 2017) culminating in a review study by Hauge (2019). The review study by Hauge (2019) displayed the many factors that influence professional development programmes for teachers and spotlighted the value of CHAT in the analysis as well as in mitigating the endemic challenges. In addition, the study showed how CHAT highlights the social nature of professional development, and in a way, the importance of PLCs.

2.7 Chapter Summary

This chapter reviewed literature that was relevant to this study. I began by articulating the key ideas in chemical equilibrium, such as reversible reactions, incomplete reactions, dynamic equilibrium, the equilibrium law, and LCP. Next, I detailed how a chemical reaction at equilibrium is affected by changes in external factors (pressure, temperature, and amount of substance) as well as how LCP and the equilibrium law can be used to predict the direction of the reaction so as to re-establish equilibrium. Thereafter, the chapter detailed the challenges that teachers face in mediating this topic to Grade 12 students, in particular student misconceptions, problems with and of LCP as well as the problems students have with calculations. Finally, the chapter presented the idea of professional development, the difficulties that the traditional forms of TPD present as well as how the CHAT framework and PLCs tend to circumvent those difficulties (Mavhunga & Rollnick, 2013).

CHAPTER THREE: THEORETICAL & ANALYTICAL FRAMEWORKS

3.1 Introduction

This study was theorised as a formative interventionist study that used "conceptual tools stemming from cultural historical activity theory" (Sannino et al., 2016, p. 2). Thus, CHAT was used to inform both methodology and analysis in this study. Additionally, Mavhunga and Rollnick's (2013) TSPCK was used to examine the learning that occurred during the intervention. This section details these two theoretical frames and elucidates the lenses of each framework that were mobilised. I start with the CHAT.

3.2 Cultural Historical Activity Theory

The CHAT was developed by Engeström (1987) based on the work of Russian theorists Vygotsky, Leont'ev, and Luria during the upheavals in Russia (Sannino, 2011). Engeström (1987) expanded the 'simple' Vygotskian triadic relations to permit analysis of the collective human activity in terms of hexadic relations. Three generations of CHAT, that represent the development of activity theory, are recognised, namely, the first generation (Vygotsky, 1978), the second generation (Leont'ev, 1981), and the current and most developed third generation (Engeström, 1987).

First generation CHAT (Vygotsky, 1978) is a derivative of Vygotsky's socio-cultural theory, and it focuses on the idea that human action is mediated by cultural tools and is directed towards an object (Morselli, 2019; Yamagata-Lynch, 2010). That is, a triadic relationship exists between the subject, object, and the mediating artefacts, but only highlights the action and ignores the activity (Sannino et al., 2009). Essentially, this idea of "mediation by tools was revolutionary as it transcended the dualistic relationship between the individual and the society" (Morselli, 2019, p. 38). Vygotsky's basic mediated action triangle (see Figure 3.1) is used to represent this dialectical relationship between the subject, object, and mediating artefacts (Yamagata-Lynch, 2010, p. 17).

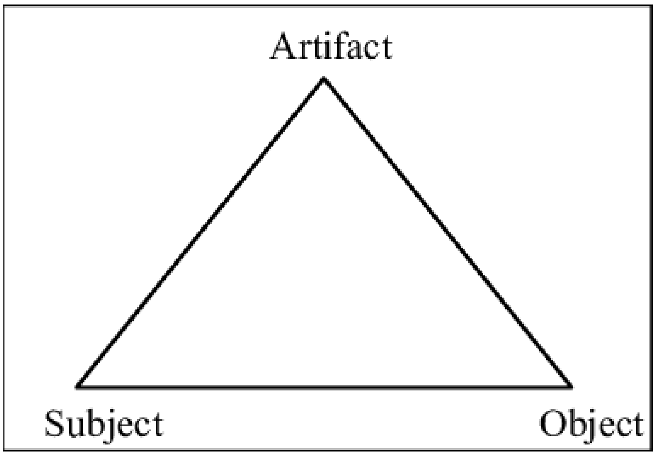

Figure 3.1: Vygotsky's basic mediated action triangle (Yamagata-Lynch, 2010, p. 17)

Leont'ev, Luria, and colleagues who were nonetheless Vygotsky's disciples found the focus on the individual subject too simplistic for elaborating human activity and henceforth "broadened the scope … by introducing human activity as the unit of analysis that is distributed among multiple individuals and objects in the environment" (Yamagata-Lynch, 2010, p. 20). This means that these scholars recognised the role of significant others in achieving the object of the activity, together with the consequent rules that govern interactions as well as the division of labour. Consequently, the Vygotskian triangle was expanded to include these additional components, producing what is now known as second generation CHAT (Morselli, 2019). This is illustrated in Figure 3.2 below whereby (a) is the Engeström (1987) model and (b) is a 3D model that I used to highlight all the complex hexadic relationships involved.

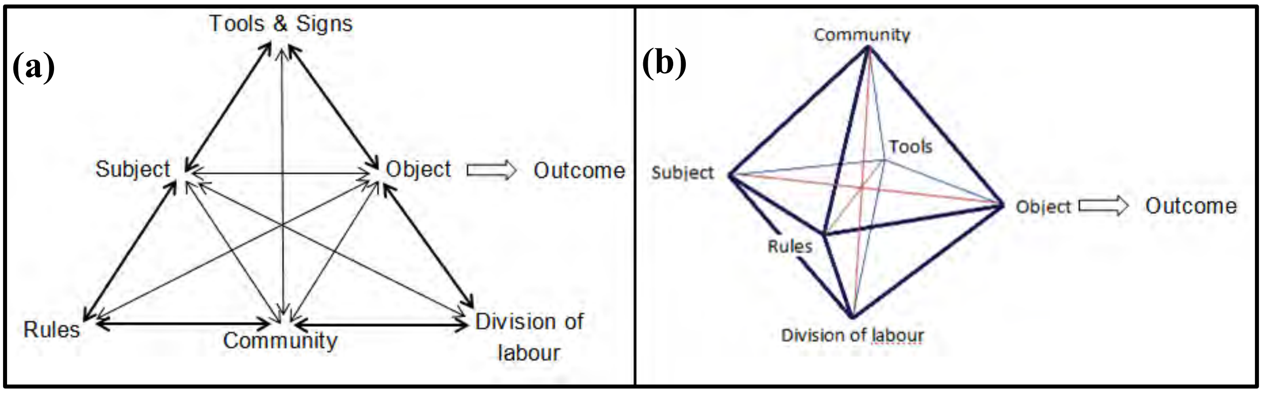

Figure 3.2: Model of 2nd generation CHAT (a) Engeström (2001, p. 135); (b) 3D model

Leont'ev (1981) demonstrated the relevance of the community of significant others in executing object-oriented, artefact-mediated human activity using the primeval collective hunt, focusing on the actions of the beater. The beater's (*subject*) task (a *division of labour*) was to frighten animals and direct them to other hunters (*community of significant others*) lying in ambush. In this case, the beater's actions alone were not adequate to achieve the *object* (obtaining food or clothing) of the activity (*hunt)* – instead, the collective action with other hunters made this possible. It is obvious that *rules* were followed to regulate the actions of all the individuals in the system.

Engeström (1987) expanded the scope of analysis in CHAT and changed its focus to the entire activity system (Sannino et al., 2009). For Engeström, human activity is "a collective, object driven complex that carries longitudinal-historical aspects of human functioning" (Morales, 2017, p. 86). Foot (2014) reinforced the complexity of CHAT by insisting that an activity system a) should be representative of the whole; b) should be analysable from multiple perspectives; c) is culturally mediated and applies only to humans and d) is continuously changing. In this regard, Engeström (2001) summarised the third generation CHAT into five basic principles: (i) the unit of analysis is a collective activity system directed towards an object and mediated by artefacts, (ii) multi-voicedness, (iii) historicity, (iv) contradictions and (v) expansive transformation of the activity system (Engeström, 2001).

Admittedly, in a formative intervention, the goal is to "analyse and change a complex activity system" (Augustsson, 2021, p. 3) using the broad concepts in CHAT as tools for identifying problems and developing solutions. In particular, *contradictions* and *expansive transformation* are exalted in formative interventions where the contradictions, that is, historically accumulated structural tensions in an activity system (Foot, 2014), are purposefully intensified by the researcher interventionist to provoke an expansive learning process (Morselli, 2019; Sannino et al., 2016). In other words, the design of a formative interventionist study is driven by contradictions to yield expansive learning which is defined as "a creative type of learning in which the students join their forces to literally create something novel, essentially learn something that does not yet exist" (Sannino et al., 2016, p. 4). Although contradictions are endemic in any activity system, the members only seek solutions that result in expansive learning when the contradictions become aggravated. In my study, for instance, the participants analysed classroom teaching as an activity system to identify contradictions, which I then magnified to help model new teaching strategies. This suggests that agency on the part of participants is critical for expansive learning to take place.

The theory of expansive learning is proposed as a cycle composed of seven learning actions: questioning, analysing, modelling, examining, implementing, reflecting, and consolidating (see Figure 3.3) (Morselli, 2019).

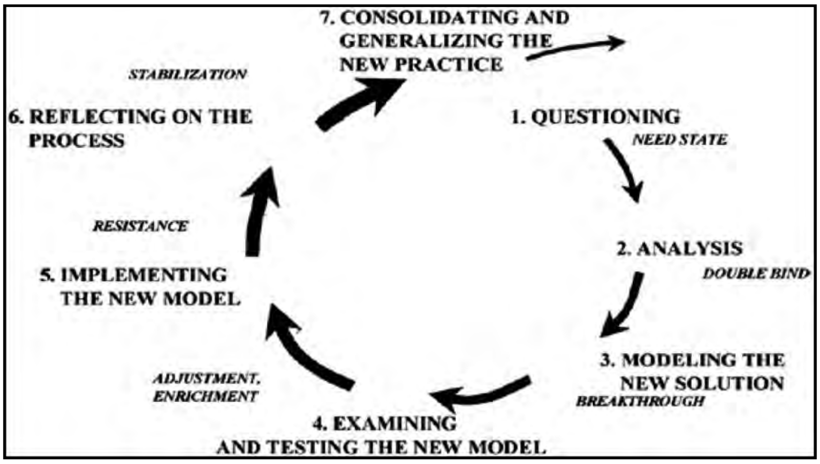

Figure 3.3: Sequence of learning actions in an expansive cycle (Morselli, 2019, p. 41)

However, Augustsson (2021) contested this idea of cyclicity in expansive learning and posited that there are numerous deviations and disruptions in the process. Even though deviations from a script demonstrates expansive learning (Engeström, 2009), the iterative nature of expansive learning begs the question of why there is an insistence on a cycle (Augustsson, 2021). Because an interventionist needs some form of procedure to follow, in this study I implemented the intervention following the cycle as is, but I expected and encouraged any deviations from the script. Also, Bal et al. (2018) and Englund (2018) followed the design in its basic form and reported concurrence with the theory. However, my criticism of this expansive cycle is where reflections on the process are. In my view, reflections should permeate throughout the research process, that is, from the beginning to the end. I would title the 'reflection' learning action 'reflecting on the new model' or 'process evaluation'.

My interventionist study was expected to facilitate expansive learning through procedures that are based on *double stimulation* which is a term Engeström (2009) borrowed from Vygotsky. Double stimulation is defined as a "principle of volition and agency" (Sannino et al., 2016, p. 5) or a principle that generates willpower (Mbembe, 2021; Morselli, 2019). In formative interventions, double stimulation is used "to re-mediate the aggravated contradictions affecting an activity system" (Morselli, 2019, p. 47). The first stimuli, also known as the mirror data, are representations, in the form of documents or video footage of critical situations and encounters, which demonstrate the problems the participants face in their work practice. The researcher interventionist introduces tools, such as the model of activity as the second stimulus which the participants will use to fashion their own new tools (Morselli, 2019; Sannino et al., 2016).

In this study, I thus gave the participants documents, such as examiners' reports, syllabi, textbooks, and research articles as the first stimuli. These were mirror data supplied to aggravate the contradictions in the activity system (classroom teaching) and encourage reflection on practices. That is, these documents were given to promote discussions about the current methodology for teaching chemical equilibrium in particular and to question its suitability or its effectiveness. Thereafter, I introduced the model of the activity system (see Figure 3.3 above), the TSPCK (which I discuss in Section 3.3) and some suggested teaching approaches as second stimuli, that is, the tools that participants used to model new teaching approaches.

In a nutshell, this formative interventionist study was analysed as an activity system in which the TPD of Grade 12 Chemistry teachers was taken as the *activity* whose outcome was to ultimately improve student learning, achievement, and attainment – the beneficiaries. During the TPD, the participants analysed classroom teaching, again as an activity system using the model of the activity system as a tool to find contradictions (purposefully aggravated by mirror data) and address them. In the process, their TSPCK for teaching chemical equilibrium developed. The *subject* (Chemistry teachers) divided duties during the workshops in order to achieve the *tool*-mediated collective *object* (improved teaching methodology) of the *activity*. The subjects' interaction with the *community of significant others* (Rhodes university staff, the Khomas regional office) were governed by *rules* (research ethics, Covid-19 protocols).

3.3 Pedagogical Content Knowledge

Prior to Shulman's ground-breaking work in the late 1980s that spawned PCK, teachers' skills and knowledge were described loosely in terms of SMK and PK. Subject matter knowledge (SMK) – also called content knowledge (Liepertz & Borowski, 2019) or academic content knowledge (Gess-Newsome et al., 2019) – and PK were understood to be discrete until

Shulman (1987) reasoned that they are interrelated. For him, teachers simultaneously mobilise SMK, which is defined as the general factual knowledge about the subject (Gess-Newsome et al., 2019) and PK, the knowledge about how to teach (Rollnick & Mavhunga, 2017), for effective teaching. In other words, according to Shulman (1987), teachers transform their knowledge of the subject into forms that can be understood by students. Shulman termed the capacity to carry out such transformation PCK and to him SMK precedes PCK. Thus, PCK can be defined as the "specialised knowledge about the content to be taught" (Rollnick & Mavhunga, 2017, p. 1) and denotes the ways in which teachers present knowledge to their classes to make the content understandable (Mavhunga & Rollnick, 2013). Therefore, we can consider PCK a "bridge between the categories of subject matter and pedagogy included in the standard view of teacher knowledge" (McEwan & Bull, 1991, p. 317).

Shulman's (1987) conception of PCK has two main elements, namely knowledge of representations or instructional strategies and knowledge of students' learning difficulties (Shing et al., 2015). In this model, PCK "was one of seven categories of 'teacher knowledge'" (Kind, 2009) also referred to as knowledge bases (Shing et al., 2015). These are content knowledge, general PK, curriculum knowledge, PCK, knowledge of students and their characteristics, knowledge of educational contexts, and knowledge of educational ends, purposes, and values and their philosophical and historical grounds (Kind, 2009). Therefore, the emphasis of Shulman's model is the transformation of SMK using PCK, meaning SMK and PCK are distinct elements of teacher knowledge (Shing et al., 2015).

Shulman's (1987) model was heavily critiqued from various viewpoints. Scholars refined, revised, and altered the model leading to the emergence of many different models of PCK (Shing et al., 2015). In addition, numerous definitions of PCK arose (Kind, 2009; Shing et al., 2015). There are three major issues in the literature about Shulman's model that I find salient, and I discuss them here. The first issue is a critique by Cochran et al. (1993) who found Shulman's PCK model static and compartmentalised. They reasoned that since teachers' knowledge grows continuously, PCK should be understood as dynamic. Thus, they changed 'knowledge' in PCK to knowing, in order to capture its dynamic nature and named their version pedagogical content knowing (PCKg).

The second issue is the limited or simplistic nature of Shulman's model. "Researchers seem to agree that PCK is more complex than Shulman implied originally" (Kind, 2009, p. 180). One piece of evidence for this is that a common feature in all major models of PCK is the addition of components to the original conception (Kind, 2009). For instance, Magnusson et al. (1999) added orientations, curricular knowledge, and assessment to Shulman's model of PCK for their model. They reasoned that these elements had to be part of PCK because they impact instruction and therefore influence PCK (Kind, 2009).

The final issue pertains to the relationship between PCK and SMK. As alluded to earlier, for Shulman (1987), PCK and SMK are separate knowledge bases and "PCK 'transforms' SMK" (Kind, 2009, p. 180). Such models are called transformative models. One example is the model forwarded by Geddis and Wood (1997) and refined by Davidowitz and Rollnick (2011). Geddis and Wood (1997, p. 612) reasoned that "the value of a focus on the *transformation of subject matter* is that it directs attention simultaneously to the subject matter, students and educational purposes, and to the interactions among these different kinds of teacher knowledge in the pedagogical encounter". Thus, teachers' knowledge domains, namely knowledge of context, knowledge of students, SMK and PK, converge in PCK during pedagogical encounters and SMK takes a central role (Davidowitz & Rollnick, 2011; Geddis & Wood, 1997; Mavhunga & Rollnick, 2013).

On the other hand, some scholars have defined PCK in a manner that makes SMK a component of PCK bringing about the so-called integrative models. In these integrative models, PCK is not seen as a separate knowledge base but a "term used to describe teacher knowledge as a whole, comprising SMK, pedagogy and context" (Kind, 2009, p. 180). In other words, PCK is the knowledge that teachers possess and use in their classrooms and SMK is an integral part of the knowledge (Kind, 2009). Segall (2004), for instance, argued that boundaries between content and pedagogy are porous – that content and pedagogy "leak into each other and through each other long before one enters the classroom" (p. 498). That is, for him, content is instructional and pedagogy content laden. He further argued that "conceiving pedagogy solely as that which is carried out by teachers, by definition restricts the way in which teachers can (and should) think about the relationship between content and pedagogy" (Segall, 2004, p. 498).

As can be established from the presentation so far, the concept of PCK has evolved over the years and its characteristics have expanded. Many models of PCK have emerged, based mainly on what they focus on (Nind, 2020). The existence of several different models of PCK implies that the application of PCK has not always been consistent among researchers (Sudhindra & Shyamsundar, 2019).

PCK has three grain sizes, namely TSPCK, discipline-specific PCK and concept-specific PCK (Mavhunga & Van der Merwe, 2020). In this study, I focused on improving the teaching of a specific topic, chemical equilibrium, and therefore I employed TSPCK following the model proposed by Mavhunga and Rollnick (2013) which was later refined to accommodate the refined consensus model (RCM). In the next section, I elucidate the conception of TSPCK and its elements.

3.3.1 Topic-specific pedagogical content knowledge

Mavhunga and Rollnick (2013) popularised the concept of TSPCK. The idea was not new in 2013. In 1999, Veal and MaKinster wrote about it in their general taxonomy of PCK in which they identified it as "the most specific and novel level of the general taxonomy" (p. 7). In addition, Mavhunga and Rollnick (2013) acknowledged that the components they identified in their model are similar to those in the work of Geddis and Wood (1997). The conception of TSPCK is justified by the fact that the teaching methodology employed to teach a particular topic in Chemistry by the same teacher is different from topic to topic (Mavhunga & Rollnick, 2013).

Mavhunga and Rollnick's (2013) TSPCK model (see Figure 3.4) has five components, namely learner prior knowledge, curricular saliency, what is difficult to understand, representations, and conceptual teaching strategies. Chemistry teachers, who are regarded as learners in this interventionist study, draw on these five interrelated components to inform the transformation of SMK into a teachable form (Mavhunga & Rollnick, 2013). In this model of TSPCK, SMK (content knowledge in Figure 3.5) is clearly shown to be of utmost importance in the development of PCK (Davidowitz & Rollnick, 2011; Mavhunga & Rollnick, 2013).

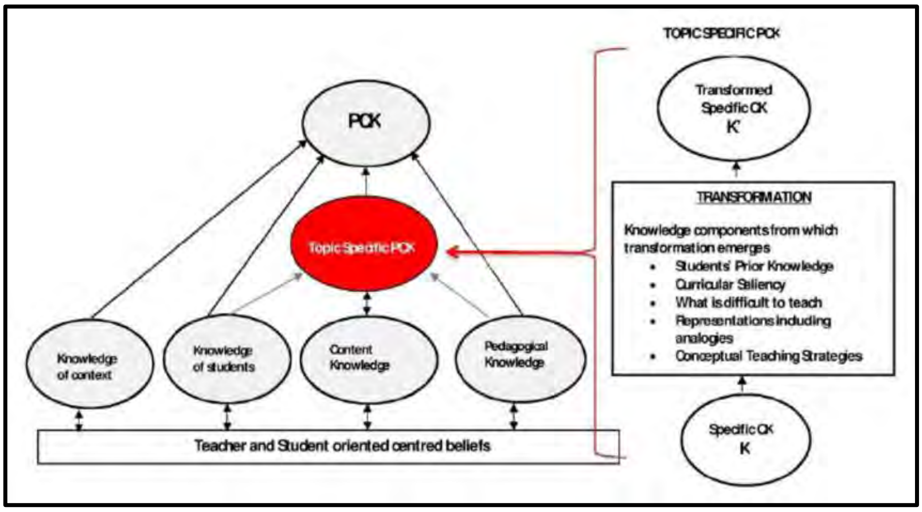

Figure 3.4: A model of TSPCK (Mavhunga & Rollnick, 2013, p. 115)

In insisting on the topic specificity of PCK, Rollnick and Mavhunga (2017) provided descriptions of the five components of TSPCK, clearly demonstrating that they can only be applied to a particular topic. For instance, s*tudent prior knowledge* refers to students' preconceptions and misconceptions. However, unlike Mavhunga and Rollnick (2013), I would argue that student prior knowledge is not limited to the knowledge covered in the previous grade, but it could be in the form of knowledge that students come with from their home or community. Such knowledge is referred to in the literature as local indigenous knowledge (Ogunniyi, 2007; Seehawer, 2018). For instance, day-to-day knowledge of the need to compromise between cooking quickly (by using maximum heat settings) and the quality of the cooking can be valuable for teaching some ideas in chemical equilibrium.

Curricular saliency entails the ability to identify the main concepts in a topic as well as the best sequence for teaching those main topics. It also includes an understanding of what topics have to be taught before the topic. *What is difficult to understand* refers to knowledge of ideas that are conceptually difficult for students, that is, the "gate-keeping concepts" (Mavhunga & Rollnick, 2013). *Representations* are analogies, illustrations, examples, or demonstrations used to support an explanation (Makhechane & Mavhunga, 2021). *Conceptual teaching strategies* are effective teaching strategies for addressing known misconceptions, important conceptions, or known areas of difficulty. The knowledge of these five content-specific components and their interaction influences the quality of teaching. However, inconsistent use of PCK has been reported (Kind, 2009).

To address this lack of consensus and ensure efficiency in Science teacher education and its research, experts in PCK from around the world met first in 2012 and then again in 2016, to deliberate towards a consensus model of PCK. The first meeting, called the first PCK summit spawned the consensus model of PCK and the second PCK summit produced the RCM of PCK (Sudhindra & Shyamsundar, 2019). In this study, I employed the principles in the RCM of PCK which I articulate in the next section.

3.3.2 The refined consensus model

I used the 2017 RCM of PCK (Carlson et al., 2019) to guide this study because it "represents the collective thinking of two dozen international researchers" (p. 77). The RCM (see Figure 3.5) is portrayed as a globe consisting of five complementary and interconnected concentric circles representing five different constructs, namely (i) enacted PCK (ePCK) (ii) personal PCK (pPCK), (iii) learning context (iv) collective PCK (cPCK) and (v) professional knowledge bases (Sudhindra & Shyamsundar, 2019). Thus, the RCM identifies three distinct realms of PCK in order to fully capture the complexity of teachers' professional knowledge. It also includes the learning context as well as teachers' professional knowledge bases without which the teacher's knowledge is limited (Carlson et al., 2019).

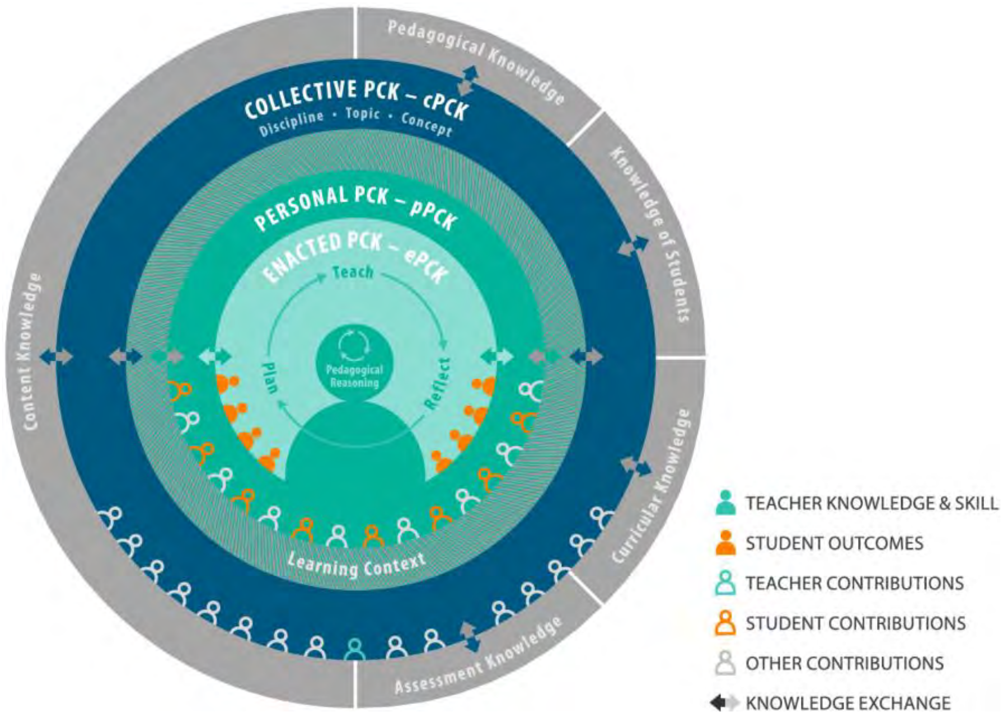

Figure 3.5: Representation of the 2017 RCM of PCK (Carlson et al., 2019, p. 6)

At the centre of RCM sits enacted PCK which refers to the knowledge and skills employed by a teacher to teach a specific group of students or a student, in a particular setting, particular concepts, or a collection of particular concepts. Enacted PCK (ePCK) can be thought of as a subset of knowledge teachers use as they plan *for* and reflect *on* their lessons or simply pedagogical reasoning (Carlson et al., 2019; Shinana et al., 2021, Sudhindra & Shyamsundar, 2019).

The next level is the pPCK, that is, the cumulative and dynamic PCK and skills of an individual teacher that reflects the teacher's own teaching and learning experiences (Carlson et al., 2019). A teacher's pPCK is fashioned by their interactions with their colleagues, their professional learning experiences, the students they teach as well as reflections on their own practice (Rollnick & Mavhunga, 2017). A teacher's pPCK can be understood as their knowledge and skills reservoir (Sudhindra & Shyamsundar, 2019) and varies from teacher to teacher and context to context (Rollnick & Mavhunga, 2017).

The third level of RCM is occupied by the learning context. This refers to a multitude of factors such as the broad educational climate (for instance education ministry regulations), the specific learning environment (such as school policies), and individual student attributes (such as language proficiency) (Sudhindra & Shyamsundar, 2019).

The next level is where we find the general teaching knowledge held by the broader community of teachers (Shinana et al., 2021), that is, "the body of knowledge established by the science education profession as good practice" (Rollnick & Mavhunga, 2017, p. 3). This knowledge is called cPCK and is relatively static and an amalgam of contributions from multiple Science educators (Carlson et al., 2019).

The last level contains the professional knowledge bases which are the five indispensable knowledge foundations without which the teacher's PCK will be quite limited (Carlson et al., 2019). As can be seen in Figure 3.6, content knowledge has the greatest proportion.

The advent of the RCM called for the positioning of Mavhunga and Rollnick's TSPCK in the new model. This was achieved through a simplified version of the RCM by Mavhunga and Van der Merwe (2020) (see Figure 3.6), in which TSPCK was identified in all the identified types of PCK. An additional type of PCK is defined in this new model – the planned PCK (plPCK) which describes an individual teacher's knowledge that they draw upon in preparing for class.

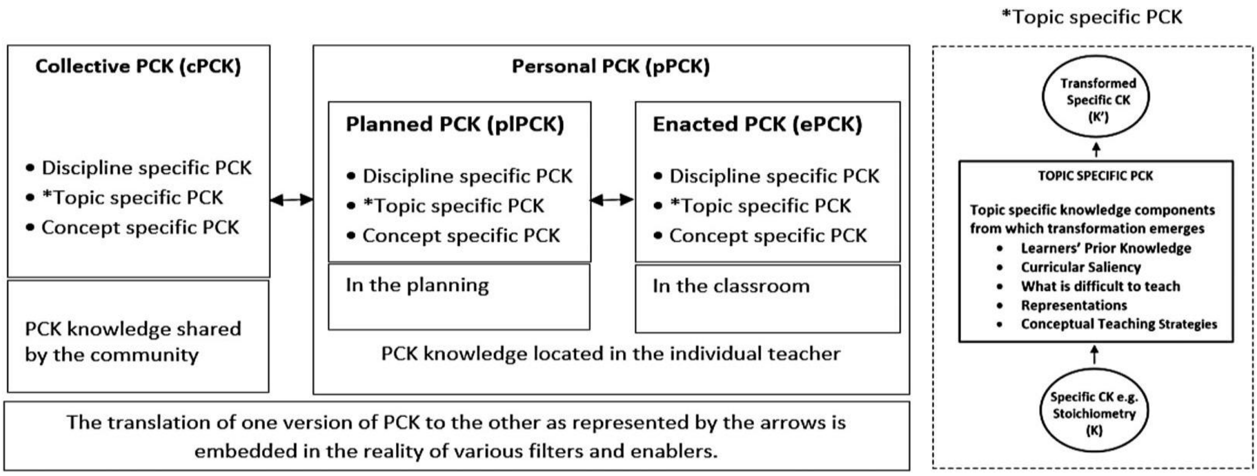

Figure 3.6: Positioning TSPCK in RCM (Mavhunga & Van der Merwe, 2020, p. 3)

Notwithstanding, PCK comes with a fair share of criticism; the main point of attack being its silence on issues about diversity, multiculturalism, and equity (Dyches & Boyd, 2017; Settlage, 2013). Settlage (2013), for instance, found PCK highly deficient when used as a theoretical framework in research and equated it "to a mirage in the desert or a mythical siren along the shore" (p. 1), whose pursuit has minimum benefits. In this study though, I found PCK useful for describing teacher knowledge and expertise, which is subject to serious contentions, and my study was not deeply vested in issues of diversity and justice.

This study employed two theories, the CHAT and PCK. The CHAT is a very expansive theory that is used, for the most part, to explain human learning or the development of human activity systems. From this broad theory, I extracted the theory of expansive learning, focusing on contradictions and double stimulation to guide the methodology and to plan the activities of the intervention workshops as well as provide the research participants tools to make sense of the problems in their teaching with a view to co-construct effective teaching methods for chemical equilibrium. However, even after such delimitations, CHAT remained too broad for this study. Consequently, I mobilised TSPCK for further delimitation: to limit the scope of analysis to just problems related to teachers' knowledge and skills.

3.4 Chapter Summary

In this chapter, I articulated the theoretical framework guiding the research process. I reiterated that this research was aimed at achieving relevant practical transformations while being rigorous in analysis (Sannino et al., 2016). Thus, a formative intervention was chosen as the mode of the study and the outcomes of this study were not known ahead of time (Morselli, 2019). As a consequence, the CHAT was necessarily mobilised as a valuable theory for constructing the framework, for illuminating and congregating the major factors that impact TPD, and for the teaching of chemical equilibrium. The TSPCK, on the other hand, was mobilised as a filter to delineate teacher challenges and to provide a means to assess the effectiveness of the teaching tools (such as schemes of work) generated in the workshops as well as describe the participants' learning. Put differently, the CHAT provided a broad scope of analysis that captured all major extenuating circumstances, while TSPCK focused the study on teachers' skills. In my view, these theories were compatible and complementary since central to both is meaningful learning.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the overall research methodology of the study. In this study, research methodology is defined as "a broad term used to refer to the research design, methods, approaches and procedures used in an investigation that is well planned to find out something" (Kivunja & Kuyini, 2017, p. 28). In other words, the methodology articulates the general plan of the investigation, including the assumptions and philosophical underpinnings guiding the research process.

Thus, this chapter articulates the research paradigm and research design. Under the research design, a case study research design is discussed followed by the research goals and research questions. Thereafter, the research site, research participants, and my positionality as the researcher and reflexivity are articulated. Subsequently, a description of the data gathering methods and details of how the intervention was conducted is given followed by a narrative of the approaches to data analysis and details of how the theoretical framework was used as a heuristic tool. Finally, a short concluding remark is made which is preceded by a brief discussion of ethical issues and trustworthiness concerns.

4.2 Research Paradigm

Research paradigm, a term coined by Kuhn (1962) to mean a philosophical way of thinking, refers to an agreed set of beliefs or thinking about how to carry out research and interpret its meaning (Kivunja & Kuyini, 2017). In other words, a research paradigm is a worldview that directs the research process (Bertram & Christiansen, 2020). To answer the research questions posed for this study, I needed to interpret the multiple realities as constructed by the participants. Therefore, this study was aligned with an interpretivist paradigm, which is rooted in the understanding that reality is socially constructed. This study attempted to understand the subjective world of human experience (Kivunja & Kuyini, 2017) and thus interpretivism was considered an appropriate paradigm because it focuses on individuals and their context rather than universal laws: this study was aimed at an improvement of teachers' PCK and skills for teaching chemical equilibrium in their schools and not to seek universal methodologies.

However, interpretivism has one major shortcoming: it is focused on providing descriptions about contexts as they are without seeking to change or improve them and yet this study had an agenda to transform the participants' teaching. Thus, aspects of the critical paradigm were incorporated. In particular, the study assumed a transactional epistemology, in which I, as the researcher, interacted with the research participants and prodigious efforts were taken to avoid privileging certain versions of reality (Kivunja & Kuyini, 2017). This blend of interpretive and critical paradigms was perfectly suited for the case study research design this study employed and this is discussed in the next section.

4.3 Case Study Research Design

This study assumed a case study approach because the study employed CHAT which steeps studies into the contexts that are being investigated for which empirical generalisations are inappropriate as they tend "to hide the cultural and historical specificity of the activity system under investigation" (Morselli, 2019, p. 42). Thus, I deemed the case study approach suitable for my endeavour to fully understand contexts as well as collect rich data that provide an in-depth picture (Hamilton & Corbett-Whittier, 2013) and was compatible with the study's theoretical framework.

The case study is generally not well understood in the research process. For instance, there are contentions on whether it is a method, a methodology, or a research design (Hamilton & Corbett-Whittier, 2013). In this study, I stayed clear of the contentions and simply considered the concept as a "way of framing a particularity, providing guiding principles for the research design, process, quality and communication" (Hamilton & Corbett-Whittier, 2013, p. 10).

Furthermore, case studies are generally misunderstood and their importance in research is underrated (Flyvbjerg, 2006). In particular, the fact that research findings cannot be generalised is erroneously taken to mean that case studies are not very useful in research. Yet, as Flyvbjerg (2006, p. 393) reasoned, context-dependent knowledge is central to expert activity and "more valuable than the vain search for predictive theories and universals". In addition, although the idea of generalisation itself may be important to scientific development, PCK is well-known to be very context specific (Mavhunga, 2019) and thus the value of generalisation might not be as important as "the force of example" (Flyvbjerg, 2006, p. 12).

This case study adopted a PAR approach in which the focus was to change collective practice through collaborative effort (Hilli, 2020; Ngcoza & Southwood, 2015). This approach can be justified for this study from two main perspectives. First, PAR promotes teacher participation and avoids the general apathy that is bedevilling educational research. Hilli (2020,) explained that teachers are generally disinterested in research because it tends to be dissimilar to their practices and too decontextualised. Secondly, the CHAT that formed the theoretical basis for this study focuses on collective design effort and participatory analyses (Sannino et al., 2016) and thus resonates with PAR. In other words, the participants would collectively design solutions to the challenges in their teaching practices rather than having solutions created for them by experts from outside (Ngcoza & Southwood, 2015).

The unit of analysis in this study was a PLC consisting of five Grade 12 Chemistry teachers, myself included. I purposefully constituted the research group as a PLC to ensure that we could all learn from each other (Lieberman & Pointer-Mace, 2008). Therefore, in this study, I worked with teachers, rather than on teachers (Ngcoza & Southwood, 2015) and my contributions in the activities were equal to those of the other participants.

4.4 Research Goal and Research Questions

The main goal of this study was to investigate how a formative intervention facilitates (or not) the development of Grade 12 Chemistry teachers' PCK for mediating learning of chemical equilibrium. To achieve this goal, the following research questions were addressed.

4.4.1 Research questions

- What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?
- How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 teachers' PCK for mediating learning of chemical equilibrium?

4.5 Research Site and Participants

This study was conducted as a PLC consisting of five Grade 12 Chemistry teachers (including the researcher) from two schools in Windhoek, Namibia (see Figure 4.2).

Figure 4.1: Research site

A purposive sample was used in which the teachers were selected based on the level of their knowledge regarding the subject matter (Palinkas et al., 2015), that is, all the participants had to be familiar with the Namibian Grade 12 Chemistry syllabus. Thus, I envisaged working *with* two Chemistry teachers from my school and another two from a nearby school. It so happened that the Chemistry teachers from the selected schools (and the neighbouring schools) were all females. Purposive sampling was also considered for this study to allow me to select participants who were likely to be available and willing to take part in the intervention and were also able to communicate their experiences and opinions in an articulate manner (Palinkas et al., 2015).

The participants' profiles are given in Table 4.1 below. To represent the participants, I used P1, P2, P3 and P4. That is, I did not use any pseudonyms as identifiers.

Table 4.1: Participants' profiles

Participant	Age	Qualification	Years teaching experience
P1	>45	BSc + PGDE	>20
P2	>50	BEd.	>20
P3	>40	BSc with Education	>15
P4	>45	BSc with Education	>20

As can be seen from the table, these are highly qualified teachers with extensive teaching experience.

4.6 Research Methods

Research methods are approaches to conducting research in addition to well-defined pre-planned steps to be followed in the research process (Virkkunen & Newnham, 2013) and are guided by the research question(s) and the type of data required (Bertram & Christiansen, 2020; Cohen et al., 2018). This research project answered two research questions that required qualitative data, that is, data that looks entirely at non-numerical representations.

I generated qualitative data using semi-structured interviews and document analysis to answer the first research question: What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms? For the second research question: How does the implementation of a formative intervention facilitate (or not) the development of teachers' PCK for mediating chemical equilibrium? I used several methods, namely, intervention workshops videotaping, participant observation, reflective journaling, and document analysis. I discuss these data generation methods in the next sections.

This study was conducted during the Covid-19 pandemic, and I gathered some data remotely through Zoom or Google-meet. Data gathering remotely proved convenient for the research participants because we could meet in their homes!

4.6.1 The intervention

The term intervention is derived from two Latin words *inter* and *vinere. Inter* means between while *vinere* means to come; together they mean to come between. Accordingly, Midgley (2000, p. 113) defined an intervention as a “purposeful action by a human agent to create change”. Therefore, for all intentions and purposes, an interventionist comes between the human being and their action to give the activity a different direction. Virkkunen and Newnham (2013, p. 3) extended their definition in order to capture the idea that human activity constantly changes to “the purposeful action by a human agent to support the redirection of ongoing change”.

An intervention is a common human action; mankind always intervenes in others’ activities whether solicited or unsolicited and with or without success. In the research process, the intervention method is a “part of the research methodology that answers [research] questions” (Virkkunen & Newnhamn, 2013, p. 3) provided some theory guides steps taken in the process as well as the reasons and rationale of those steps. There are two such interventions in research, namely linear interventions, and formative interventions. The formative intervention used in this study is distinguished from linear interventions, which focus on randomised controlled trials, in that the dilemma is fixed through a collective expansive learning process (Virkkunen & Newnham, 2013). This formative intervention was self-analytical, enabling us to check if it achieved the goals that it claims to achieve as well as merge “practical transformation and rigorous research” (Sannino et al., 2016, p. 1).

Drawing from the work by Morselli (2019), this study’s intervention was composed of four two-hour-long workshops with each workshop designed to target specific expansive learning actions (see Table 4.2). During the workshops, data were gathered through videotaping, participant observation, reflective journaling, and document analysis.

Table 4.2: Intervention workshops (Morselli, 2019)

Workshop	Learning action(s)	Activities/ tasks
1	1. Questioning 2. Analysis	Discussion of practices to trigger dissonance Analysis of problems in practice to find contradictions
2	3. Modelling	Creation of new practices using available examples
3	4. Examining	Thought experiments on the new model to anticipate matters that could hinder change
4	6. Reflecting 7. Consolidation	Evaluation of the expansive learning Generating a document that describes the new model

For the fifth learning action, the implementation, the participants implemented the newly acquired skills in their classrooms without my involvement. Data for the study were further harvested from the participants' reflective journals. This choice to transfer responsibility to the participants was justified because during implementation "the lead of the expansive learning process has passed from the researcher to the participants" (Morselli, 2019, p. 55).

The design of the intervention and workshops was based on the CL, a type of formative intervention "developed from the '90s at Helsinki University to promote deep and intensive transformations as well as incremental improvement" (Morselli, 2019, p. 44). The CL is designed in the form of workshops and each workshop targets a specific expansive learning action (Virkkunen & Newnhamn, 2013). However, this study was not identical to the CL in several ways. Firstly, fewer participants were used for the workshops. That is, four participants were involved, instead of the 15–20 individuals recommended for a CL (Morselli, 2019) because of the difficulty and expense that would be involved to congregate Advanced Subsidiary (AS) level teachers, who are stationed at significantly distant geographic locations. Second, the concept of 3 x 3 writing surfaces was not strictly adhered to, instead, informal discussions on the issues were held to minimise unnecessary clerical work on the part of the participants.

4.6.2 Data gathering methods

The term data refers to small pieces of information and the raw materials for a research project (Walliman, 2018). Data were generated for this study with the understanding that data is ephemeral and corruptible, that is, the truth that data hold changes from place to place and from time to time and is drenched in inconsistencies and bias (Cohen et al., 2018). Four methods were used to gather data in this study, and I discuss these below.

4.6.2.1 Interviews

An interview can be defined as "an interaction between an interviewer and a respondent in which the interviewer has a general plan of inquiry" (Hofisi et al., 2014). Thus, an interview is a formal conversation between at least two people wherein the interviewer asks questions and the interviewee(s) provide answers (Hofisi et al., 2014). Consequently, I used interviews to extract in-depth qualitative data (Chadwick et al., 2008) that was important for answering the first research question.

From the three formats of interviews – structured, semi-structured, and unstructured interviews (Walliman, 2018) – I elected to use the semi-structured interview format in which I used an interview schedule (see Appendix VI) to ask "pre-set, standardised normally closed ended questions" (Hofisi et al., 2014, p. 60). However, I also had sections in which I asked open-ended unstructured questions to dig-out in-depth data (Walliman, 2018). I reasoned that a structured interview, that is, a verbally administered questionnaire (Chadwick et al., 2008), in which standardised questions are read out as they are in an interview schedule (Walliman, 2018), would not have given me the in-depth data I desired. On the other hand, I believed that an unstructured interview would be too flexible in format and may provide broad rather than in-depth data (Chadwick et al., 2008).

I used the metaphor of a miner and a traveller to visualise the interviews, in the sense that a miner digs out data from the respondents and as a traveller I was free to explore and roam freely (Hofisi et al., 2014). I considered interviews suitable because I could judge the quality of the response and notice when a question had not been understood properly and could rephrase the question to obtain a better response (Walliman, 2018).

All the interviews, which lasted about 15 to 20 minutes, were tape-recorded to ensure that the raw data could be made available for different analyses by other researchers (Walliman, 2018) as well as to retain an accurate record of what was said which is known to help avoid bias (Chadwick et al., 2008). Consent was obtained from the participants (see Appendix V). The recordings were transcribed verbatim, with repeated checking to guarantee the accuracy of the transcription (Walliman, 2018). The transcripts were then returned to the participants for member checking (Birt et al., 2016) and thus ensure the record (or data) captured the intended sense. The participants changed at least one of their responses because they felt what was recorded did not exactly match what they intended to portray.

The semi-structured interviews generated very rich information about the teachers' practices, much more than I expected! Consequently, I changed my research question from: "*What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium in their classrooms?"* to: "*What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?"* The participants did not only articulate the challenges they faced in their teaching practices but provided some remedial strategies.

4.6.2.2 Workshops: Video data collection

All the intervention workshops were video recorded because videos have a "higher degree of fidelity in their records of the flow of action and interaction being studied" (Leung & Hawkins, 2011, p. 345). That is, the dense video data collected can be understood with a perception of order and continuity (Ukkonen-Mikkola & Ferreira, 2020). In addition, videos allow "the complexity within interactive processes to be broken down into different dimensions, and by doing so it is possible to address phenomena from different points of focus" (Ukkonen-Mikkola & Ferreira, 2020, p. 3). Furthermore, video data can be accessed multiple times, from multiple perspectives, and they capture every utterance and all the other cues that accompany speech (Ukkonen-Mikkola & Ferreira, 2020). Thus, by using video recording, I was able to collect dense information that captured the complexity of human interactions and learning activities I needed in the meaning making of the phenomena I was studying.

However, video recording is not fool proof – there are three main limitations. First, the recording will always capture a partial view of what is happening and thus only a small portion of what occurs will be in the frame of recording, whether the camera is fixed or moving (Leung

& Hawkins, 2011). Secondly, video is unable to capture the physical, cultural, social, and historical contexts that are responsible for people's perceptions and actions. In other words, video-audio recordings only "represent mere observational fragments of what is occurring [and] a good deal of work has to be done before video-audio material can be regarded as fit for description, let alone analysis and interpretation" (Leung & Hawkins, 2011, p. 346). This makes video research workflow highly iterative: "the researcher marks, transcribes, and categorises a little; analyses and reflects a little; searches and finds a little; and so on, in the recursive loops" (Pea & Lemke, 2007). Third, video recordings present special ethical considerations that are not present in the other data collection methods. With a video record, anonymity is not as easy to maintain if the tape is to be shared with other researchers (Leung & Hawkins, 2011).

4.6.2.3 Document analysis

Document analysis is defined as a systematic procedure for the review and analysis of text and images that were "recorded without the researcher's input" (Bowen, 2009, p. 27). Document analysis is reputed as a data source in qualitative research because it produces rich descriptions that are critical for in-depth analyses (Bowen, 2009). In addition, the documents used are stable and non-reactive, that is, "the investigators presence does not alter what is being studied" (Bowen, 2009, p. 31). Furthermore, document analysis affords a revision of the source document for further insights or to verify the accuracy of the analysis (Bowen, 2009).

Document analysis was used during workshops to start the discussions about the teachers' practices in searching for contradictions in their work schedules and resources that made teaching chemical equilibrium difficult. We considered the NSSCAS Chemistry syllabus, textbooks, and research journals. I considered these documents to mirror data. The participants were in awe of the wealth of information that the process brought to their attention. One participant reflected that "*I was made aware of issues that were always there, but I never really paid attention to*" (P3).

After the workshops, I mined the participants' reflective journals (see Appendix VII for the reflective prompts) for "excerpts, quotations or entire passages" (Bowen, 2009, p. 27) as means of tracking development during the intervention and as a source of data.

The data collected from the journals were used in combination with the data from the other data gathering methods for triangulation purposes (Bowen, 2009). I believed that it was important for this study to draw data from multiple sources for purposes of collaboration and validity.

4.6.2.4 Participant observation

Participant observation has its origin in ethnographic studies (McGrath & Laliberte-Rudman, 2019) and "later spread to a full range of human studies fields" (Jorgensen, 2015, p. 1). Participant observation involves the researcher interacting with people in the tacit aspects of their activities and interactions as a way of collecting information about their practices, performances, and actions (Jorgensen, 2015; McGrath & Laliberte-Rudman, 2019). This method of data collection is only valid when three assumptions are made: (i) knowledge can be gained by observation, (ii) when a researcher is actively involved with the participants, they are likely to understand their point of view and (iii) it is possible to understand humans and their behaviour (McGrath & Laliberte-Rudman, 2019).

In this investigation, participant observation was the main data gathering method during the intervention workshops to capture "complex, conflictual, problematic, and diverse experiences, thoughts, feelings, and activities of human beings" (Jorgensen, 2015, p. 1). One major problem of participatory observation is the unavoidable influence of the researcher and the co-constructed nature of what is observed (McGrath & Laliberte-Rudman, 2019). However, this was not a significant problem for this study because, as the researcher, I was part of the learning community and a co-learner.

Another problem, arising because I had to intervene and provoke the learning process (Sannino et al., 2016), is that it appeared as if I was in the know and the participants expected me to lead the discussions. Nonetheless, I thought the workshops worked very well. On one hand, the participants were willing to share their expertise and engaged in creating the solutions needed to address the contradictions that emerged. On the other hand, they found the environment conducive for learning and would ask questions about their teaching practices, including areas not related to chemical equilibrium.

I considered participant observation for data generation because it captures the seemingly mundane day-to-day aspects of human lives that may not be extracted by interviews. After all, the participants may consider them irrelevant or they may not be conscious of them (McGrath & Laliberte-Rudman, 2019). This meant that participatory observations permitted me to extract very rich data, more so when accompanied by videotaping and the reflective journaling of the participants. In addition, participant observation enables the examination of human interactions, that is, it facilitated the examination of multiple factors as required by this study's CHAT theoretical framework, to extend "beyond interpersonal elements … to other factors" (McGrath & Laliberte-Rudman, 2019, p. 3).

Table 4.3 gives the data generation methods employed in this study and links them to the research question they were designed to address.

Table 4.3: Data generation methods

DATA GENERATION METHOD	**RESEARCH QUESTION ADDRESSED**
Semi-structured interviews	What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?
Video data collection	How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 teachers' PCK for mediating learning of chemical equilibrium?
Document Analysis	
Participant observation	

4.7 Approaches to Data Analysis

Data analysis can be defined as a "process of making sense out of the data" through a complex process involving "moving back and forth between concrete bits of data and abstract concepts" (Merriam, 1998, p. 178). Data analysis involves the three steps: data reduction, data display, and drawing conclusions, in a highly iterative manner, where revision or review of previous data is carried out and analysis of preliminary data informs how and what data will be collected subsequently (Walliman, 2018).

A huge amount of data was generated in text format (reflective journals, field notes taken during participant observations) or converted into text format (transcripts of the interview audiotapes and transcripts of the videotapes of the intervention workshops). This information was difficult and too complex to process directly and to draw meaningful conclusions. Therefore, the initial step for the analysis was data reduction through coding and summarising. During the coding process, codes, that is labels or tags that allocate units of meaning to the data, were used to organise the piles of data (Walliman, 2018). I was careful to interpret and summarise the data without distorting it (Walliman, 2018).

Some codes were brought to the data similar to how Isaacs (2019) employed an activity system analysis (ASA), as a heuristic tool, to explore the challenges that teachers face in mediating learning of chemical equilibrium in the context of teacher knowledge, by identifying the contradictions and tensions in the activity system. In addition, the five constituent components of TSPCK, namely *learner prior knowledge*, *curricular saliency, what is difficult to understand, representations, and conceptual teaching strategies* were also brought into the analysis to help define teacher knowledge, skills, or competencies and the analysis because teacher knowledge, as a construct, is a subject of contention (Yamagata-Lynch & Haudenschild, 2009), Thus, ASA was used as a lens for analysis and TSPCK as a filter to delineate teacher challenges.

A more open coding system was also used, especially by the research participants during the workshops in which the data were allowed to 'speak' and 'name' the codes (Rule & John, 2011). A prodigious effort was made to leave ample room for the data to generate the majority of the codes.

In evaluating the workshops, and hence solving the second research question, the focus was placed on identifying learning that occurs in the context of expansive transformation, that is, whether (or not) the identified contradictions could be resolved. I expected that non-expansive learning would occur (Augustsson, 2021) during the workshops, which was also desired. Additionally, the analysis sought evidence (or lack thereof) of practitioners' transformative agency. Furthermore, I checked how well the participants managed to recognise conflicts by adopting the new strategies or the conflicts that arose with adjacent activities and how these were resolved. Finally, I assessed the new teaching model (scheme of work, lesson plan, or scheme-cum-plan) using the TSPCK translation device designed by Mavhunga et al. (2016) to verify its efficacy (see Appendix VIII).

4.8 Trustworthiness, Authenticity, and Validity Issues

Research studies conducted within the constructivist paradigm should meet three main criteria for trustworthiness and authenticity, namely credibility, dependability, and confirmability (Kivunja & Kuyini, 2017). Credibility means that the data must describe the participants' reality (Bertram & Christiansen, 2020) and data analysis must be believable. This was achieved by audio recording interviews, video recording workshops as well as using excerpts from the data in the research report. I repeatedly re-read the data, including triangulation between the different data collection methods, to make sure I had a full, non-superficial understanding of the data (Bertram & Christiansen, 2020).

Dependability means that the same findings are obtained when the research is repeated under similar conditions (Kivunja & Kuyini, 2017). Put differently, dependability can be taken to refer to reasons for divergence of findings compared to previous studies in the field (Bertram & Christiansen, 2019).

Confirmability refers "to the extent the research findings can be confirmed by others in the field" (Kivunja & Kuyini, 2017, p. 34). This was achieved by making the research process transparent and providing enough details in the report so that other researchers could check if they would have reached the same conclusions (Bertram & Christiansen, 2020).

Furthermore, by virtue of the research being a case study there were three main validity concerns: "(a) to ensure that the data collected reflect the case; (b) to ensure that the claims are supported by the data and not generalised beyond what the case can warrant, and (c) it must be carefully considered how typical the case may be, and which findings can or cannot be transferred to other cases" (Bertram & Christiansen, 2014, p. 43). These concerns were addressed by a "prolonged engagement with data sources" (Bertram & Christiansen, 2014, p. 189), providing significant amounts of details in the report and a clear explanation of my positionality.

4.9 Ethical Considerations

Ethical treatment of research participants is mandatory for the successful conduct of any research study. Research processes that do not adhere to ethical considerations risk harming or violating the research subjects and the findings obtained are generally questionable (Ramrathan et al., 2017). In this study, I was mindful of the importance of adhering to ethical guidelines and conscious of the consequences of unethical conduct on research findings. In addition, I was conscious of the malpractices that are tarnishing education research, such as duplication, manipulation of data, plagiarism, and forgery which has led to research loss (Govil, 2013). Accordingly, I avoided topics that have been "subjected to too much research" (Govil, 2013, p. 17) and chose an area that I assumed would genuinely impact teaching practice. Therefore, this research project was not "simply an attempt leading to a degree" (Govil, 2013, p. 17).

I carefully considered the ethical risks of this study before the investigation as required by the Rhodes University Ethics Committee (RUEC). In addition, I was cognisant that ethical risks "cannot always be pre-empted" (Ramrathan et al., 2017, p. 433), that is, some risks only emerge during the investigation; I was always on the lookout for these and resolved them as they arose. I applied for and was granted ethical clearance to conduct this study by the RUEC. All the research participants were provided with the RUEC's contact details so that they could contact the committee in the event of unethical conduct.

In this study, I considered Ramrathan et al.'s (2017) perspective on research ethics where ethics are guiding principles for researchers' behaviour during all research processes which involve moral issues in the context of dealing with human subjects and includes the preservation or protection of human rights. In other words, ethics are guidelines on what is considered right or wrong (Kivunja & Kuyini, 2017). Thus, in this study ethics were viewed as utilitarian: they are guidelines for conduct that is beneficial to the majority and is not harmful to the research participants (Ramrathan et al., 2017). In addition, I included Brydon-Miller and Coghlan's (2019) take on research ethics in which ethical conduct is about conscious self-analysis of values and conduct when dealing with other people.

Bertram and Christiansen (2020) dissected the broad ideas of ethical conduct into three actionable principles or criteria, namely autonomy, non-maleficence, and beneficence. Autonomy means that every participant in the research willingly agrees to take part in the investigation after being informed fully about the purposes and potential risks. In addition, autonomy means the participants are allowed to withdraw from the study without penalty (Derry et al., 2007). I made a prodigious effort to obtain informed consent from the Director of Education for the Khomas region and principals of the schools where the participants were stationed as well as from the research participants. I explained the purpose of the study in detail, focusing on what I wanted to achieve, and I gave the Director and the principals the abstract. I negotiated with the teachers verbally and explained the potential risks and the steps I was to follow to reduce those risks. I explained to them that they were not under any obligation to work with me and were free to leave the study should they choose to. All the participants were very eager to partake in the study; they all wanted to learn how to mediate the learning of chemical equilibrium. Thus, my task was not as difficult as I anticipated, and they all eagerly signed the required documentation.

Beneficence means that the research process should be beneficial to the research participants, other researchers, and/or society as a whole (Bertram & Christiansen, 2020). This study was carried out to collectively improve teachers' skills for teaching chemical equilibrium – a topic well-known to be notoriously difficult to teach and learn (Van Driel & Gräber, 2002). I anticipated that the advanced skills we would acquire would create a turnaround in student outcomes. Furthermore, I wished to share the exemplar lessons and/or schemes of work that we would model in the intervention workshops with colleagues in neighbouring schools for them to implement them, if they wanted, in their classrooms.

Non-maleficence means that the research should not harm the research participants or any other people in any way (Bertram & Christiansen, 2020). Thus, the participants' right to privacy were honoured (Derry et al., 2007). Pseudonyms were used instead of real names to protect the participants' identity and all the data used was taken in confidence.

4.10 Chapter Summary

This chapter articulated the methodology, that is, the philosophical worldview that guided the study as well as the procedures followed, and the techniques employed to conduct this investigation. The chapter pronounced that the interpretivist paradigm and the critical paradigm guided the research and justified the choice. In terms of procedures, the chapter detailed how the case study approach was mobilised as a research genre, wherein the case study was treated as a guiding framework for the study. The chapter also presented the intervention and detailed how the intervention guided the participants' activities. Finally, details of the four main data collection techniques employed, namely interviews, video data collection, document analysis, and participant observation, the approaches to data collection as well as the ethical considerations and trustworthiness issues which were enunciated.

CHAPTER FIVE: SEMI-STRUCTURED INTERVIEWS

5.1 Introduction

In this chapter, I present, analyse, and discuss the data generated from the semi-structured interviews. I anonymised the data generated from the participants as follows: P1 to represent participant 1, P2 for participant 2 and so on. I conducted semi-structured interviews mainly to answer my research question 1: "*What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?*" In addition, the data generated from these interviews were required as mirror data to inform the subsequent steps of the investigation. Consequently, once each interview was conducted, I immediately transcribed the recordings and began the analyses straightaway.

The purpose of this study, as articulated earlier in Chapter Two, was twofold: to improve teachers' skills for mediating learning of chemical equilibrium through a formative intervention as a vehicle and to study the efficacy of the formative intervention. Thus, an important initial step was to establish the challenges that the teachers (the participants) faced in their classrooms and how they were coping.

I provided the research participants with the interview questions beforehand. I believe that this improved the quality of their responses and henceforth enabled them to provide deeper information about their practices.

My findings resonate, to a large extent, with those presented by Chani et al. (2018). However, there were a few differences, which I can attribute in part to the fact that my participants were drawn from both private and public schools, whereas Chani et al. (2018) focused on the teaching of high achieving students. The next section focuses on my findings.

5.2 Data and Findings

As an initial step of making sense of the huge amounts of data that I generated from the semi-structured interviews, I collated the participants' interview answers. I then proceeded to analyse that data for patterns and themes (see Appendix IX). I permitted the data to generate its own themes (Rule & John, 2011). However, I also used theories (CHAT and PCK) as well as literature to help identify the key concepts from the data. Three main themes emerged from the data as shown in Table 5.1 below.

Table 5.1: Themes, key concepts and related literature or theory

Themes	Key Concepts	Theory/ Literature
Students' difficulties in learning chemical equilibrium	Misconceptions	Üce & Ceyhan, 2019
	Language	Andriani et al., 2021; Chani et al., 2018
	Lack of requisite prior knowledge	Canpolat et al., 2006; Van Riesen et al., 2018
	Mathematics skills	Andriani et al., 2021; García-Lopera et al., 2014
	Concepts are abstract/difficult	Canpolat et al., 2006; Van Driel & Gräber, 2002
Teachers' instructional problems	Time constraints	Guzey & Roehrig, 2009; Teig et al., 2019
	Lack of /low quality resources/ cost of resources	Boakye, & Ampiah, 2017
	Failure to link concepts to real life	Gwekwerere, 2016; Mizzi, 2013

	Limited PCK, lack of SMK and Teacher Misconceptions	Makhechane & Mavhunga, 2021; Mavhunga & Rollnick, 2013
	Teacher dilemma in sequencing/lack of consensus	Makhechane & Mavhunga, 2021; Mavhunga & Rollnick, 2013; Morselli, 2019
Teacher instructional strategies	Use of representations (Analogies, demonstrations, Experiments)	Makhechane & Mavhunga, 2021; Mavhunga & Rollnick, 2013;
	Use of YouTube videos and online resources	Koto, 2020
	Relating chemical equilibrium concepts to real life	Gwekwerere, 2016; Mizzi, 2013
	Use of past examination questions in instruction	Turner, 2018

I now discuss each of these themes below.

5.2.1 Students' difficulties

A number of student difficulties emerged from the data. Here are the major ones: (a) chemical equilibrium concepts are abstract; (b) lack of the requisite prior knowledge; (c) language; (d) student misconception, and (e) mathematics skills.

- **Chemical equilibrium concepts are abstract**

Firstly, students seemed to find the ideas in chemical equilibrium abstract. Numerous scholars point to the abstract nature of equilibrium as the reason why students find chemical equilibrium difficult to learn (Van Driel & Gräber, 2002) and develop misconceptions (Machekhane & Mavhunga, 2021). There is also a need for a conceptual change approach (Canpolat et al., 2006) or the use of analogies (Üce & Ceyhan, 2019) for teaching chemical equilibrium.

For instance, P3 contended that the topic "*is quite abstract and is difficult to bring it down to the level of the students*". P1 provided further insight contending that "*the concept of equilibrium is very abstract to them because they can't see it so it's difficult for them to understand that a reaction is happening in both directions*". P2 agreed and thought that the students struggle because the situations are mostly theory which according to P1 makes is "*difficult for the children to visualise something they can't see*".

- **Lack of the requisite prior knowledge**

The participants complained that the students seemed to lack the prior knowledge that they need to learn chemical equilibrium. Constructivist approaches for teaching and learning seem to valorise students' prior knowledge as a key to learning (Van Riesen et al., 2018), that is, "meaningful learning only happens if students can make connections between the new information and their prior knowledge" (Gwekwerere, 2016, p. 38). In this regard, Üce and Ceyhan (2019) explained that students need to have enough and proper prior knowledge in order to correctly perceive concepts. Canpolat et al. (2006) agreed and asserted that the "existing knowledge of a learner plays and important role in the learning process because learning is the result of the interactions between what the student is taught and his/her current ideas or conceptions" (p. 217).

Hanson (2020) identified an inadequate understanding of rates of reaction as one of the major sources of the difficulties that learners face in learning chemical equilibrium. Kousathana and Tsapalis (2002) explained that learners fail to solve chemical equilibrium problems because learners need good understanding of the mole and reaction stoichiometry, gases, and the ideal gas law. To this end, Andriani et al. (2021, p. 1) explained that students find chemical equilibrium concepts difficult to understand because "students should understand several other related concepts such as concepts of concentration, stoichiometry, gas, and mole".

P4 explained that chemical equilibrium is really difficult for the *"students because they need to know the background of a reaction"* which P2 expanded on and gave the topics that the students have to understand. P2 says that students "*Need to have a good understanding of energetics of a reaction. So, they need to be familiar with the endothermic and exothermic reactions. They also need to have a good understanding of the rate of reaction concept as well*".

P1 concurred about this importance of prior knowledge and focused on the equilibrium ideas they would have done earlier in Grade 10.

- **Language used for chemical equilibrium and instruction**

Students seemed to struggle with understanding the language that is used to explain the concept. This challenge appeared at a number of levels. First, the learners seemed to struggle to understand chemical equilibrium. P4 supposed that "*the language used is difficult* [for the students to understand]". This finding coheres with Chani et al.'s (2018) finding that the language used, particularly for LCP, is vague, demanding, and difficult to explain. Secondly, the students tended to find the use of some terms confusing. P2 explained that "*sometimes they struggle when you then bring the term 'yield'".*

Makhechane and Mavhunga (2021) identified the terms used as a common difficulty for students and Andriani et al. (2021) considered the language troublesome because everyday words are given different meanings. Finally, the students struggled with the way different people speak, in particular the different accents and pronunciations when teachers use online resources. P4 recalled that her students complain about the difficulties they face in trying to understand concepts when she uses YouTube resources in her teaching: "*My students always complain and say, 'ma'am we do not understand' … 'he (a YouTuber) talks too fast, and we do not understand him'. Maybe the pronunciation is different*".

- **Students' misconceptions**

The participants identified student misconceptions, also known as alternative conceptions, as a major problem in their teaching. These misconceptions are known to prevent students from learning chemical equilibrium (Üce & Ceyhan, 2019) because they act as barriers to learning (Morales, 2017). In this regard, P2 asserted that the students' misconceptions as a serious challenge in her teaching. She observed that students:

> *Do not realise that when we talk about equilibrium it doesn't mean that the reaction has stopped at a halfway point … or it is not a matter of the reaction having stopped but [that it is at] dynamic equilibrium.*

She explained that these misconceptions are especially rife in students who do Physics "*because they would have learnt equilibrium from the forces kind of concept* [static equilibrium]". She added that "*for them [students], at dynamic equilibrium the reaction stands still and there's nothing happening anymore at that point*."

- **Lack of Mathematics skills**

The Grade 12 students struggled with calculations and Mathematics. García-Lopera et al. (2014) indicated that students have difficulties with calculations and fingered stoichiometric calculations as the chief problem. Kousathana and Tsapalis (2002) found that students make a lot of calculation errors due to hastiness or overload of the working memory or by having misconceptions about the topic such as "incorrectly applying the stoichiometry, for example, multiplying the initial quantities by the stoichiometric coefficient" (García-Lopera et al., 2014, p. 450). P3 presented this problem with calculations. She submitted that "*Mathematics is the main challenge"* [that her students have] due to *the fact that they have to find units, which they struggle with*". Andriani et al. (2021) weighed in on this and said they believe that the need to carry out mathematical calculations and drawing graphs makes chemical equilibrium concepts complex.

5.2.2 Teachers' instructional problems

Each of the challenges listed in Table 5.1 were faced by at least one of the research participants, which I reiterate here: (a) time constraints; (b) limited PCK, lack of SMK; (c) lack of resources for teaching; (d) failure to link concepts to the students' lived experiences, and (e) teacher dilemma and lack of consensus on sequencing.

- **Time constraints**

The one challenge that most of the participants said they faced in teaching chemical equilibrium was time constraints. They complained that they struggle to go through all the content for chemical equilibrium in the allotted time, especially when they try to use hands-on practical activities and demonstrations (Asheela et al., 2021). This challenge was mentioned by Guzey and Roehrig (2009) as one of the main constraints that teachers experience in teaching Science.

According to P3, teachers are always in a race to complete the syllabus in a time frame that is not adequate to properly teach chemical equilibrium. She described this problem explicitly: "*We are racing against time. We don't really have all the time in the world to sit with the topic*." P4 concurred with this, adding that "*at times you are forced to continue even if they* [the learners] *do not grasp it well because of time. You tell yourself I will come back to this later but then you can't.*" P2 supported this notion saying "[we are] *always under that pressure of … an external exam so you always want to give them extra time to get the content through"*. Teig et al. (2019, p. 4) agreed that time can be a constraint because it is important to devote "adequate time to actively involve students in the process of knowledge construction". A study by Asheela et al. (2021) on the use hands-on practical activities in teaching also found that teachers expressed concerns on the time-consuming nature of these activities. However, Teig et al. (2019) warned that these perceived time constraints can hinder a teacher's willingness to use hands-on practical activities in their teaching, even when the time is adequate. Based on my personal experiences, if a teacher plans for the activities well ahead of time, involves the learners in preparation and cleaning up, and has good classroom management skills, these activities are not dissuasively time consuming.

Covid-19 lockdowns seemed to have exacerbated this challenge. According to P2, "*because of lockdown there was not enough time to give them all the content you would want them to have*". Parents, who became stand-in-teachers overnight, had a lot of issues to overcome in order to be of assistance to their children and the learning process in those circumstances was slow (Thomas & Rogers, 2020).

- **Limited PCK, lack of SMK**

The other challenge that the teachers encountered is that they lacked the knowledge and skills required to effectively teach chemical equilibrium. In other words, teachers had limited PCKe, lack of SMK on chemical equilibrium and espoused some misconceptions about the topic. According to Makhechane and Mavhunga (2021, p. 161), chemical equilibrium requires "teachers with a well-developed PCK and competence to teach for understanding" because the topic is abstract, and students find it difficult to learn.

P3 spoke at length in describing the teachers' lack of SMK:

> *There was a workshop with some teachers in the Khomas region, where I was surprised with the difficulties they showed. It's a topic that many people struggle with. I don't know whether it is taught at university or not but if teachers struggle like that then you can imagine the learners.*

In this excerpt, P3 was not referring only to other teachers but to herself as well. She further said: "*I think maybe over the years I have never really taken time to expose myself to the topic*" and that "*I understand it* [chemical equilibrium] *a little bit, not enough to really explain it*".

This lack of SMK had me concerned for the viability of my study because I understand that "possession of good SMK is a prerequisite" for the development of PCK (Kind, 2009, p. 186). However, I got encouragement from a description by Kind (2009) in which a teacher grappling with learning new content knowledge while teaching it, provided learning opportunities for her students. This meant that in my study the participants could also improve their PCK while learning the content knowledge from each other.

The limited nature of the participants' PCK is clear from what they said. For instance, P3 confessed that she could not find real-life examples to use in explaining chemical equilibrium yet "*for other topics …* [I use] *very nice examples that will just help the child*". She attributed this lack of knowledge to not exposing herself to the topic, postulating that "*the more you expose yourself to different materials on the topic then you come across all those things* [representations and teaching strategies]". P4 simply said that it "*is one of the topics that we as teachers struggle to bring forth to the learners*", which I interpreted could mean a lack of PCK.

Additionally, the participants do not check their students' prior knowledge before teaching as teachers with exemplary PCK do (Mavhunga & Rollnick, 2013) further demonstrating limited PCK. For P3, this is obvious from what she said: "*I just start and as we go, I see what they are struggling with, and I explain*". P1 simply said they "*sort of*" assess the "*general appearance*" and do not give a test.

Another indication of limited PCK is that some of the participants initially had an opinion that their students do not struggle with chemical equilibrium. They could not think of any difficulties that students have with the topic. Yet, a study by Chani et al. (2008) clearly showed that students in Namibia struggle with learning the topic, even the high achieving students she explored. In addition, the difficulties that Namibian students face with chemical equilibrium are well documented in examiners reports (MoEAC, 2014; 2019; 2020).

Kind (2009) considered this problem teacher "over-confidence" and asserted that this can result in poor quality teaching. She said that this is prevalent in teachers who feel they have good SMK. However, I think that any way we look at it, this kind of confidence translates into lack of PCK. For instance, P1 simply "*talks about what we would have done for that previous section and see what they can remember and start from there*" without formerly checking the learners' prior knowledge. On the other hand, P3 "*just starts and as we go she sees what they are struggling with and explains".* P2 relies on their order of teaching (curricular saliency) and argued that:

> *We usually place it in that order where we start with energetics, rate of reaction kinetics then chemical equilibrium ...* [and] *since we teach in that order so you would have gotten an idea whether they have a sound understanding.*

- **Lack of quality resources**

The participants lamented the lack of quality resources to use in their classrooms as another reason why they struggled in mediating learning of chemical equilibrium. The participants reported that they fail to carry out experiments with their students or demonstrate some concepts in their teaching because they do not have enough equipment or apparatus. This challenge of unavailability of teaching resources was also found in a study by Boakye and Ampiah (2017).

For instance, P3 said that "*the problem with doing experiments in public school [is that] we do not have enough materials. Like if you want to do a certain reaction and you do not have enough reagents then you cannot do it anymore*". For P1 the problem was slightly different; she was more worried about the cost of the apparatus as well as the preparation time. This is what she had to say:

> *We are lucky to have the lab technician that we have and also have enough equipment. For example, the other day a child broke a burette and pipette and that's really a costly mistake, also there is need to replace parts and some markings wear away. It does take a lot of money and a lot of time.*

For P4, her complaint was directed towards the quality of the textbooks. She was of the opinion that *"the available textbooks are really not useful, especially for some of these topics".*

- **Failure to link the concepts to the students' lived experiences**

Another major challenge that the participants mentioned is that they fail to link the concepts in chemical equilibrium to the students' lived experiences due to the abstract nature of the topic. P3 was explicit in describing this challenge. She said that "*just to relate it to real life is a little hard"* because she *"understands the topic a little bit not enough to really explain it"*. She really had a lot to say about this and the importance of relating Science concepts to real life.

> *Most of the time in teaching, we always have to apply whatever we are teaching to everyday life, but for this particular topic, if you ask me how relevant it is on everyday life, I would not be able to give you an answer. I think I need to read more about the topic.*

These excerpts clearly showed that P3 is aware of the importance of contextualism in Science education, that is, she understands that her students will only learn Science if she uses "examples and application of scientific principles to situations that are familiar to the students lived experiences and worldviews" (Gwekwerere, 2016, p. 40). However, as Mizzi (2013) asserted and these excerpts explicitly show, her lack of subject matter means she cannot relate the various Science concepts to students' everyday life situations.

- **Teacher dilemma on sequencing concepts**

This challenge is very complex, and it may be difficult for teachers to find a common solution. The participants did not seem to have a common position on how the concepts should be sequenced in teaching. The logical sequence for teaching chemical equilibrium, "in accordance with the way chemical equilibrium is taught in many countries" should start with the position of equilibrium then LCP (Van Driel & Gräber, 2002, p. 281). However, the NSSCAS Chemistry syllabus has LCP above Kc which may be the source of the problem because some teachers follow this sequence. In this regard, P1 said "*I definitely teach LCP first* [before position of equilibrium]" while P2 teaches the idea of position of equilibrium before they teach LCP. P3 agreed with P2 and follows a sequence different from that given in the syllabus. She said:

> *I start with reversible reactions. From there, what I normally do is I show them YouTube videos on dynamic equilibrium and animations then I move to explain the principle itself*

> *and then I go to the conditions; the pressure, the temperature and the concentration. Thereafter* [I do the] *calculations.*

This teacher dilemma or disagreement between individuals is referred to as a contradiction in CHAT terminology and is considered a gateway to collective transformation (Morselli, 2019). However, in light of Mavhunga and Rollnick's (2013) curricular saliency, which Makhechane and Mavhunga (2021, p. 162) succinctly described as "knowing the most important and core concepts of the topic, what is peripheral, pre-concepts and the logical sequencing of the concepts", this lack of consensus can mean there is a huge problem in teaching.

A further problem in terms of the participants' curricular saliency which I think arises from the syllabus and also results in the teachers' dilemma, relates to sequencing of the topics. The syllabus explicitly requires teachers to "explain, in terms of rates of the forward and reverse reactions, what is meant by a reversible reaction and dynamic equilibrium" (MoEAC, 2020b, p. 14) yet rates of reaction comes after chemical equilibrium. P1 and P2 said that they explain chemical equilibrium in terms of rates of reaction, as required by the syllabus. For instance, P2 explained it as follows: "*As you have a forward reaction and a reverse reaction happening at the same time you get to a point where both reactions are happening at the same rate*". Consequently, she said "[we teach in] *the order, where we start with energetics, then rate of reaction then chemical equilibrium*", an order different from the syllabus sequencing. P1 tended to include the idea of the constancy in the amounts of the reactants and products to help her students understand equilibrium better.

For P3, the curriculum complicates her teaching by including this difficult topic for students in Grade 10 who may not be ready for it. She lamented the inclusion of chemical equilibrium in the Grade 10 syllabus saying: "*We are now teaching it to younger learners – the Grade 10s – and they are really struggling with it*".

5.2.3 Teachers' instructional strategies

One major observation in the findings was that the teachers' skills and competences for mediating learning of chemical equilibrium were varied. For instance, when I asked P4 about the importance of chemical equilibrium in the school curriculum it seemed she was not sure which topic I was referring to. She asked "*Its importance? Are you talking about Le Chatelier's Principle?*" In contrast, P1 was well attuned to the topic. For instance, in response to the same question about the importance of chemical equilibrium she said: "*I think it's an important concept in Chemistry and I feel it links different sections together, but it is quite a difficult topic for the students to understand*".

This validated my choice to set up the study group as a PLC – PLCs are acclaimed for TPD because they permit the participants to learn *from* and *with* each other (Lieberman & Pointer-Mace, 2008; Ngcoza & Southwood, 2019). Liebermann and Pointer-Mace (2008) explained that a PLC provides an ideal environment for learning as "teachers learn best when they are members of a learning community" (p. 227).

However, it should be noted that where one participant showed some deficiencies another was very strong; where one participant had limited knowledge in one area, they showed exemplary knowledge in another. For instance, P4, who needed to be reminded of the topic as described above used excellent strategies to help her students understand chemical equilibrium, while the same cannot be said for P1.

A number of useful instructional strategies emerged from the data: (a) the use of representations and conceptual teaching strategies; (b) the use of YouTube videos and other online resources; (c) relating chemical equilibrium concepts to students' real-life experiences, and (d) the use of past examination questions in instruction.

- **The use of representations and conceptual teaching strategies**

The use of representations is a major component of Mavhunga and Rollnick's TSPCK for transforming SMK into a form that can be understood by students. I was impressed by the way the participants described how they use analogies, demonstrations, and hands-on practical activities to explain the difficult concepts in chemical equilibrium. P1 spoke about the use of an analogy: "*When I teach equilibrium, I teach it like a scale that is balanced. If something happens to one side of the scale, then something must happen in the other direction to keep the scale balanced.*" P3 described the use of experiments and demonstrations*: "So you start by doing the experiments with hydrated copper sulfate, start there and show how reversible it is. So, it starts there; you use hydrated copper sulfate [and hydrated] cobalt chloride".*

On other hand, P2 highlighted the use of conceptual teaching strategies. She said:

> *Like you put typical reactions on the board and then you play around and say this is what it means if the overall reaction is exothermic; which side will it shift. So, we just use some practical examples and facts. So, they are just presented with facts; this is what an equilibrium reaction is and they make predictions on the given scenario.*

She added, "*and I usually show them graphs as the amount of products being formed increases and the amount of reactants being used up decreases it will level up at a certain point*". This showed she had a good understanding of the problems that learners face in interpreting graphs and the need to make sure the students get a good grasp of chemical equilibrium.

- **The use of YouTube videos and other online resources**

Another important strategy was the use of YouTube videos and other online resources. The use of these valuable resources has been necessitated by a lack of resources or because some videos explain the concepts very well. This is what P4 had to say:

> *What I do with my students* [is that] *I go to YouTube, get a video, and show them. I usually show them videos when I realise that I do not have enough reagent or chemicals. I just go to You Tube and download a specific video.*

It is clear from this excerpt that even though the school does not have resources to do a demonstration the learners will get a similar experience. Koto (2020, p. 106) considered this usage of YouTube videos and other video streaming media in the classroom as important and advised it should be "considered as an alternative educational tool to promote students' engagements".

P3 was very grateful for YouTube and uses the videos because their explanations are good. She said: "*What I normally do, is I show them YouTube videos on dynamic equilibrium and animations. We are lucky we have YouTube, some videos explain these ideas very well*".

- **Relating chemical equilibrium concepts to students' real-life experiences**

The participants indicated that they try to link chemical equilibrium concepts to their students' real-life experiences in their teaching in order to enhance the students' learning. Gwekwerere (2016, p. 40) concurred with this and averred that, students only learn Science when the ideas are contextualised to their lived experiences because "understanding emerge at the boundary of the person and the environment". In this regard, P2 has demonstrated proficiency. For instance, P2 spoke about the topic of chemical equilibrium in light of its importance in showing the value of Chemistry in life. She said: "*I think it brings Chemistry into real life especially when you talk about processes, where it is brought to the student attention that there is real application of what we learn in class*". However, as I have alluded earlier, some participants expressed a lack of knowledge, and a desire, to learn how to contextualise chemical equilibrium.

- **The use of past examination questions in instruction**

The participants mentioned the use of past examination questions in their teaching. They contended that they help their learners to have an in-depth understanding of chemical equilibrium; in particular, when they use the AS level Chemistry questions that require higher level thinking skills. These findings have affinity to Turner (2018), who supported this use of past examination questions in teaching and argued that it has huge potential in helping students to develop deeper cognitive skills.

P4 spoke at length about this strategy:

> *I always want my students to go through old papers so that they acquaint themselves on how to approach them. There is this question that they normally ask* [in examinations about] *the conditions that the students need to put in effect when they are looking at equilibrium. They will say for instance temperature or pressure, but now they should indicate the exact temperature or pressure.*

From this excerpt it was clear that the teacher wants to make sure students are exposed to all the different circumstances about chemical equilibrium as guided by the more difficult questions in the examinations.

P2 also made use of examination questions to guide her teaching. She explained that "*when you look at exam questions, when they usually ask what it means by equilibrium, they usually ask for both* [rate of reaction and concentration or reactants and products]". Even though she "*emphasises more on the fact of the rate of reaction being the same*" as required by the syllabus, she uses the past examination questions for guidance on what else to teach.

5.3 Chapter Summary

In this chapter, I presented, analysed, and discussed the data that I generated from the semi-structured interviews. These data sets were generated to answer my research question 1: "*What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?*" The data exposed numerous challenges, which I placed into two categories: (i) students' difficulties and (ii) teachers' instructional problems. The students' difficulties in learning chemical equilibrium were: (a) chemical equilibrium concepts are abstract; (b) lack or the requisite prior knowledge; (c) language; (d) student misconception, and (e) mathematics skills. The teachers' instructional challenges were: (a) time constraints; (b) limited PCK, lack of SMK; (c) lack of resources for teaching; (d) failure to link concepts to the students' lived experiences, and (e) teacher dilemma and lack of consensus on sequencing.

In addition, the data revealed some instructional strategies that teachers employed to remedy these challenges that they experienced. The participants used: (i) representations; (ii) YouTube videos and other online resources, and (iii) past examinations questions in instruction. Also, they tried to relate chemical equilibrium concepts to students' real-life experiences. In the following chapter, I present, analyse, and discuss the data generated through the intervention workshops to answer the second research question of this study.

CHAPTER SIX: INTERVENTION WORKSHOPS

6.1 Introduction

In the previous chapter, I presented findings and discussions of the challenges that teachers face in mediating learning of chemical equilibrium and some strategies that they employ to remediate those challenges based on interview data. I reminded the reader that the teachers involved in this seemed to face a plethora of challenges that I placed into two categories: (i) students' difficulties in learning and (ii) teachers' instructional problems. These findings were subsequently used in the workshops as mirror data.

In this chapter, I present, analyse, and discuss the thick data generated by the four intervention workshops. Similar to what I did for the interviews, I anonymised the data generated from the participants and maintained P1 to represent participant 1, P2 for participant 2 and so on. In addition, I used terms W(P1) and R(P1) to represent P1's contributions extracted from the workshop data and participants reflections, respectively. Each workshop was designed to trigger specific learning actions following the expansive learning cycle (Morselli, 2019). The expansive learning, however, is not cyclic (Augustsson, 2021) and we had to move back and forth between the learning actions in the individual workshops. I do not think this had a material impact on the learning that we sought.

The workshops were conducted to answer my research question 2: "*How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 teachers' PCK for mediating learning of chemical equilibrium?*" The workshops were, as a matter of methodology (see Chapter Four), video recorded and transcribed. The collated and colour coded transcripts of the recordings, together with the collated and colour coded participants' reflections, are given in Appendix X. Again, in maintaining the practices that I used for the interview data, I permitted the data to generate its own themes (Rule & John, 2011). Similarly, I also used theories (CHAT and PCK) and literature to help identify the key concepts from the data. The next section focuses on my findings.

6.2 Data and Findings

Here I present the data and findings from the intervention workshops.

6.2.1 First Workshop: Questioning & analysis

The first intervention workshop was carried out over Zoom and the three main objectives were: (i) to familiarise the participants with CHAT and its concepts; (ii) to present the mirror data and begin the questioning, and (iii) to begin the analysis of problems in the practice and to find contradictions.

I first explained CHAT as a theory of human learning, emphasising that human learning is a complex process that is socially situated (Engeström, 1987). This is where I presented the triangular model of the activity theory and my 3D model (see Figure 6.1, Engeström, 2001). I presented the two components of CHAT that I considered relevant for this study, that is, expansive learning and contradictions. I explained that we were going to use the expansive learning cycle to guide our activities. I defined contradictions as structural tensions in the system and that they should not be viewed as problems but as gateways to collective transformation (Engeström, 2001). That is, I emphasised that the contradictions were a driving force for change (Morselli, 2019).

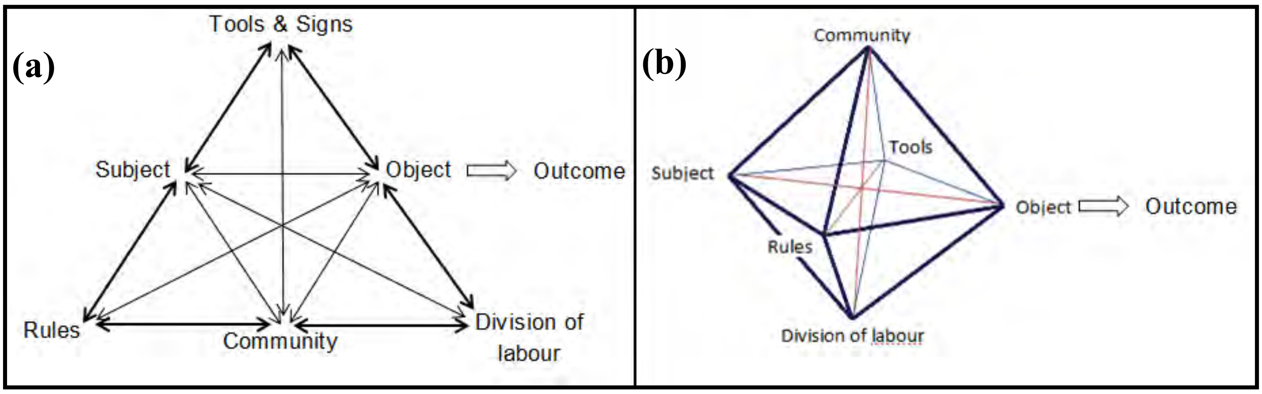

Figure 6.1: Model of 2nd generation CHAT (a) Engeström (2001, p. 135); (b) 3D model

I observed that CHAT terminology was difficult for them to understand but explained that it was important in the analysis because we had to seek out the contradictions to make sense of all the challenges in our practice. Consequently, I streamlined the definition for contradictions into two main focus areas (manifestations) that I thought were relevant for this study: (i) practitioners' dilemmas or double bonds and (ii) conflicts and disagreements (Morselli, 2019). I gave the following examples to help them make sense of contradictions:

- The time required to use all the relevant representations that ensure student understanding compared to the time allotted in the scheme of work from the regional office.
- The cost of equipment and chemicals required for teaching compared to the budget availed.
- The use of analogies and students' conceptual learning of chemical equilibrium – the understanding being that misconceptions may arise through the use of analogies (conceptual tools in CHAT).

These examples emerged from the interviews, and I considered them here as mirror data. I implored the participants to make use of the triangular model of the activity theory as a heuristic tool to ensure that we could think through all possibilities and discover as many of the problems as possible. I defined the elements of the activity system shown in Table 6.1 below:

Table 6.1: Some components of classroom teaching activity system

Subject:	Students
Object:	Understand chemical equilibrium → **Outcome**: improved student achievement
Tools (mediating artefacts):	Textbooks, syllabus, past examination questions (papers), laboratory equipment, language, teacher representations, LCP
Community of significant others	Teachers, school administration, parents, laboratory technicians, subject advisors

Rules	School rules, classroom rules, lab rules, timetables, timelines, time schedules, schemes of work, school policy
Division of labour	Cleaning of laboratory, cleaning up after lab sessions and packing away equipment, distribution of resources, class presentations

The first workshop was set to commence the *questioning* of current practices in mediating learning of chemical equilibrium. To kick-start the discussion, I asked the participants: *"Do you think there is a problem, or do you think there is an issue to discuss in teaching chemical equilibrium?"*

There was no consensus in the responses, with P2 disagreeing with the other participants. She seemed to be consistent with the position that she had when I conducted the interviews and maintained that she did not think there was a problem and she said:

> *What we were talking, when we had our interview before, is that when you just teach it at ordinary or IGCSE level, without the calculations and all of that, it can actually be quite simple - quite simplified. The students usually don't struggle too much getting the idea … That is my opinion, because as I said, I didn't think of it as being too hard.*

Later, after going through the mirror data, it appeared as if she finally realised there was a problem, saying "*I never thought of that one* [referring to the problem of LCP when temperature is raised in a container of fixed volume]". She added "*I never considered that changing temperature actually does change the pressure as well".*

However, her position was not shared by the other two participants who were, by and large, in agreement that there was a major problem. For instance, P3 was very explicit in describing the problem:

> *There is an issue. Like I said the other day, the topic itself is a little bit abstract so on both the teacher and the student side it should be discussed because there need to be a little bit more understanding of this topic. When you bring it up with the students at the beginning, you really have to find a way to bring it home.* [Especially], *when you bring in the equilibrium issue, which is something that I think is appearing for the first time.*

> *Even just that word itself, if you look at the whole syllabus, you'll find, you don't really use it so much.*

From this excerpt it was clear that teachers and students struggle with teaching or learning chemical equilibrium. P1 showed agreement in saying that:

> *There are children who seem to cope very well with IGCSE* [chemical equilibrium] *but struggled with AS work … because at AS level they have to master all these other sections, such as the rate of reaction, the enthalpy and stoichiometry calculations. So aside from the fact that it is quite an abstract concept, there is all this other stuff they have to understand … That for me is what makes it more complicated.*

Later, P2 conceded that there was a problem in teaching chemical equilibrium by the application of LCP because the prediction could be different from the empirical results. She thought she was "*lucky that the kids never figured that out themselves*". Having learnt this, she realised she would face a dilemma in future in which she would not know whether to explain this concept to the students or just hope the students would accept "*the simple idea*". She reasoned that: *"I now need to be careful, now that I'm in this situation where you think: 'Shall I tell the students in future that actually there is a problem? Or shall we just hide it under the'* …". P3 suggested that she had to be honest, but instead of seeking better scientific explanations she thought of using a "disclaimer" that Science is tentative. She said that she just tells her students that "*we (teachers) do not have all the answers …* [and] *we're trying to understand the principles of the universe and these* [explanations we are giving] *are currently the best explanations we have*". I observed that these participants seemed unsure of the content and would prefer the students getting a superficial understanding, especially one sufficient to answer examination questions, rather than being challenged by the students.

The participants' reflections also showed that P2 maintained her general position that chemical equilibrium was easy and would not accept the suggestion by Cheung (2009) to remove LCP from the school syllabus. She, however, accepted the suggestion by Van Driel and Gräber (2002) to break LCP down into simple standalone statements. My observation here is that she was beginning to appreciate the complexity of the topic and that it is indeed difficult for the students.

In her reflections, P1 indicated that she had always thought there were problems in teaching chemical equilibrium but conceded she never thought they were as bad as presented in the mirror data. Here is what she had to say: "*The problem is more complex than I at first thought it to be there are many circumstances that I haven't really considered to be a problem before".* P3 resonated with P1 and said that: *"I was made aware of issues that were there but I never really paid attention to".*

For the analysis, in which we sought the main contradiction causing difficulties in teaching chemical equilibrium, we used the triangle of activity theory (Engeström, 1987). However, the participants did not immediately understand it and we discussed the problems without having to identify exactly the nature of the contradiction. I focused on the nature of the contradiction after the workshop. The contradictions are given in Table 6.1 on the next page.

At face value, it seemed there was no consensus among the participants regarding what they considered the biggest problem. However, when I looked at what they presented carefully, it was clear that their concern was that, despite all their good intentions in their teaching, their students were failing to understand chemical equilibrium. That is, in CHAT terms, the object of the activity was not being realised, even though effort was there. P3 presented the problem succinctly: "*You teach thinking you are doing well, not knowing that you are actually creating some problems in the learners' conception of the ideas*".

It was explicit at this point that although the teachers' intentions were good, the use of the physical and conceptual tools (which were limited), correctly or otherwise, was leading to incorrect or poor understanding of the concepts by the students. For instance, P1 complained that the laboratories were not adequately resourced or manned to conduct classes using hands-on practical activities (Asheela et al., 2021) and P3 lamented the lack of time to do practical activities. In this regard, P2 argued that:

> *The main problem has to do with misconceptions however they arise, and I think it is the one that we should focus on. You see, if the teaching is done well enough from the onset, then most of these challenges simply disappear.*

I observed that the other participants agreed that this had to be the pertinent problem that we had to work on in the subsequent workshops.

As can be seen from Table 6.2 and depicted pictorially in Figure 6.2, the major contradiction raised by the participants was between the object and the tools, with a very strong innuendo about unavailability or improper use of both conceptual and physical tools. For instance, there was a language barrier between the teacher and the students impeding understanding of the concepts. In CHAT terms, this simply means the conceptual tool, language, was not available for use to mediate the learning.

Table 6.2: Identified contradictions in the participants activity (Engeström, 1987)

Contradiction area	Problem	Participant excerpt
Tools ⚡ Object	Limited resources	There was only one laboratory but for two campuses. R(P1)
	Limited resources (time constraints)	A lot of syllabus (content) to cover and we are under time pressure to finish everything … yet students may need more time to learn the topic. R(P1) We do not have enough time to thoroughly prepare, research or do practical activities … We do not have enough time to assess each student to see if they have mastered the content. R(P3)
	Sequencing	The way the new syllabus is organised is problematic. The old syllabus was organised in a much better way; we would teach chemical energetics and chemical kinetics before chemical equilibrium - students had the prior knowledge that we need. Pertaining to the order of objectives I am not too sure of the order to use and may follow what they give in the syllabus. W(P3) In the NSSCAS syllabus the problem seems to be the order of [the objectives in] the syllabus. R(P1)
	Students' misconceptions	The main problem has to do with misconceptions however they arise … if teaching is done well enough from the onset, then most of these challenges simply disappear. W(P2) The time to teach thinking you're doing well not knowing that you are actually creating some problems in the students' conceptions of their ideas. W(P3)

	Limited conceptual tools	The idea of experiments for this topic is new to me; I do not know what experiments one can do for LCP. W(P3) Differentiated learning to allow for different ability levels within the same group of students. R(P2) Language barrier. R(P2)
Subject ↯ object	Younger students	Teaching these difficult topics to younger students is causing misconceptions that are making our jobs even more difficult. W(P3)
	Students do not do homework	In our school the problem is that if an assessment is not for marks, then the students do not do the work. I want to be able to give assessments that students can take home to save some time, but the students simply do not do the work if it is not for marks. W(P1)
Community ↯ subject	Classroom management	The large class sizes of 38 + lead to difficulty in managing the class. R(P1) We have big classes and we have the issue of having to deal with crowd control while at the same time having to teach the content. W(P1) The issue of the big classes is that when you give an experiment you want to be able to move around and provide help and guidance as the students carry out the experiments. W(P1)
Community ↯ Division of labour	Excessive work for practical activities/ Absence of lab assistance	I have to make all the solutions and setup and pack away on my own. R(P1) We have to prepare all those chemicals and do the demonstrations without the assistance of lab technicians. W(P3)

In the table, W(P1) stands for workshop contribution by participant 1 and R(P1) stands for reflections by participant 1 in their reflective journals.

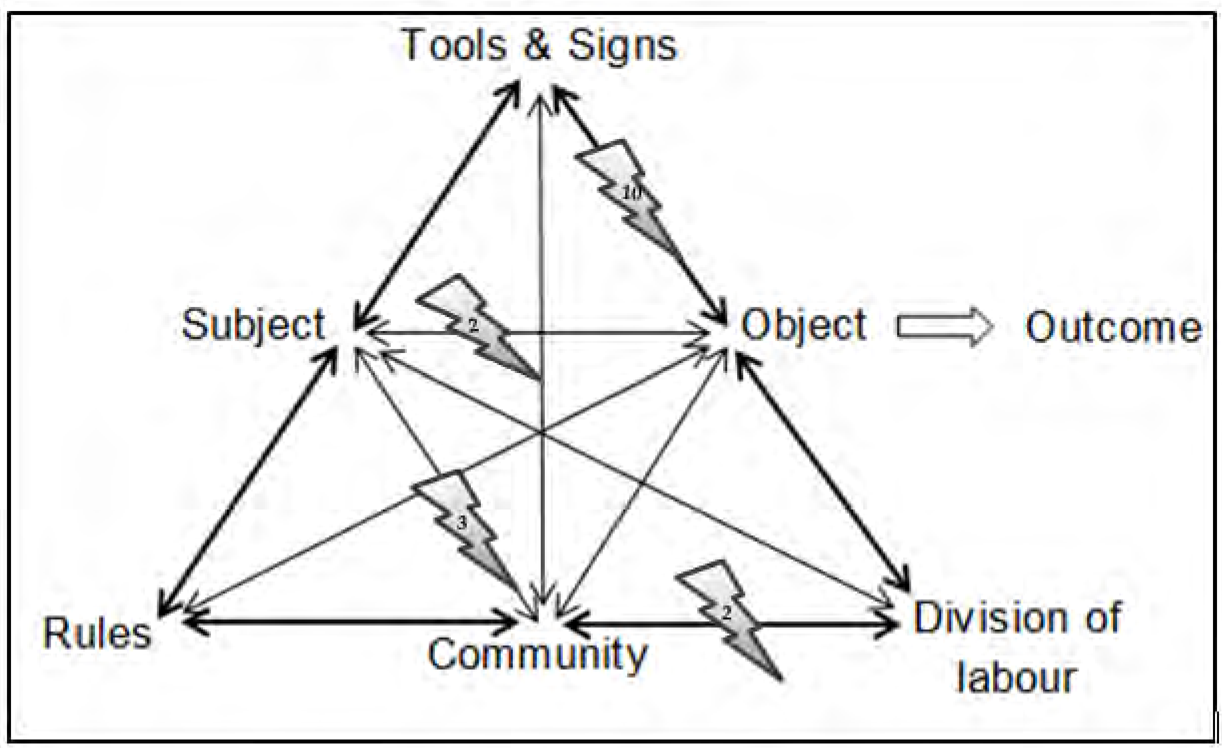

Figure 6.2: Contradictions in the activity system (Engeström, 1987)

6.2.2 Second workshop: Modelling

The purpose of this workshop, conducted over Zoom, was to *model* a new way of teaching chemical equilibrium that addressed the main contradiction identified by the participants. We started the session by going back to the analysis. This was because I had to share the data from reflections and ask again if the participants agreed with the main contradiction identified. P1 opined that it was not necessary to have consensus because an individual's problems "*depends, sort of, on what situation you are in at the time ... when I was in different schools, I had different conditions and different things were a problem for me*". However, she did concede that there was a problem that needed solving saying: *"I suppose that most of these things will be a problem no matter what syllabus you are doing or your individual circumstances"*.

The main issue that P2 presented in this workshop was the concern she had pertaining to the difficulties of demonstrating concepts in chemical equilibrium. She made it clear she understood that demonstrations were a necessity in teaching but did not always work well. For instance, she explained that the reaction between iron (III) chloride and potassium thiocyanate is a fantastic demonstration to show the effect of change in concentration on the position of equilibrium. However, she observed that it only works well when one alters the concentration of iron (III) chloride but does not seem to work when one adds more potassium thiocyanate. She expressed her frustration and fears in the following excerpt:

> *I haven't quite figured out what the story there is* [adding potassium thiocyanate does not cause a colour change] ... *I stopped using that experiment for the Grade 10s. I just quickly showed them, if I add more iron (III) chloride, it moves that way, and I thought let me just put it away before someone gets the idea: 'let's add the other stuff and see' and then I'll look red in the face.*

The excerpt shows teachers may avoid practical activities that can help their students understand the concepts if there are chances it might not work because they want to avoid the embarrassment. The silver lining in this case though is that P2 realised that she "*needs to do a read up a little more*".

The discussion moved to the problem of sequencing of topics and objectives where P2 contended that it "*should be an easy thing to solve*". She added that there was a need to come up with a common scheme of work because *"there are a lot of teachers who will be new to having to teach at AS level ... and that would be something that could be very helpful"*. P1 initially disagreed and insisted on the personal style saying that "*even I am going to teach it differently to that other time ... so I suppose even just variety and style is going to lead to changing the order"*. Fortunately, she would agree later to the need of a new scheme and was at the forefront of generating it.

I then introduced the Refined Consensus Model of Pedagogical Content Knowledge (RCM of PCK) and the Topic-Specific PCK (TSPCK) to help us model the new way of teaching chemical equilibrium. I explained the five elements of TSPCK. However, it turned out that instead of immediately using it for the modelling we went backwards and used it for analysis. The first contribution on analysis using TSPCK was by P2, who confessed that "*sometimes you do not necessarily double check if they actually have those prior concepts available. We just assume that they should be there because we taught them before*". She noted, because TSPCK considers learners' prior knowledge important, that it was important "*to have a mechanism to activate the prior knowledge again so that they see the connection and that they do not start afresh with an empty mind*". She explained that *"one needs a strategy to double check* *whatever you think they should know"*. She explicitly described the problem of checking students' prior knowledge (SPK) verbally in class, where we normally judge understanding by listening to the brighter students. She contended that:

> *Sometimes it's not necessarily about the weaker ones and the stronger ones; sometimes it's more outspoken and the shy ones. I mean sometimes it goes hand in hand that the outspoken ones are the ones that are confident and understand ... But it's sometimes we need to get them out of their reserve to actually see whether there now just quiet because it's their personality or whether they are quiet because you lost them completely in the process.*

Interestingly, this led to a discussion on how the Covid-19 pandemic had complicated teaching, in that it became difficult to judge students' understanding based on their facial expressions. In adhering to Covid-19 regulations, students have to put on masks which meant that the "*students had half their faces hidden behind the mask*" (P1). P2 resonated with this thought and added that online teaching was no better because the students would "*choose not to have their cameras on"*.

Most of the challenges that were raised in the previous workshop and interviews were repeated again, but this time with a strong emphasis on TSPCK related to SPK and 'What's difficult to teach' (WD). In particular, the data showed that the students seemed to lack adequate knowledge about chemical energetics and stoichiometry (SPK). Additionally, the students appeared to find chemical equilibrium abstract and difficult to understand, and that the language used in the LCP, such as position of equilibrium, incomprehensible.

I observed that the participants were developing a deep understanding of the topic and were getting attuned to the difficulties they had to address in their teaching. I then presented suggestions for teaching chemical equilibrium from the literature by Canpolat et al. (2006), Raviolo and Garritz (2009), Van Driel and Gräber (2002), and Xian and King (2019). They were really excited and went on to create a very good scheme of work that we used and refined in the next workshop. P1's reflection on this new scheme was: "*I am looking forward to trying the proposed model with next year's students*".

6.2.3 Third Workshop: Examining and testing

The goal of this workshop was to *examine* the new solution. This workshop was conducted face-to-face in the school laboratory. We had a couple of experiments set up to carry out some of the hands-on practical activities as a way of checking which ones worked well and which ones did not work so well. I observed that P2 really enjoyed hands-on practical activities in her teaching and was highly motivated in this workshop – she demonstrated three practical activities: hydration and rehydration of copper (II) sulfate; the effect of temperature on the $2NO_2(g) \rightleftharpoons N_2O_4(g)$ reaction; and the iron (III) chloride/potassium thiocyanate reaction that produces a blood red solution. I demonstrated the use of cobalt (II) chloride for showing the effect of changing the concentration of reactants or products, the use of wooden blocks to model dynamic equilibrium and moving water between containers to model equal forward and reverse rates. I explained that instead of the wooden blocks one could use coins or better still, small pebbles which are readily accessible resources (Asheela et al., 2021). Figure 6.3 below shows pictures of these activities.

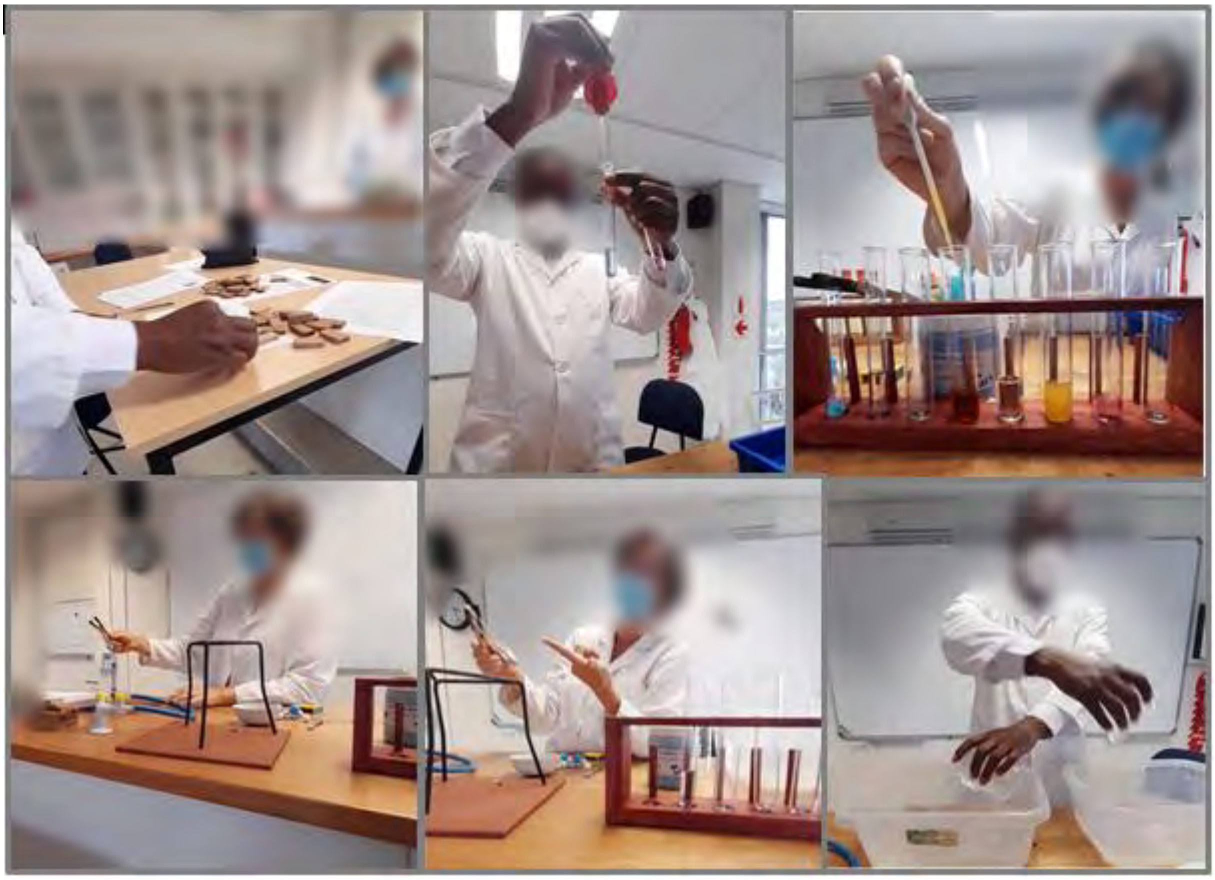

Figure 6.3: Pictures of demonstrations during the workshops

Numerous speaking turns are not discernible because most of the discussions were voices speaking over a demonstration and really only make sense to someone looking at the activities. In addition, in the excitement of the moment, the participants were interrupting one another and there are numerous incomplete sentences in the transcript.

However, the following speaking turns are worth sharing:

T	What problems can we find with this analogy? Besides the compartmentalisation of equilibrium, I have examples of some misconceptions.
P2	I haven't taught at AS level and never taught Kp. So, for me it stops where I'm saying the rate of the forward is equal to the rate of the backward. Then when you now will say you use half going this way but for this one only a quarter, but for me, I'm reading that there's different rates.
T	More of the rate constant, it's a bit of a tricky one.
P2	So, from rate to rate constants, I think we need to scaffold it carefully as well.
T	Rate and rate constants, the concept is a little bit difficult.
P2	Even when you go back with your water bucket analogy you used different sizes. That I would interpret as they are different rates but if you want, as I said, to use the same rate you will … you get to this as well.
T	What we are pushing for is that … because if you use the same size then they will have the same volume for both sides then it also adds to that misconception that equilibrium is when the concentrations are the same. So, that's the one we were trying to avoid – having equal numbers and to have different numbers but still have the rate being the same.

These speaking turns clearly show that the workshops provided an environment for sharing ideas and asking questions about concepts one was not well-versed in. There were a few more similar episodes and I have highlighted them in Appendix X.

On the other hand, the participants' reflective journals seemed to have rich information, explicitly showed the participants excitement in the process and their appreciation for the learning opportunities that the workshop presented. However, they anticipated some challenges for their specific classes and thought of ways to modify the activities. For instance, P1 decided she will "*bring a paper punch from home and punch red and black circles … for this kind of demonstration*". Thus, the participants continuously updated the model as it developed, "in line with the theory of expansive learning" (Morselli, 2019, p. 78). In addition, it appears as if the participants were making progress with regards to understanding of the issues under discussion. For instance, P1 opined that "*no analogy is perfect"* which illustrates that she understood that the use of analogies has shortcomings, an important concept that the participants were required to appreciate.

However, not everything was positive. As a case in point, referring to checking SPK, P2 worried that *"giving a formal assessment at the start could backfire as you might be shocked on how little students internalised"* and may force her to reteach the previous topics. Well, this would exactly be the purpose of the assessment and therefore this vocalisation of her worries surfaced a misconception about teaching that we would have never known she espoused. She was also concerned about the budget limitations insisting that she felt it was important for students "*to be allowed to execute hands-on practical activities".*

There was some display of emotion in the reflections by P2 in describing her frustrations with the use of practical activities in the context that the laboratory was a shared resource and would not support everyone using hands-on practical activities in their teaching. P1 resonated with this and was the opinion that there is "*not enough laboratory space or time for all science classes*". For P2, the use of hands-on practical activities would give the laboratory assistant extra work particularly in instances when a teacher has to "*rush off to the next class without ensuring the students pack up properly*". This showed me that the participants were invested in the process and in line with this type of intervention workshop (Morselli, 2019).

With regard to the new model, there was some exhibition of worry. In particular, P1 was concerned that it might not be permitted by the school principal, who may insist that teaching is "*completed as set out in the scheme of work from the regional office"*. However, P2 was so impressed with the new model generated for teaching reversible reactions and was not preoccupied with this possible resistance. In fact, she was inspired to find "*how we can teach the Mathematics*" noting that "*basic fractions are not well understood*".

6.2.4 Implementation: No workshop

No workshop was conducted for the *implementation* learning action of the expansive cycle. Instead, the responsibility for this learning action was transferred to the participants and they had to do it by themselves. This approach was not unprecedented; in fact, as mentioned earlier, the responsibility for this learning action in formative interventions resides with the participants (Morselli, 2019).

The original plan for the implementation was to have the participants teach their classes using the new model during their usual teaching sequences as dictated by the syllabus (and the changes they would apply according to the new model). However, this plan was changed slightly; instead of teaching a 40-minute lesson the participants planned a 40-minute lesson and reflected on the plan and the planning process. Thus, from enacted PCK, the focus changed to planned PCK (plPCK). The change arose because when the time to teach arrived, the participants' students where not learning chemical equilibrium. Again, this is not original; Makhechane and Mavhunga (2021) used a similar approach in their study.

The lesson plans produced by the participants were very impressive. In particular, P1 made a genuine attempt to use the newly laid terminology on PCK in making notes of the lesson (see the vignette below).

SPK : previous topics on stoichiometry, energetics, gas laws & reaction kinetics, assessed in prior tests.
: previous day's lesson introduced the idea of reversible reactions as a concept
: $CuSO_{4(s)} + 5H_2O\,(l) \rightleftharpoons CuSO_4.5H_2O$ was previously explained & demonstrated.

WD : Bear in mind that this topic is difficult to grasp & not easy to see. I aim to visually help them to conceptulise the ideas.

CS : The basics of reversible systems & equilibrium is taught before bringing in calculations & Le Chatelier's Principal notes

Interestingly, P1 provided significant details about the representations that she chose to use for her lesson. Conversely, P2 simply stated the activities to be carried out. It is important to note that P1 needed clarification on these activities during the previous workshops.

Both participants' lesson plans explicitly demonstrated that they were generated following the five components of TSPCK. The annotated lesson plans are in Appendix X. For instance, it was clear that students prior knowledge (SPK) was considered. On this point, P2 planned to start the lesson by reminding "*them* [the students] *of what was observed … in the previous lesson*" and P1 planned to begin her lesson by checking the SPK using a well-known reversible physical change: evaporation and condensation of water. The logical sequencing of the concepts, that is curricular saliency (CS), was also unambiguously articulated in the plan. In this regard, P1 split her lesson into parts: Part 1 to Part 4; P2 used the terms such as 'introduction' and 'homework' to show at which point certain concepts were presented.

The participants relied heavily on representations (R), that is, demonstrations, analogies, and hands-on practical activities for their planned teaching. P1 planned to use LEGO, copper (II) sulfate, and the 'treadmill' analogy and also planned to ask students to come up with their own. P2 also planned to use copper (II) sulfate and burning just a piece of paper demonstrating her acuity in making use of readily accessible resources (Asheela et al., 2021). In addition, she planned to ask the students to heat the copper (II) sulfate themselves to understand the ideas better as well as *"to build their confidence in their lab skills, such as heating gently, lighting the burner, where to attach the test tube holder*".

The participants' reflections were very positive, in my view, the complaints changed from "*I do not know what representation to use during interviews"*, to *"how do you use the treadmill to show a reversible"* and now to "*there are so many analogies to draw from*" (P1). I was also impressed by how they owned the new model and even addressed the challenges they could still see in the model. In this regard, P1 said that "*although we have come up with a proposed work scheme, exactly what to cover or leave out in each lesson was tricky to decide upon*". P2 concurred that there will be problems such as "*the high demand on the laboratories"* but was quick to add that "*there might* [be a] *need* [for] *negotiations with colleagues*".

6.2.5 Final workshop: Reflecting

This workshop was aimed at *reflecting* on the new model as well as the entire process of creating the new model. In addition, in the workshop we looked at *consolidating* and *generalising* the new model. In other words, in this workshop we looked at whether the new model had addressed the challenges we set out to solve, at quaternary contradictions between "the main activity and the interconnected activity systems" (Morselli, 2019, p. 55), and produced a finalised document of the new model. I observed that the participants were not as enthusiastic about this workshop as they were in the previous workshops, which really dealt with the skills they needed to teach. In this regard, issues relating to their time and how the workshops added to an increase in their work emerged. In this regard, P2 reflected that time constraints are unfortunately a sign of our times, and it was hard to fit in the workshops. Yamagata-Lynch and Haudenschild (2009) reported this problem in professional development programmes and referred to the extra work the teachers have to do as a "burden". In spite of this, the participants "*found a lot of value in the sharing of experiences with co-teachers*" (P2) and enjoyed being "*part of the study and help come up with a scheme of work as a team"* (P1) on how best to teach chemical equilibrium. P1 singled out the third workshop, in which we did the hands-on practical activities as "*extremely helpful".*

In the reflections, the participants took note of the challenges we faced with regard to undertaking the workshops. On this point, P2 noted that "*it was a pity that some teachers could not attend all the time".* P1 concurred with this and averred that this was *"due to external factors beyond our control".* In addition, they also took note of the challenges that might arise when we implemented this new scheme of work (see Appendix XI). On this matter, P1 could foresee "*afternoon sessions since laboratories were busy with full classes*" and took note "*that this may cause conflict with colleagues*". This point resonates with Yamagata-Lynch and Haudenschild's (2009) findings that new programmes tend to affect how the old ones are conducted. P2 took exception to this point and averred that if *"teachers are well trained they can even 'bring the laboratory to the classroom'"*, that is, the teachers do not necessarily have to be in the laboratory for all hands-on practical activities and some can be done in the classroom or even outside in the open air.

6.3 Chapter Summary

In this chapter, I presented, analysed, and discussed the data that I generated from the workshops, including the observations that I made and the participants' reflective journaling. These data sets were generated to answer my research question 2: *"How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 teachers' PCK for mediating learning of chemical equilibrium?"* The data revealed numerous challenges that teachers faced in teaching chemical equilibrium that were not apparent in the interviews.

In addition, the workshops provided the participants an opportunity to engage and learn from each other without being worried about being ridiculed or looked down upon. In fact, they could ask about concepts that were not under discussion, such as how to take care of laboratory equipment. The workshops also revealed that this approach promoted ownership of the model generated developed, and the practitioners were inclined to find solutions to any problems that arose during its implementation.

With resonance to other professional development programmes, the participants displayed fatigue. However, this only became apparent in the final workshop where we reflected on the process and tried to anticipate possible problems with the new model. Here, the participants were not convinced these reflections were worth the extra burden the workshops placed on their work. In the following chapter, I present a summary of my findings, a conclusion drawn from these results and my reflections as the researcher.

CHAPTER SEVEN: SUMMARY OF FINDINGS, RECOMMENDATIONS & CONCLUSION

7.1 Introduction

In the previous two chapters, I discussed the results obtained from the semi-structured interviews (Chapter Five) and through intervention workshops (Chapter Six). In this chapter, I present a summary of the findings, recommendations, and conclusion.

The main goal of this study was to investigate how implementing a formative intervention facilitates (or not) the development of teachers' skills and competencies for teaching chemical equilibrium. It was premised on the hypotheses that teachers lack adequate PCK for mediating learning of chemical equilibrium (García-Lopera et al., 2014) and that current TPD programmes "do not always address teachers' needs" (Pretorius et al., 2014, p. 553).

For this process, it was important to establish from the participants' perspectives if there was a need for such an intervention. Therefore, I began by investigating the challenges that the teachers faced by means of semi-structured interviews as well as taking note of the issues brought up in the *questioning* phase of the first intervention workshop. Thereafter, we held the intervention workshops. This study had two research questions:

- *What are the challenges that Grade 12 Chemistry teachers face in mediating learning of chemical equilibrium and what remedial strategies do they employ in their classrooms?*
- *How does the implementation of a formative intervention facilitate (or not) the development of Grade 12 teachers' PCK for mediating learning of chemical equilibrium?*

In the next sections I present a summary of the findings.

7.2 Summary of Findings

I present my summary of findings in relation to my research questions.

7.2.1 Research question 1

The first research question was answered predominantly using the data from semi-structured interviews. As detailed in Chapter Five, the challenges were placed into two categories: (i) students' difficulties in learning chemical equilibrium and (ii) teachers' instructional problems.

The major problems reported by the participants that I placed in the first category were: (a) chemical equilibrium concepts are abstract; (b) lack of the requisite prior knowledge; (c) language; (d) student misconception, and (e) mathematics skills. That is, the students were failing to access the content because they did not have adequate prior knowledge to learn chemical equilibrium (Mavhunga & Rollnick, 2013). However, in some instances the students did have some knowledge about the topic, but this knowledge comprised of alternative conceptions, which Morales (2017) reasoned students find very difficult to relinquish unless they are addressed directly by the teachers. Additionally, the students could not access the content, which they found difficult to understand due to its abstract nature, because they understand neither the language used, nor the mathematics involved.

In the second category of teachers' challenges were the teachers' instructional difficulties as follows: (a) time constraints; (b) limited PCK, lack of SMK; (c) lack of resources for teaching; (d) failure to link concepts to the students' lived experiences, and (e) teacher dilemma and lack of consensus on sequencing. In other words, the teachers could not deliver the lessons in a manner that would help the students understand the Science because they lacked the resources and were constrained in terms of time. In addition, the teachers were not adequately equipped with the skills and knowledge for teaching the topic. Moreover, the sequencing in the syllabus created a dilemma for the teachers in that teachers would want to teach some topics, such as reaction kinetics, before chemical equilibrium because it would provide the students with some of the requisite prior knowledge (Mavhunga & Rollnick, 2013). However, these topics are placed in the syllabus after chemical equilibrium and teaching them first may disadvantage their students in regional examinations, which are set following the syllabus sequencing.

CHAT's foraging prowess came to the fore in the first workshop as it helped surface or unearth more teachers' challenges that could not be discovered through simple questioning. The key challenges were: (i) teaching very large classes and the classroom management problems in relation to that, particularly in the context of hands-on practical activities and demonstrations; (ii) difficulty in giving formative assessments, such as homework because students avoid doing assessments that are not graded; (iii) the difficulty in preparing laboratory sessions and the lack of knowledge on how to run such sessions, and (iv) the misconceptions that arise because younger students are required to learn chemical equilibrium in the new curriculum.

The participants expressed that they employed, or had a desire to employ, strategies in their teaching, beyond 'chalk-and-talk' to make the topic accessible to their students. Here are the instructional strategies that emerged from the data: (a) the use of representations; (b) the use of YouTube videos and other online resources; (c) relating chemical equilibrium concepts to students' real-life experiences, and (d) use of past examination questions during the instruction.

Regarding the use of representations, the participants indicated that there were instances in their teaching where they did not employ them. They explained it was because they did not know any representations that they could use for this topic, especially ones that would be doable within the time allotted considering their class sizes and available resources. I also observed that in instances where the participants used analogies, they did not seem to know Raviolo and Garritz's (2008) findings that analogies can cause misconceptions and that in their teaching, there is need to explicitly elucidate where the analogue would differ from the concept being taught.

7.2.2 Research question 2

I selected the formative intervention as an approach for this study-cum-professional development project because I imagined that it addresses some of the problems bedevilling TPD. The main problem, discussed in detail in Chapter Two, is that TPD is seen as "irrelevant to the real problems of classroom practice" (Lieberman & Pointer-Mace, 2008, p. 226) and fails "to address the teachers' needs" (Pretorius et al., 2014, p. 553) because the facilitators have "their own commitments and accountabilities" and may ignore the teachers' contexts (Mbekwa & Julie, 2019, p. 16).

Thus, in this interventionist study the endeavour was to address the teachers' challenges and how they experienced them in their classrooms, and my role as the researcher was simply to provoke and support the process of transformation owned by the participants (Sannino et al., 2016). In that regard, the workshops began with *questioning* and *analysis*, in which I presented the participants with mirror data; namely: (i) their responses to the interviews and (ii) selected journal articles on teaching and learning chemical equilibrium. Initially, there were strong disagreements among the participants with regard to whether there was a problem that needed to be solved. However, the mirror data and the in-depth discussions among the participants led to a consensus that indeed, chemical equilibrium was difficult for the students, and they really had a problem.

The participants encountered a few 'aha moments' in which they realised that they were not aware of some of the difficulties that their students faced in learning chemical equilibrium. In fact, there were epiphanies in which they realised that they were not well versed with certain issues in chemical equilibrium, such as the scientific inadequacies of LCP (Cheung, 2009). For the participants who had acknowledged the need for this intervention from the onset, these initial workshop discussions and mirror data helped them to fully reflect on their teaching. This also led to revelations about more grey areas in their teaching and enabled them to express these areas without fear of judgement.

Once the participants' needs had been established and well-articulated to an extent where everyone had a common understanding of the problem, we embarked on a mission to find a collective solution – but, we had to go through another cycle of disagreements. This time the participants initially would not agree that there was a need for a common solution, that each person could teach any way they wanted. Again, the CHAT-driven process reigned supreme, and the participants were able to convince one another of the need for collective transformation. It is at this point that collective transformative agency, in which the participants "break away from the given frame of action to implement a new model" (Morselli, 2019, p. 38) began to become apparent. In other words, the participants began to realise the need for cooperative effort and that they were to design a new model to address their collective problems. It is interesting to note that the participant who was most vocal against a common scheme of work is the one who was in the forefront of preparing it.

During the entire process of designing, examining, and refining the new model, the participants were attuned to the possible challenges they would encounter during implementation and continuously updated the model. This shows that there was a sense of ownership for the new model. Thus, the participants were attuned to adjusting the model should they encounter any difficulties in their teaching, rather than discard it and revert to their old ineffective methods.

In terms of the development of the teachers' PCK, the results explicitly showed that there was definitely a marked improvement in the teachers' pedagogical or instructional skills. The participants transitioned from a position of lack of knowledge, where they confessed ignorance of usable analogies or demonstrations for teaching chemical equilibrium and how to relate the concepts in this topic to the students' existential experiences, to a position in which they could prepare a lesson plan that tried to incorporate all five components of TSPCK. As a case in point, please look at P1's notes in Figure 6.2. The lesson plans the participants prepared were impressive and attempted to capture all the five components of TSPCK (see Appendix X).

At the time of the interviews as well as the *questioning* stage of the intervention, the teachers seemed to have very weak TSPCK. That is, there was minimum evidence of any of the five TSPCK components in the teachers' strategies and no evidence for any links between the components. After the workshops, however, as can be seen in the prepared lesson plans (plPCK), the participants had very strong TSPCK in which all five TSPCK components were considered and the links between them made in the teaching!

7.3 Recommendations

The main focus of this study was to investigate the efficacy of formative interventions as an approach for TPD. The results revealed that this approach is ideal; the research participants were productively engaged in the activities, were free to express themselves, could voice their concerns, and most importantly could seek guidance and assistance without being self-conscious. Therefore, I recommend the formative intervention methodology as an alternative approach for TPD. In addition to the above argument, there are three other points to support my recommendation.

First, the approach is characterised by a bottom-up approach, which tends to address some of the challenges associated with current TPD programmes, wherein facilitators impose methods and ideas on the teachers which they simply discard when they return to their duty stations.

Morselli (2019, p. 126) cohered with this point and argued that a top-down approach results in resistance from the teachers while a bottom-up approach, such as formative interventions, enable the participants to tackle their challenges collectively.

A second important aspect of the formative intervention is that it generates agency in the teachers, as espoused by Sannino et al. (2016). They own the new model and will be attuned to face and address any challenges that emerge.

A third aspect of the formative intervention is that no one knows what is to be learnt during the process. Everybody attends the workshops to learn and thus all participants will be free to express themselves without fear of ridicule.

7.4 Reflections

This interventionist study, known for its appetite for significant human interaction, was carried out during the difficult time of Covid-19 when it was mandatory that we maintained social distancing. Thus, I could not to carry out the formative intervention workshops exactly as suggested in the literature; I had to make significant alterations. Here are my reflections on the activities, giving some detail of the things that went well, those that did not go so well, and the times I was left frustrated.

I completed my research proposal in early August and was ready to continue with my study. However, as is procedure in postgraduate study, I had to wait for ethics clearance from the university and be granted permission by the institutional gatekeepers, in particular the principals of the schools where I was drawing the participants and the Director of Education for the Khomas region. The process to obtain the ethical clearance took some five weeks, and I had to wait a further six weeks before I had all the gatekeepers' letters. I found this somewhat frustrating because I worried that I would struggle to get the participants to take part in the workshops in November. However, I understood that all these institutions were also bearing the brunt of Covid-19 which was complicating the ways of doing work.

After I had obtained permission to conduct this study, I negotiated with the participants to interview them. The interviewing was smooth, enjoyable, and rewarding. Initially, I was nervous to do the interviews; interviews are a nerve-wracking experience and I worried that the participants would be too busy to be interviewed in November. I was pleasantly surprised that all the participants were very cooperative and helped to put me at ease during the interviews. I conducted the interviews over the phone, and I used a phone app to record the conversations, of course with the permission of the participants. The data sets that I generated were very rich and I think the participants were not overly inconvenienced. I transcribed all the interview data manually, which I realised was a tedious process. Nonetheless, I was afforded an opportunity to internalise my data.

The workshops were not as straight forward; we needed all the participants to be available at the same time. This was impossible in November because learners were writing external and internal examinations, and teachers were busy marking or preparing report cards. I negotiated with the participants and managed to conduct two workshops via Zoom. Unfortunately, one of the participants, P4, could not attend the workshops because, being head of the Science department in her school, she had extra responsibilities at that time of the year.

Zoom was a convenient platform which permitted the participants to join from the comfort of their homes. In addition, we did not have to worry about Covid-19 regulations. However, Zoom had the inherent problem that we did not have writing surfaces as suggested for the workshops in literature. Therefore, I had to prepare and distribute the material needed such as stationery and mirror data to the participants well ahead of time. It worked! The participants submitted their writings together with their reflections.

Similar to interview data, I began transcribing the data manually but realised that I had too much data and I would need a long time to finish the transcribing. For instance, the video for the first workshop was 80 minutes long. Accordingly, I sought an app to assist with the transcription of the videos. It was at this point that I discovered Google’s voice typing function which I found invaluable in compiling my thesis!

7.5 Limitations

The main limitation for this study was the unavailability of the research participants. As articulated above, I received all the paperwork to conduct the study at the time of year when teachers were very busy. Thus, P4 could not attend any of the workshops due to work commitments. In the new year, another participant, P3, could not attend due to marking external examinations until the end of January. The delay in the marking was due to leakage of the national examination papers to the public and the examinations having to be rewritten.

Although I attest that the data generated were still rich, I believe it would have been richer if I had more participants that were available for the workshops.

7.6 Future Study

I believe the study is part of a sequence of studies that were started by Chani et al. (2018) on the teaching and learning of chemical equilibrium in Namibia. I think this study has exposed a few areas to be investigated. Firstly, this study chose to address the main contradiction as chosen by the participants, but the other identified teacher dilemmas were side-lined; as a case in point, the problem that the topic is now being taught to younger students, who are failing to cope with the abstract concepts of chemical equilibrium and are developing misconceptions that they find difficult to relinquish in subsequent studies.

Secondly, we realised or established that it was difficult to relate the topic to the real-life experiences of the learners as reiterated by Gwekwerere (2016) and others. We did not do much in this regard and I think this is an area that needs extensive research in future.

Thirdly, the participants found some of the simulations difficult to understand, such as the computer simulations that are available for free on the internet. The participants seemed unsure of how to use them in the classroom or to appropriate them for use in their online classes. I believe a paper should be written that puts together some of these simulations in one place and explicitly explains how each can be used to demonstrate reversibility and incomplete chemical conversions, dynamic equilibrium, and LCP.

7.7 Conclusion

This formative interventionist research project was "aimed at merging practical transformation efforts and rigorous research" (Sannino et al., 2016, p. 2). That is, one of main aims was a desire for the participants to gain something significant.

The study revealed, as hypothesised at the onset, that teachers encountered serious challenges when teaching chemical equilibrium, which I placed into two categories. These challenges were: (i) students' difficulties in learning chemical equilibrium and (ii) teachers' instructional problems.

In their defence, the participants did use a number of strategies to try to make the topic accessible to their students. However, they seemed oblivious to the fact that some of these strategies, especially analogies, could be the reason why their learners were developing alternative conceptions on the key concepts in chemical equilibrium.

The intervention workshops enabled the participants to model a new way of teaching chemical equilibrium that would address the participants' most pressing challenges. They used their newly acquired skills to prepare a very impressive lesson plan and were guided by a scheme of work (see Appendix XI) that they developed as well as TSPCK. The lesson plan showed a marked improvement in the participants' teaching skills for mediating learning of chemical equilibrium. Not only that, the participants seemed to enjoy the entire TPD process!

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APPENDICES

Appendix I: Ethical Clearance

RHODES UNIVERSITY
Where leaders learn

Rhodes University, Education Faculty
Research Ethics Committee
PO Box 94, Makhanda, 6140, South Africa
Tel: +27 (0) 46 603 8393
Fax: +27 (0) 46 603 8028
email: e.rosenberg@ru.ac.za

https://www.ru.ac.za/researchgateway/ethics/

21/09/2021

Prof Kenneth Ngcoza

Education Department

K.Ngcoza@ru.ac.za

Dear Prof Kenneth Ngcoza and Tasara Manamike

Your application The development of teachers' pedagogical content knowledge (PCK) in the mediation of chemical equilibrium: A formative interventionist study, 2021-5154-6301has been reviewed by the Education Faculty Research Ethics Committee [EF-REC].

Ethics approval has been granted pending the required Permission Letters being obtained from the organisation(s) listed in your application:

Regional Director: Khomas Region

Principals of participating schools

Your application can be downloaded as a PDF version and forwarded with your permission letter request. Please refer to the Applicant User Guide for how to do so.

Please forward the required permission letter/s, once received, to the EF-REC Chair (E.Rosenberg@ru.ac.za) and to the Education Research Ethics Coordinators (s.mangele@ru.ac.za) in order for your approval to be finalised.

Sincerely

ERosenberg

Professor Eureta Rosenberg

Chair: Education Faculty Research Ethics Committee

Appendix II: Permission Letter Regional Director

REPUBLIC OF NAMIBIA

KHOMAS REGIONAL COUNCIL

DIRECTORATE OF EDUCATION, ARTS AND CULTURE

Tel: [09 264 61] 293 4356
Fax: [09 264 61] 231 367/248 251

Private Bag 13236
WINDHOEK

26 October 2021

P. O. Box 94
Mashonga

For Attention: Mr. Tawira Munamike

REQUEST FOR PERMISSION TO CONDUCT RESEARCH INTERVIEWS WITH SELECTED SECONDARY SCHOOLS IN WINDHOEK, KHOMAS REGION

Your letter dated 22 October 2021 on the above topic is hereby acknowledged.

Permission is hereby granted to you to conduct research on "The Development of Teachers Pedagogical Content Knowledge (PCK) [illegible] of Chemical Equilibrium: A formative Interventional Study" at [illegible] in Khomas Region under the following conditions:

- The Principal of the selected school to be visited must be contacted in advance and agreement should be reached between you and the Principal.
- The school programme should not be interrupted.
- The teachers and students who will take part in this exercise will do so voluntarily.
- The Directorate of Education, Arts and Culture should be provided with a copy of your thesis/ findings.

We wish you success in your research.

Yours sincerely

Paulus D. Nghikembua
Director of Education, Arts and Culture

Page 1 of 1

Appendix III(a): Permission Letter to the Principals

October 6, 2021

Dear Sir/Madam,

RE: Grant of Permission to Conduct a Research Project with Teachers at

I hereby approve your request to conduct a research study at our College with two Science teachers for your current Master's degree in Science Education at Rhodes University.

Once you have selected the teachers and obtained their agreement to participate in your research, please inform their Heads of Department and me.

I would be interested in your research findings once the project is completed.

Regards,

0 6 OCT 2021

WINDHOEK REGION

Appendix III(b): Permission Letter To The Principals

27 September 2021

Dear Mr Manamike

Request [redacted]permission to conduct a research project with teachers at
[redacted]

I hereby approve your request to conduct a research study at the College with two Science teachers for your current Master's degree in Science Education at Rhodes University.

I would be interested in your research findings once the project is completed.

Once you have selected the teachers and obtained their agreement to participate in your research, please inform their Head's of Subject and me.

Regards

[redacted]
Principal

Appendix IV: Letter of Consent to Teachers (participants)

RHODES UNIVERSITY
Where leaders learn

EDUCATION DEPARTMENT
Tel: +27 (0) 46 603 8383
Fax: +27 (0) 46 622 8028
P.O. Box 94, Makhanda

06 November 2021

Dear esteemed colleague

Subject: Invitation to participate in my research project

My name is Tasara Manamike and I am a senior chemistry teacher at St Paul's College. I am currently enrolled part time at Rhodes University, Makhanda, South Africa for a Master of Education (MEd) degree in Science education. I write to humbly invite you to take part in my study. I envisage collecting the data for this project for about four to five weeks through semi-structured interviews, participatory observations and journal reflections, and will not involve my attending any of your classrooms or have any direct interaction with your learners.

The research is aimed at improving our (Chemistry teachers) knowledge for mediating the learning of chemical equilibrium as well as to investigate the efficacy of formative intervention methodology for carrying out professional development. Thus, I wish to conduct weekly 2-hour intervention workshops over a period of four weeks in the afternoon after all classes and I intend to video record them. The data collected will be used for reporting in my thesis and possible publications.

This study was approved by the Rhodes University Ethics committee (please find attached the approval letter) and will be conducted according to their guidelines. Prodigious effort will be taken to protect confidentiality and ensure anonymity, where necessary, of all the participants involved. It is recognised, however, that since this is an interventionist study the anonymity of the participants might be a challenge. Nevertheless, I will ensure that your individual contributions will be kept anonymous. All the data that I will collect from you will be stored on password protected devices or kept under lock and key, if on paper.

I will make the research findings available to you should you desire them.

Yours sincerely

Tasara Manamike

If you require any further input or have further questions please contact either myself or my supervisor, Prof Kenneth Ngcoza:

	Tasara Manamike	**Prof. Kenneth Ngcoza**	**RU Ethics coordinator**
✉	tmanamyke@gmail.com	k.ngcoza.ru.ac.za	s.manqele@ru.ac.za
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Appendix V: Informed Consent Declaration

RHODES UNIVERSITY
Where leaders learn

EDUCATION DEPARTMENT
Tel: +27 (0) 46 603 8383
Fax: +27 (0) 46 622 8028
P.O. Box 94, Makhanda

RESEARCH PARTICIPANT INFORMED CONSENT LETTER (PARTICIPANT)

PROJECT TITLE: The development of teachers' pedagogical content knowledge (PCK) in the mediation of chemical equilibrium: A formative interventionist study

Tasara Manamike (19M9166), currently a Master's student at Rhodes University, has requested my permission to participate in the above-mentioned research project.

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

I am therefore aware that:

1. The purpose of this formative interventionist study is the development of chemistry teachers' pedagogical content knowledge (PCK) in the mediation of chemical equilibrium.

2. The intervention for this study will be composed of **four** two-hour long workshops. During the workshops, data will be gathered through; videotaping, participant observation, reflective journaling and document analysis. The workshops will be conducted at a place and time that is convenient to me and the other participants.

3. I will be interviewed individually and/or in a focus group interview format whereby all the COVID-19 protocols will be observed. Should the COVID-19 restrictions be in force, Google Meeting or Zoom or WhatsApp will be used with my permission. The interview will take approximately 30-45 minutes and will be audio recorded with my permission.

4. By participating in this research project, I will contribute to knowledge and understanding in the mediation of learning of the topic chemical equilibrium.

5. My participation is entirely voluntary and should I at any stage wish to withdraw from further participation, I may do so without any prejudice.

6. I understand that participating in this study is voluntary and that I will not be compensated for participating.

7. They may be risks associated with my participation in the project. I am therefore aware that of the following steps:

   a) All information shared in the group is strictly confidential and will not be used for purpose other than of the above mentioned research project;
   b) All the data collected will be kept in a locked cupboard and electronic data will be kept in a computer only accessible through a secure password.
   c) The researcher intends to publish the research findings in the form of a thesis towards a Master's degree in Science Education, and later present it in papers conferences or journal articles. However, confidentiality will be maintained.

8. Any further questions that I might have concerning the research or my participation will be answered by the Rhodes Master's student (tmanamyke@gmail.com) or the supervisor Professor Kenneth Mlungisi Ngcoza (k.ngcoza@ru.ac.za).

9. By signing this informed consent declaration, there are no legal implications.

10. A copy of this informed consent declaration will be kept in a safe place by the researcher.

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

I have not been coerced or pressurised in any way. I therefore voluntarily agree to participate in the above mentioned research project.

………………………………….. ………………………….

Participant's signature Witness

Date ………………….. Date …………………..

Rhodes University, Research Office, Ethics

Ethics Coordinator: ethics-committee@ru.ac.za

T: +27 (0) 46 603 7335 F: +27 (0) 82 739 4378

Room 220, Main Admin Building, Drostdy Road, Makhanda, 6139

Appendix VI: Interview Schedule

Good afternoon colleague, thank you so much for giving up some of your valuable time to speak to me this morning. As explained in the letter that I sent to you detailing this study, I would like to understand the challenges that you face in mediating learning of chemical equilibrium.

I would like to start by asking you your general views about chemical equilibrium, in terms of its importance in the school Chemistry curriculum.

Q 1: What topics do you think your students should understand well to properly learn chemical equilibrium? *Could you please tell me how do you elicit your students' prior knowledge to mediate learning of chemical equilibrium?*

Q 2: Could you please tell me the difficulties that your students encounter when learning chemical equilibrium?

Q 3: Could you please briefly describe the procedure of your lessons for (i) introducing the topic (ii) calculating Kc and (iii) explaining Le Chatelier's Principle? Which one do you teach first Kc or Le Chatelier's Principle?

Q 4: How well do your students cope with understanding Le Chatelier's Principle.

Q 5: What are your thoughts regarding the shortcomings (if any) of Le Chatelier's Principle?

Q 6: What instructional strategies do you use to make your students understand chemical equilibrium? *For instance, one can use analogies or assessment or hands – on practical activities.*

Q 7: What experiments or demonstrations, if any, do you use in mediating learning of chemical equilibrium? *If none, why? Do they help and in what way?*

Q 8: In general, what challenges do you face in mediating learning of chemical equilibrium?

Appendix VII: Questions/Prompts for Reflective Journaling

Workshop #1

Learning Action: Questioning

What were your views, after looking at the mirror materials, about the problems in teaching chemical equilibrium?

Which of those views were strongly opposed by colleagues and yet you still feel strongly about them?

Do you think we can find a single solution that can overcome these opposing ideas?

Learning Action: Analysis

Which disturbance(s), i.e. negative deviation from plan that jeopardises learning that were identified in the workshop do you think really affects your teaching?

Do you agree with the identified major contradiction? If not, can you describe what you consider the main contradiction?

Workshop #2

Learning Action: Modelling

Where your ideas of the new model considered? If they were not, were you satisfied with the ideas considered and how does this affect your willingness to make further contributions in the workshops?

Workshop #3

Learning Action: Examining and Testing

What problems do you think were overlooked associated with implementing the new model (e.g. the new strategy requires much more time).

Learning Action: Implementation (NO WORKSHOP)

What problems did you encounter in implementing the new model? (e.g. in teaching previously we needed gas jars, but the new technique requires gas jars as well as beakers). How did you resolve them?

Workshop #4

Learning Action: Reflecting

What problems emerged between your classroom teaching and other activities as a result of implementing new teaching strategies? Focus on the problems that you think will persist in the future and can cause tension with colleagues from other departments.

Learning Action: Consolidating and generalising

Write your scheme-cum-plan for the topic; or a lesson plan for one lesson; or a scheme of work for the topic that other teachers who were not part of these workshops can employ in their teaching. Provide some justifications for any differences between the ones generated in the workshop.

Appendix VIII: TSPCK Translation Device (Adapted from Mavhunga et al., 2016, pp. 312-313)

COMPONENTS	**DESCRIPTION**	**SPK⁻⁻ (Weak)**	**SPK⁻ (Moderate)**	**SPK⁺ (Strong)**	**SPK⁺⁺ (V. strong)**
SPK	Includes what was taught in the previous grade or lesson. Includes common learner misconceptions known in a topic. This also includes everyday knowledge from home and community	No identification or no acknowledgement or no consideration of learners' prior knowledge or misconceptions; no attempt to address the learners' misconceptions.	Identifies prior knowledge or misconceptions; provides standardised definition as a means to counteract the misconception; no evidence of drawing on other TSPCK.	Identifies prior knowledge or misconceptions; provides standardised knowledge as definition; expands and re-phrases explanations using one other component of TSPCK interactively.	Identifies prior knowledge or misconceptions; provides standardised knowledge as definition; expands and re-phrases explanation correctly; confronts misconceptions or confirms accurate understanding drawing on two or more other components of TSPCK interactively.
Comments:					
		CS⁻⁻ (Weak)	**CS⁻ (Moderate)**	**CS⁺ (Strong)**	**CS⁺⁺ (V. strong)**

Curriculum saliency (CS)	Refers to the identification of the most important meaning of major concepts of a topic, without which understanding of the topic would be difficult for learners. It also includes the knowledge to logically sequence the learning and knowledge of pre-concepts needed prior to teaching a topic	Identified concepts are a mix of Big ideas and subordinate ideas; identified pre-concepts are far from topic; sequencing no value due to mixed concepts; reasons given are generic benefit of education.	Identifies at least 3 Big ideas; not all 3 Big ideas and subordinate ideas identified; identified pre-concepts are far from the current topic; suggested sequencing has one or two illogical placing of Big ideas; reasons exclude conceptual considerations and show no evidence of drawing on other TSPCK components.	Identifies at least 3 Big ideas; subordinate concepts correctly identified for all Big ideas; identifies pre-concepts relevant to the topic; provides logical sequence; reasons given for importance of the topic include reference to conceptual scaffolding/sequential development draws on other TSPCK components, e.g., what makes topic difficult.	Identifies at least 3 Big ideas; subordinate concepts correctly identified for all Big ideas with explanatory notes; identifies pre-concepts relevant to the topic and explanatory notes given; provides logical sequence of all Big ideas and with logical reasons; reasons given for importance of the topic include reference to conceptual scaffolding/sequential development draws on other TSPCK components,

					e.g., what makes topic difficult.
Comments:					
		WD⁻⁻ (Weak)	**WD⁻ (Moderate)**	**WD⁺ (Strong)**	**WD⁺⁺ (V. strong)**
What is Difficult to Understand (WD)	Refers to gatekeeping concepts which are difficult to understand often because they cause conflict with previously established understanding	Identifies broad topics without reason and specifying the actual subordinate sub-concepts that are problematic.	Identifies specific concepts but provides broad generic reasons such as abstract concepts.	Identifies specific concepts leading to learner difficulty; reasons given relate to one other TSPCK component.	Identifies specific concepts with reasons linking to specific gate keeping concepts and to TSPCK components such as prior knowledge and aspects of CS.
Comments:					
		RP⁻⁻ (Weak)	**RP⁻ (Moderate)**	**RP⁺ (Strong)**	**RP⁺⁺ (V. strong)**
Representations (R)	Refers to a combination of representations at macro, symbol and	Limited to use of only macroscopic representation (analogies, demos etc.)	Use of macroscopic representation (analogies, demos etc.) and use of	Use of macroscopic representation (analogies, demos etc.) and use of	Use of macroscopic or symbolic representation with sub-microscopic

	sub-microscopic levels that may be employed to support an explanation	with no explanation of specific links to the concepts represented.	scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.	scientific symbolic representation with explanatory notes linking the two representations to the aspect(s) of the concept being explained; use of above combination of representations with reference to one other TSPCK components, e.g., prior knowledge.	representation to enforce a specific aspect; Explicit link with other components of TSPCK, e.g., emphasis on core aspect of CK demonstrated in the representations and learner prior knowledge.
Comments:					
		CST^{--} (Weak)	**CST^{-} (Moderate)**	**CST^{+} (Strong)**	**CST^{++} (Very strong)**
Conceptual Teaching Strategies (CST)	Refers to teaching strategies derived from the consideration	No evidence of acknowledgement of learner prior knowledge and	Acknowledges learner misconceptions verbally with no corresponding	Considers confirmation/confrontation of learner prior knowledge and/or	Considers learner prior knowledge and evidence of confrontation

	s made from the other four components and excludes general teaching methodologies	misconceptions; lacks aspects of curriculum saliency; use of representations limited to macroscopic or symbolic scientific symbolic representation.	confrontation strategy; lacks aspects of curriculum saliency; use of macroscopic or symbolic representation with no linking explanatory notes.	misconceptions; considers at least one aspect related to curriculum saliency, e.g., sequencing or what not to discuss yet or emphasis of important aspects; uses at least two different levels of representation to enable understanding.	of misconceptions; considers at least two aspect related to curriculum saliency, e.g., sequencing or what not to discuss yet or emphasis of important aspects; uses either the macroscopic or symbolic representation with sub-microscopic representation to enable understanding.

Appendix IX: Interview Transcripts

Question 1

T. I would like to start by asking you your general views about chemical equilibrium in terms of its importance in the school curriculum.

P1. I think it's an important concept in chemistry and I feel it links different sections together, but it's quite difficult for the students to understand.

T. You think it's difficult to them? How do you think it compares to stoichiometry?

P1. Well that's the thing, I think to do equilibrium properly you need to understand a lot of different things and one of them I think is stoichiometry. □

T. Thank you so much for giving up your time to take part in this investigation. As I explained this basically is about understanding the challenges you face when teaching chemical equilibrium.

I will start by asking you your general views about chemical equilibrium in terms of its importance in the school chemistry curriculum.

P2. I think it is very valuable because I think it brings Chemistry into real life especially when you talk about processes, where it is brought to the student attention that there is real application of what we learn in class. □

T. Thank you so much for giving up your time. I am going to take about 15 minutes of your time

So I'll go straight into the matter. What are your general views about Chemical Equilibrium in terms of its importance in the chemistry syllabus?

P3. Which Chemical Equilibrium, you mean the topic Chemical Equilibrium?

T. Yes, the topic of Chemical Equilibrium in the chemistry syllabus.

P3. Is it in our syllabus?

T. Yes in the AS syllabus, the one that has Le Chatelier's Principle and Kc

P3. Oh that one. I think that topic was taught at the regional office but I taught it at [the old] higher level. This time around I just had to revise it with the students.

T. When you were teaching it at higher level how did you find it? Is it something that you feel is important for our syllabus?

P3. (hesitates) Let's just say that over the years I did it, studied it at university but I have never really thought of it because most of the time in teaching we always have to apply whatever we are teaching to everyday life, but for this particular topic, if you ask me how relevant it is on everyday life I would not be able to give you an answer. I think I need to read more about the topic. □

T. Thank you so much for giving up your time. Like I explained I just want to establish the challenges that we face in teaching chemical equilibrium and then we'll do workshops to find solutions on how best we can teach it.

T. I will start by asking you your general views about chemical equilibrium in terms of its importance to our school syllabus.

P4. Eeh… its importance? You are talking about Le Chatelier's Principle?

T. Yes the topic that has Le Chatelier's Principle

P4. I think the importance is on how you are able to study reactions. If you don't know what causes the effects on chemical reactions you may not fully understand them. You know in the syllabus for ordinary level, we just look at the rates of reaction but we don't look at what affects the reaction like temperature [and] pressure. That is why it is important to go to a deep concept like Le Chatelier's Principle so as to have a broader understanding of chemical reactions [and] how they occur. □

Question 2

T. What topics do you think students should understand well to properly learn chemical equilibrium? Could you please tell me how you elicit your students' prior knowledge to mediate learning of chemical equilibrium?

P1. Quite often, as I have taught before, I just ask them some questions of what they should know. For example with my grade 11, I would have done equilibrium in Chemistry in Grade 10. So we talk about what we would have done for that previous section and see what they can remember and start from there.

T. So you ask questions just in general without a test? It's just verbal?

P1. I think so. Yes. It's trying to assess, sort of, the general appearance to check whether they understood or not; not giving them a test.

T. So you mainly require some knowledge of chemical equilibrium as prior knowledge.

P1. Yes and follow up. For example the G10 would have done how to write and balance equations and for example you could have done a Haber process or Contact process and add equilibrium processes a bit.□

T. What topics do you think students should understand well to properly learn chemical equilibrium?

P2. I think they need to have a good understanding of energetics of a reaction. So they need to be familiar with the endothermic and exothermic reactions. They also need to have a good understanding of the rate of reaction concept as well. We usually place it in that order where we start with energetics, rate of reaction kinetics then chemical equilibrium.

T. How do you elicit your students' prior knowledge before you start teaching the topic?

P2. Since I say we kind of teach in that order, so you would have gotten an idea with regard to whether they have a sound understanding of energetics, so that will give you an indication. □

T. What do you think are the topics that your students should understand well to learn the chemical equilibrium?

P3. The fact that they have to find units, and my students struggle with that, then I would say Mathematics. I can't think of anything off-head but I'll let you know if I remember. We are also teaching the topic in 'O' level. There's a bit of introduction. I'm not just thinking of how the students are struggling and what prior knowledge they need.

T. Do you elicit any prior knowledge when teaching and how do you do it?

P3. I think I just start and as we go I see what they are struggling with and I explain.

T. So you do not ask any questions to check their prior knowledge?

P3. No. □

T. What topics do you think your students must understand well so that they can learn chemical equilibrium?

P4. This is a tough one. The number 1 problem I always have is that they struggle with writing equations, like writing and balancing equations in terms of how the products are related to the reactants.

T. So that is stoichiometry?

P4. Yes stoichiometry, number 1. Secondly, I would perhaps say chemistry has a lot of rules, even the type of reaction as to what happens: The reaction of this substance reacts with that substance. Students always struggle with that. Also knowing what affects the reaction for the formation of ammonia. They need to know that it is affected by pressure.

What I know is that if they do not understand the background of the reaction. Like what am I dealing with here or what type of reaction this is? Like if I have magnesium reacting with hydrochloric acid; that would be an extra reaction. It will be difficult for them to relate it to Le Chatelier's Principle. That is just my view.

T. How do you elicit your students' prior knowledge before you teach chemical equilibrium?

P4. You know like with Grade 11; I taught them last year that part of Chemistry. It was not easy on the part of the students. You know they are coming from Grade 10 and in that grade they are only taught the basic equations in Physical Science. Now when they come to Grade 11, introducing this new topic was very difficult for me. So what I had to do is just to go back to the basics of the reactions themselves. They need to understand the chemical reactions. You need to go back to that otherwise they will be totally lost.

T. So do you teach them again?

P4. Yes, you know that topic is one of the topics that we as teachers struggle to bring forth to the students.□

Question 3

T. Could you please tell me the difficulties that the students encounter when learning chemical equilibrium?

P1. I think that the concept of equilibrium is very abstract to them because they can't see it so it's difficult for them to understand that a reaction is happening in both directions. It is very difficult for them to understand that something is going to change to shift the equilibrium; that concept of shifting to the left and shifting to the right is difficult for them to understand.

T. Do you prepare your teaching with these difficult ideas in mind? How do you approach them in the preparation stage?

P1. Do you mean counteract or kind of anticipate the problems they struggle with?

T. Yes. To anticipate these problems they may struggle with in your preparation.

P1. I suppose I view it as a mini revision as we go along. For example when I teach equilibrium I teach it like a scale that is balanced. If something happens to one side of the scale then something must happen in the other direction to keep the scale balanced. □

T. Could you please tell me the difficulties that your students encounter when learning chemical equilibrium?

P2. I think one of the challenges is they need to realise that when we talk about equilibrium it doesn't mean that the reaction has stopped at a halfway point, that a reaction can be anywhere, and the fact that it is not a matter of the reaction having stopped but that it is in dynamic equilibrium. Sometimes, especially those who do Physics, because they would have learnt equilibrium from the forces kind of concept, so I think for them even though you use the same language they don't get that idea. For them, it stands still and there is nothing happening anymore at that point.

T. With that in mind, do you prepare for these kinds of misconception before you enter the classroom or it's just something off the cuff; you respond to the students' questions or their confusion as they present them in the classroom?

P2. What I like to do with them before I go into dynamic equilibrium that is I like to introduce it with practical activities where I have two containers with water like beakers equally full then I get two volunteers. Each one gets a cup and one has to move water from left to right and the other from right to left. So I let them do it for a while and let them understand that even if it looks like nothing is happening, but there are definitely some changes; there is in fact back and forth reactions taking place and then you can play around with you can have your water level at 30 – 50 but then you can also have it a 20 – 80%. It is important to let them understand that it has to do with the rate of the reaction and not the amount of substances being used. □

T. Could you please tell me the difficulties that your students encounter when learning Chemical Equilibrium?

P3. Many of them struggle especially with Le Chatelier's Principle. I think just the whole principle really confuses them. There was a workshop with some teachers in the Khomas region, where I was surprised with the difficulties they showed. It's a topic that many people struggle with. I don't know whether it is taught at University or not but if teachers struggle like that then you can imagine the students. They struggle with just the principle itself or what is going on there or just to give the explanation of the whole reaction.□

T. What difficulties do your students encounter when learning chemical equilibrium?

P4. You know they should be able to explain [changes to dynamic equilibrium] in terms of temperature and pressure. For me, I thought it was difficult for them. It's like relating in the same reaction changes in temperature. I remember that when I started teaching this topic was tricky for me. When the temperature is raised, for instance, or reactants added, what will happen to the products? So that is really difficult because, like I said, they need to know the background of that specific reaction [and] only then can they tell. Ok so in this reaction does the temperature increase at the reactant or the product side, depending on that specific reaction? If it has to do with another variable then you come and explain it in terms of that variable. Like I remember with the reaction of ammonia, I explained it in terms of pressure then they said "ma'am may you please explain it in terms of temperature as well". It becomes very difficult if you do not know the background of what you are looking at. In this particular reaction, what do I need to deal with it?

T. So it's mainly the prior knowledge that the students are coming to the classroom without?

P4. Yes prior knowledge. You know the way our curriculum is designed. It is not designed for the students in Grade 8 and 9 to have a little bit of knowledge of this before they get to it in grade 11.□

Question 4

T. Can you briefly describe the procedure of your lessons for introducing the topic, calculating Kc and explaining Le Chatelier's Principle? Which one do you teach first Kc or Le Chatelier's Principle?

P1. I would definitely teach Le Chatelier's Principle first. However, in G10 we only teach them to remember; the concepts of Le Chatelier's Principle are not expected, so I find it difficult to teach chemical equilibrium without Le Chatelier's Principle. I think that general concepts helps them to understand it and I feel that they need details to prepare them for the next round of work for example AS. So I taught them Le Chatelier's Principle in G10 although they were not examined on those specific concepts.

T. So you are saying if Le Chatelier's Principle is taken out, the ideas of chemical equilibrium will be difficult to teach?

P1. Yes, they kind of go together. I would definitely do Le Chatelier's Principle first and then make sure they understand it well then we move to Kc.□

T. Could you describe briefly your procedure of the lesson when you introduce the topic, calculating Kc, explaining LCP in terms of which one you teach first, Kc or Le Chatelier's Principle, or just your overall presentation.

P2. I haven't been teaching AS, I was just teaching IGCSE and they don't require the students to do any Kc calculations. In fact they do not need to know the term Le Chatelier's Principle, they actually just need to know how disturbing an equilibrium affects the position. I do introduce the expression saying it is called Le Chatelier's Principle. I will state this is what it says and we take it from there; this is how you apply it and we run through some scenarios. Like you put typical reactions on the board and then you play around and say this is what it means if the overall reaction is exothermic; which side will it shift. So we just use some practical examples and facts. So they are just presented with facts; this is what an equilibrium reaction is and they make predictions on the given scenario.

T. I will change the question just slightly because of that issue of Kc. When you present the Le Chatelier's Principle or the ideas of Le Chatelier's Principle what do you start with; the idea of position of equilibrium or the change of equilibrium?

P2. I usually start with the fact that as you have a forward reaction and a reverse reaction happening you get to a point where both reactions are happening at the same rate and that point is the equilibrium and I usually show them graphs as the amount of products being formed increases and the amount of reactants being used up decreases it will level up at a certain point. I do start with position of equilibrium at a certain point then I get to the reactions when it is disturbed.□

T. Can you briefly describe the procedure of your lessons, as in how you present your lesson, what you start with; reversible reactions, calculating Kc, explaining Le Chatelier's

Principle? Which one do you teach 1st; Kc or Le Chatelier's Principle? Can you just give me an overview of how you present this topic?

P3. For the AS I didn't really do it. Over the years it starts with reversible reactions, so you start by maybe doing the experiments with hydrated copper sulfate, start there and show how reversible it is. So it starts there; hydrated copper sulfate and cobalt chloride. Then from there, what I normally do, is I show them You Tube videos on dynamic equilibrium and animations. We are lucky we have You Tube, some videos explain these ideas very well. Then I move to explain the principle itself, and then I go to the conditions, the pressure, the temperature and the concentration. Thereafter calculations, I am not sure now about the calculations whether I put them right at the end. □

T. I just want a general overview of how you teach the entire topic, in terms of how you order the concepts. Please also describe how you introduce the topic?

P4. I haven't gone through my syllabus. It would be nice if I had gone through so that I can see.

T. Ok. That is fine.

P4. I haven't taught chemistry this year. Perhaps maybe for that question, if I can just go through the syllabus, only then will I be able to tell you where I would start.

T. That's perfect. You can just put down the order as a text or something.

P4. I will send in a text or voice note once I go through the syllabus.

Question 5

T. How well do your students cope with Le Chatelier's Principle?

P1. I think Le Chatelier's Principle is OK for them. I think it's just about the general whole concept of equilibrium that is new to them.

T. Kc is much more difficult than Le Chatelier's Principle?

P1. I think so; I think Le Chatelier's Principle is more basic.

T. How well do your students cope with understanding Le Chatelier's Principle or the idea? How well do they cope with a change and the system trying to oppose it?

P2. I think they mostly cope quite well it might take each one the first lesson they might get a bit confused but I think once they get the idea especially with energetics, then you actually get them to the direction they need to go. I think they cope quite well, sometimes they struggle when you then bring the term "yield" then you have to remind them that when you talk about yield you are talking about the amount of product. But then when the reaction moves to the reverse then the yield becomes little but I think most of it requires practice. When it is practiced it becomes clear.□

T. How well do your students cope with Le Chatelier's Principle?

P3. It is difficult. I think the one they find a little easy is pressure when explaining the equilibrium shift to the side with the least number of moles. I think that part is a little bit easier. But the temperature, you know the reaction can be exothermic or endothermic and then when you increase temperature they find that very difficult.

T. So its lack of prior knowledge on chemical energetics that comes into play there, that makes it difficult?

P3. Yes.□

T. How well do your students cope with understanding Le Chatelier's Principle.

P4. They don't. It's not easy. It is one of those topics that at the end of the day you realise students struggle. I remember there was a time in the old curriculum when we taught balancing equations, there was a way when I really tried my best to figure out how best I can really make my students understand and get to the point of writing chemical equations and balancing them but then at times you are forced to continue even if they don't grasp it well because of time. Then you say I'll come back to this later, but then you can't. It is really not an easy topic. The language for LCP used is very difficult for the students to understand. □

Question 6

T. What are your thoughts regarding the shortcomings of Le Chatelier's Principle, if you can think of any?

P1. I can't think of any, for me it works quite well.□

T. What are your thoughts regarding any shortcomings of Le Chatelier's Principle? Any?

P2. Sometimes I guess it is one of these things where you have to say this is how it is and you just have work with that. Where it is not clear how you can explain it to the student, where it is coming from, how and why but you just apply it. That is how it is, just apply it.□

T. What are your views regarding the shortcomings of Le Chatelier's Principle, if any?

P3. I think, like I said at the beginning, when the concept can be related to something in everyday life, can be brought down to earth where the children can also see it can become easy for the students. But if something is abstract or maybe us the teachers have not studied it enough to be able to bring it down to earth, I don't know, but it is quite abstract. It is difficult to bring it down to the level of the students.

T. What are your thoughts regarding Le Chatelier's Principle? Is it a concept that you feel has shortcomings or you're fine with it?

P4. No the principle is fine.

Question 7

T. What instructional strategies that you use to make your students understand chemical equilibrium, for example you spoke about one that I like, the analogy of a scale, do you have anything else that you use?

P1. If I can just elaborate on the scale; If I am talking about the scale I'm talking about one of those old fashioned ones from old days which if it is carrying a weight on one side it has to be equally balanced for the scale to be horizontal. So when I'm teaching I use my body, like I spread my hands. I haven't done experiments using Le Chatelier's Principle to teach chemical equilibrium.

T. Ok. You could think about demonstrating this idea of the scale using a triple beam balance, maybe. That's what I thought of when you spoke about the scale.

P1. I haven't done it using the triple beam balance. I don't know that we have one at the school. At the previous school we had one of the old, old scales so I would lever on the middle and then would show if it is not well balanced it would tilt to one side.

T. We have some triple beam balances in the junior lab. I would love to see how you do it. I have never thought of it that one could demonstrate chemical equilibrium using such simple and straight forward demonstrations.

P1. I'm thinking of using the triple beam balance then you would put weights and the whole thing will keep on tipping until you make it balance.

T. You said you have never used any experiments or demonstrations for Le Chatelier's Principle.

P1. We have done a little bit of one of the nitrogen oxide gases… one of the gases, I think NO and the other N_2O but I'm not so sure. We were putting it in ice and taking it out of the ice and making observations.□

T. What instructional strategies do you make use of to make the topic easier to understand? Earlier you spoke about analogies, like the one of moving water from one vessel to another.

P2. You mean the practical activities that we do to illustrate what it [chemical equilibrium] means or just the use of analogies? I use the escalator going down. If you try to go up the escalator opposing the direction which it is going, or a treadmill.

T. And hands on practical activities, do you give them any?

P2. I try and include the one with nitrogen dioxide and the dinitrogen tetroxide with brown and colourless gas. I put one container in ice and one in hot water so that they try and visualize what its looks like.□

T. I like the idea that you mentioned just now about demonstrations using copper sulfate when you introduce reversible reactions and making use of you tube animations. Are there any other instructional strategies that you use for instance hands on activities, games, analogies in class to try to make the topic clearer for the students?

P3. No not for this particular topic. For other topics maybe I can give but for that one not at this point.

T. Why is it that you don't use any; is it that you don't have the resources or you haven't come across analogies that teachers can use?

P3. Maybe it's a topic that I have never really thought about. Because sometimes the more you expose yourself to different materials on the topic then you come across all those things. I think maybe over the years I have never really taken time to expose myself to the topic. You see, for other topics you will find us using very nice examples that will just help the child in the classroom.□

T. What strategies do you use in teaching? For example do you use analogies, hands on activities? What strategies do you employ in your classroom?

P4. Yes, hands on activities most of the time; old question papers where they can look at how they can approach that specific question and how it is asked. The other thing is there is also this question that they normally ask: the conditions that they need to put in effect when they are looking at equilibrium. They will say for instance temperature or pressure, but now they should indicate the exact temperature or pressure. So I always want my students to go through old papers so that they acquaint themselves on how to approach them.

T. Do you use demonstrations or experiments when teaching?

P4. I do. □

Question 8

T. Do they [representations] help your students and in what way?

P1. It's difficult for the children to visualise something they can't see. Say for example air pressure. The air is pushing on you but you can't see it. But if you have a syringe and you try to push it form the other side, now you feel the resistance.

T. Do you think they [representations] help in understanding and in what way?

P2. I think just because the situations are mostly theory, it helps them to kind of link the situations that they have been given by observation. For example, when they are given random chemicals they normally don't come across they see the colour of the reactions. Then they can link the chemical to the colour.

Often the question will say this is what you observe then you have to conclude or you make the inference that therefore the equilibrium will shift to either side. So I do think it helps but this is also if we cannot do it in the lab, there are quite a few who will need visual aids and sometimes we are in a lucky position because of Lockdown, so the students are quite familiar with their classroom online and you often post visual things that they can access.

T. If I read your last part well it seems you are saying sometimes you do not have time to give your students whatever they need to understand the topic well.

P2. Yes you are always under that pressure that we are going to have an external exam, so you always want to give them extra time to get the content through and because of Lockdown sometimes there was not enough time to give them all the content you would want them to have, so I think the challenges I find when they are not always at school then you have to find a way to reach them.□

T. Why is it that you don't use any [representations]; is it that you don't have the resources or you haven't come across analogies that teachers can use?

P3. Maybe it's a topic that I have never really thought about. Because sometimes the more you expose yourself to different materials on the topic then you come across all those things. I think maybe over the years I have never really taken time to expose myself to the topic. You see, for other topics you will find us using very nice examples that will just help the child in the classroom or at home. □

T. Do they [representations] help your students and in what way?

P4. Yes they help. The only problem with doing experiments in public school, I don't know about you guys, we do not have enough materials. Like if you want to do a certain reaction and you do not have enough reagents then you cannot do it anymore. But now with technology, what I do with my students I always go to You Tube, get a video and show them. I usually show them videos when I realise that I do not have enough reagent or chemicals. I go to You Tube and download that specific video.

T. Does this really help your students or it also confuses them at times?

P4. At times it does because you know most of these videos that you find on You Tube are European based and these people speak in a different way. My students always complain and say "ma'am we do not understand". [For example] there is this Physics guy from Cambridge, who has really nice videos on Physics and science, they always say he talks too fast and we do not understand him. Maybe the pronunciation is different. □

Question 9

T. Any general challenges that you face in teaching chemical equilibrium in general.

P1. I think the fact that it is abstract and the different aspects to it. They need to understand writing and balancing equations, phase change, equilibrium in acids and bases and stoichiometry calculations. One needs a very solid foundation in all those topics to cope in one section.

T. How do you define equilibrium? Do you define it in terms of the quantities being constant at equilibrium or in terms of rates of reactions being equal, the forward and the reverse or you use both?

P1. Both

T. Which means you teach kinetics first?

P1. Yes. That's the other thing; they will also have to understand kinetics. They also need to understand the temperature change, if it is going exothermic or endothermic direction; which way is it going to react.

T. You have mentioned about a lot of work to set up. Do you think it could be a hindrance to hands on activities that you would want your students to do?

P1. Yes. We are lucky to have the lab technician that we have and also have enough equipment. For example the other day a child broke a burette and pipette and that's really a costly mistake, also there is need to replace parts and some markings wear away. It does take a lot of money and a lot of time. It is really a hindrance.

T. What general challenges do you face in general when teaching chemical equilibrium?

P2. In general I find that it is sometimes a bit difficult to find the right level because you find children with different abilities in class. You find that sometimes those who are getting it very quickly get bored very easily, and those who are finding it tough sometimes get to give up. I find it hard to accommodate all students.

T. Which one do you emphasize more when you discuss dynamic equilibrium, the idea that the concentrations are constant or that idea that the rates of reaction are the same? The rates of the forward and backward reactions are the same, which one do you emphasize?

P2. I emphasize usually more on the fact that the rate of reaction being the same. But we do such, usually when you look at exam questions, they usually ask if they ask what it means by equilibrium they usually ask for both. So I make it a point that this is what it means; concentration of reactants and rate of reactions. I try to avoid even though they say there is not visible change but I try to make it my last point to avoid misconceptions that there is nothing happening at the point. I make it as my last point. When you look at it from outside it looks like there is no change but something is going on inside.

T. Anything else you would like to share about chemical equilibrium in general?

P2. I cannot think of anything else right now. But I think it's an interesting topic because it is real life.

T. What general challenges or difficulties do you face as a teacher with this topic?

P3. Just to explain it. I understand it a little bit not enough to really explain it. Again, just to relate it to real life is a little hard. Like now we are teaching it to younger students, Grade 10 and they are really struggling with it. In addition, we are also racing against time. We don't really have all the time in the world to sit with the topic. I think we need to teach the students the language that we use right at the beginning. I never thought about the before but I think I will be doing that in the future.

T. What challenges do you as a teacher face in teaching chemical equilibrium?

P4. Oh like that chemical equilibrium for grade 11. I taught higher level before [and] only with time [did I gasp it]. Roughly after about two to three years of teaching, that is when I grasped it. But it was a big challenge for me because looking at it, it was only after I had put it like "What type of reaction am I looking at? Am I looking at temperature or pressure?'" Only then did I really grasp it. But without prior knowledge like we said it is very difficult to teach equilibrium. So you must equip yourself well, otherwise you just confuse the students.

T. How do you find the textbooks that were presented to us for teaching AS?

P4. Those textbooks are really not useful, especially for some of these topics.□

Appendix X: Workshop Transcripts & Participants' Journaling

VIDEO TRANSCRIPT: WORKSHOP 1

T I will record this session so that I'll have access to this material for further analysis and for writing up the research.

Okay, so I've tried to put all the materials that I think we need in the files that I have given you. If you can read along with me that will probably help a little bit to make the process faster.

For starters, I'm using a very difficult theory. It's very complex for me but my lecturer said it is the one that we have to use when it comes to human learning or human activity. So, the theory that I'm using here is called CHAT. It's the Cultural Historical Activity Theory and it places human learning or any human activity in society. It says any activity that we do is mediated by tools and we also have other things involved for that process to occur. So we have what they call the triangular model of activity that puts everything in one place.

We have the subject, who basically is the human being who's doing a certain activity, or who's learning. And we have the tools that mediate the learning, for instance, language. So when we are teaching, we make use of language to make learners understand whatever we want to teach, or when somebody wants to do something. P2 is the one who does a lot of this; she works a lot with tools. When she wants to achieve something, she uses a certain tool. Thus, we have physical tools, and then we have conceptual tools. The object is what we want to achieve; the rules are what governs whatever activities being done, that is, the rules of engagement; community refers to all the people that are involved. Division of labour would be how we share the duties that are supposed to be done. So basically, this is the theory.

The type of intervention that we are doing here is called a formative intervention in which we come together, and we learn something that does not yet exist. So the idea here is we have a problem that we want to solve, but we don't know the solution and we are going to come up with the solution together. So basically, all I have said is what is on the first page. The second page explains one aspect, one of the important aspects of CHAT, which is called expansive learning, where we are learning something that does not yet exist. So in this project, what we want to do is, we want to come up with a model for teaching chemical equilibrium that is not there, but that suits our classrooms. So we start off from the problem and then we discuss, we pull our ideas together and then we come up with a model that's going to work for us in our classrooms. So it is something that is going to be new, but we are going to analyse and see what other challenges the model or the system that we design is going to bring forward and then try to solve them before we actually use the model.

Another concept of CHAT that is important for us is the one that is called contradictions. Now for contradictions, we are saying these are tensions that exist within an activity system; so we have a problem. We have our activity system and then we look for the problems that make achieving the object of that activity system difficult.

So they (the notes) are saying contradictions cannot be seen directly, but then they show as disturbances, deviation from script, conflict or disagreement between individuals and dilemmas. For us, probably the one that we face most is the dilemma whereby we don't really know what to do when we have conflicting issues or circumstances. For instance, you want to teach chemical equilibrium but you don't really know which concept you start off with, or if doing all the practicals that you think will help your students will give you enough time for them to learn other topics, as demanded by the syllabus, as another example. So I have those contradictions.

I extracted some contradictions from the discussions that we had in the interviews. So the first one that I have right at the top is that the time that teachers are required to teach and make use of all the teaching strategies is not adequate. So we have a problem where we think we want to do seven practicals for learners to understand the topic, but the time that is afforded is not enough for that. So that comes in as a contradiction, where on one side, you know what the learners need to understand and on the other side, the regional office is telling you, you need to move to the next topic after three weeks, for instance. So three weeks is for chemical equilibrium, after three weeks you need to go on to the next topic, so that you can complete the syllabus.

The other one was budget limitations, as a contradiction. Where there is the cost of equipment, apparatus and chemicals that you have on one side and on the other side, there is the budget. So they will tell you, this is the money that we have for you but you know the practicals that you need may need a little bit more than that. I also got this one from the interviews.

The use of analogies can cause misconceptions in student learning. It is another one; you are trying to teach and trying to make learners understand but the problem is misconceptions are coming through - they will understand the concept that you're trying to teach in their own way.

Another example that I have there is Le Chatelier’s principle is scientifically inadequate, and causes misconceptions. So these ones I have put them as a as examples as I've extracted them from the interviews. But basically, what we want to do now is to try to find those contradictions - the dilemmas that we face in teaching chemical equilibrium that makes it difficult.
For analysing our teaching, there is the tool (CHAT triangular model) on the last page, where I have listed some examples.

- I have the subject. I am taking the students as the subject of this activity system [learning chemical equilibrium]
- The object, for us, is [for students] to understand chemical equilibrium - what we want is for our students to understand chemical equilibrium
- The outcome of that is to improve student achievement - we want them to get better grades. Then we have the tools – I have given the tools - textbooks, syllabus, past examination papers, and things like that.
- The community of significant others – I have put in the parents, lab technicians, subject advisors
- The rules that govern the teaching, and the division of labour.

This for me is basically the introduction, where I'm just giving the theory that we are using for this workshop. The understanding is that the practitioners usually have the best solutions for the problems that they face. The issue is they just have to meet and discuss and then come up with the solution.

So the first thing is to find the biggest problem. I have done a lot of talking. Now I shift it to you. The question that I will ask to start us off: *When it comes to chemical equilibrium, do you think there is a problem or do you think there is an issue?*

P2 I think it depends to which depth they need to know it. What we were talking, when we had our interview before, is that when you just teach it at ordinary or IGCSE level, without the calculations and all of that, it can actually be quite simple - quite simplified. The students usually don't struggle too much getting the idea, then applying what happens to a system if you change the concentration or if you change the factor. I think the problem comes in at AS level when calculations and all that come in. That is my opinion, because as I said, I didn't think of it as being too hard. Now with the Grade 10s and at that level, once they got the idea of it, they seem to quite enjoy it. You know, the shift to the left, shift to the right, and you know. So that's my point on that.

T okay, my Grade 10s were not probably as successful as yours, because they always appeared to have misconceptions. I would have three or four learners who would struggle to get it. But then you will get three who get it first time. Those ones I have been trying to use to explain to the others, but I've have some who, even up to now, I think, they still have issues with chemical equilibrium.

P1 P2, I'm picturing you like dancing there, in your classroom, sort of the Macarena.

You know, how you get?

Yes, I think, I hear what you're saying Tasara. I think, like what I've seen, for example, with the children are moving to the new syllabus. So we wrote the IGCSE exams, the

Grade 11s writes in May, June. Now we started with AS syllabus. So we've done this in IGCSE. We haven't started with it yet in AS but what I've just noticed in general, is that the jump from IGCSE to AS is quite significant. And then there are children who seem to cope very well with IGCSE, but with AS work, they look like they have a permanent headache. You know, they like their faces punched up and confusion all the times. And I haven't even got to like this section, which is trickier. Yes. So what I said in the interview to Tasara was that, you know, there are so many different aspects to it. And I think, to be able to do it successfully, then at the higher level or the AS level, and they have to be able to master all these other sections, such as the rate of reaction, the enthalpy can come in, stoichiometry calculations. So aside from the fact that is quite an abstract concept with all this other stuff they have to understand, so that they can actually complete everything successfully. And that is for me, that is what makes it more complicated.

T Oh, Yes, I'm fine with that, that that makes perfect sense. P3 is out at the moment. She is going to be back in a second. P3? The same question with chemical equilibrium - what do you think?

P3 Ah, sorry. Hi again, Can you hear me? My laptop is challenging me with the audio. So I switched to my phone? Yes, you can hear me? So I don't know what happened. I actually didn't even get what the explanation for my burette was, I will get it later. What's your question again?

T The question is: do you think there is an issue here for us to sit and say, "Let us talk about chemical equilibrium and try to find a solution". Do you think there is an issue to discuss?

P3 Yes, obviously there is an issue, I think. Like I said the other day, the topic itself is a little bit abstract. Okay, so on both the teacher and the learner side, it should be discussed because they need to be, I think, a little bit more understanding of this topic, you know, normally when you bring it up with the learners at the beginning, you really have to find a way to bring it home before you take it away. Because, like I said, it is a bit abstract for them. So when you bring in, you know, the equilibrium issue, which is something that I think is appearing for the first time that even just that word itself, you know, from, if you look at the wholesale syllabus, you will find, you don't really use it so much in the syllabus. So, you are just bringing it up like that and using it to answer "to which side the equilibrium shifts". You need to know that very well, so that you are on the same page with the learners.

T Yes, all right. Thank you so much, you have also brought in another concept that is very high up when it comes to, to this topic in terms of the language being difficult for the learners. Like the idea itself of chemical equilibrium, being difficult with the background that they have of reactions, only going to completion - You mix reactant they react and you get products. Now this idea now of saying now, we are changing all that understanding, and saying that there are some reactions that go in reverse, and then they start having a lot of misconceptions basing on that. All right, so that's the initial part.

In your packs, I have the Scientific Inadequacy of Le Chatelier's principle. I want us to have a look at that – I will just point you in a few directions. So this is what they call the mirror material that talks about teaching. And then we look at it and see if it applies to our teaching and that so the first one is the scientific inadequacy of Le Chatelier's principle. I'll just point you in the direction of what I feel is pertinent and probably if you want to read you can. See the second paragraph after "In the introduction", the second paragraph, after they give the definition of Le Chatelier's principle starts with the research. Probably, if you can just look at that paragraph. Just read through it.

P3 Sorry, where are we, on which page?

T Just after the syllabus: The order is: The information about the workshops; then there is part of the syllabus; then after the syllabus there is what says the Scientific Inadequacy of Le Chatelier's principle.

P3 Okay, I'm here.

T We want the paragraph that starts with 'Research'. Just read it.

After the paragraph - that one that has 'Research' - Case 1 and Case 2 do not really apply very well to our circumstances. But the one that I saw applies very well is Case 4: Changing the temperature of gaseous equilibrium system at constant volume - a very common one that uses nitrogen dioxide and dinitrogen tetroxide. If you can just read on the case

P2 I never even thought of that one; (laughs) because whenever we use that we really only focus on the temperature we don't look at pressure.

T We are lucky with this one that usually it works. It's only under extreme conditions that it fails

P2 if they use it not in combination, right? They either use it as… simply asking what happens if you do this and that to the temperature? Or then they ask alternatively, what happens if you do XYZ to the pressure but I'd also never considered that changing the temperature actually does change the pressure as well. Actually it's quite a popular question. It is. Yes.

T And then after that – that is Case 4 - we then go to the concluding remarks; just the one paragraph – Just the first paragraph.

P1 I'm not actually familiar with this Van't Hoff's equation. What does it say?

T We don't use them at all, even the idea of Kc, no sorry Qc - the reaction quotient we do not even use that idea as well. We are just required to use Le Chatelier’s principle, but I'm just presenting it as one of the reasons why, probably, our students fail, as mirror data.

What do you think now having read the Scientific Inadequacy of Le Chatelier’s principle in terms of teaching? Anyone?

P2 Maybe I'm lucky that the kids never figured that out themselves - like me. Actually, they were quite happy to have it in the simplified version. No one has ever! What I'm thinking there is because when they learn about behaviour of gases and temperature and gas pressure, and so on, it's kind of compartmentalized, when they are looking at kinetic theory, and so on. So, so I have in these years…. no one ever made that connection in class and said, but ma’am, if you do that, maybe I was just lucky. They accepted this simple idea behind it..

T Oh, we are all lucky in this particular one. Because what we observe when we do the experiment, usually corresponds to the predictions according to Le Chatelier’s principle. But there are a few where you make one prediction, and then you see something else.

So Yes, basically, so you are saying you are lucky and you are happy, for now?

P2 So now I need to be careful that, where you think now shall I not tell the students in future that actually that there is a problem? Or shall we just hide it under the …

T Like these ones we are all lucky - we are safe? Is the other ones, where we are not so lucky, where they actually conflict and you get different results from what you are expecting? P1, what would be your contribution, scientific inadequacy of Le Chatelier’s principle and how it impacts your classes?

P1 Yes, so it's, I haven't taught it to the AS students this particular topic at the moment. So I must be honest, I also haven't really thought of these limitations. But I think it would, it really occurred to me when I was doing a memo for the cycle test or for the exam. I've been asking myself why am I not getting the right answer? It's a bit late. But then you learn from it. And next time you adjust your teaching. Yes. So I had not thought about it like that before. But I don't know my reply, P2, to your dilemma is, you know, especially if some of the concepts seem very abstract to deepest, as I just said to the children, you know, we don't have all the answers. We all basically are just human beings; we're trying to understand the principles of the universe and these are currently the best explanations we have. Like I just think of the theory of the atom, you know, it changed and changed and changed. And then, you know, we teach the theory of the atom. I said, no, hold on, and learn a different one. If we find one, it gives us a better understanding. So that's, I suppose my disclaimer that I put out there.

T Okay, Yes, that helps also, P3, you want to say anything about Le Chatelier's principle.

P3 Not really, but it's relieving to know that it could have some incorrect predictions. I've always suspected that this principle is somehow too ….. Yes, I've always had those suspicions. Maybe I just never took time to really go deep into it. It's a relief, actually to know that they could be, you know, one or two things that it could have limitations.

T So something that is coming out as well through the research now from the some of these papers, is the fact that it is ambiguous. It's very unclear what it really talks about Le Chatelier's principle, which makes it very difficult to know exactly how to apply it, where to apply it and how to make the predictions. The language also is very difficult - the language that is used for the Le Chatelier's Principle - that is actually given to us. It's probably coming from its nature that is not really very scientifically accurate, so in the process of trying to make things work they came up with long sentences.

P2 Maybe it's because it was a French guy (laughs)

T Most of it was lost in translation

T Another problem now comes in for one of the ideas that we use for teaching where you use practical activities. Le Chatelier's principle talks about only one variable being changed, like pressure for instance or temperature. But real life at times it's very difficult to find an experiment where you only change one factor; like the NO_2 - N_2O_4 example that we had - our focus is on changing the temperature, but at the same time the pressure is changing as well, but we were targeting temperature. So that is one difficulty that comes through.

Still on the mirror materials but we are going to be kicked out in no time. There is a next article it says "Misconception in chemical education". It says Red Fame. The part that we want is on the next page; under 'Findings'. The paragraph that we're interested in is the one that starts with "The purpose of the literature titled: 'Removing misconception of high school second grade students'" - just glance your eyes quickly over it to get an idea of what's going on - just that one paragraph.

So once we are kicked out I'll start the call again – same code, same everything.

T. Welcome back. What did you make of the mirror data?

P2 The compartmentalized understanding of equilibrium as a misconception is something that I have been aware of in my learners when teaching, also understanding the swinging pendulum as given in the research papers that you gave us [mirror]. I am at awe at the other misconceptions that the learners have and for me this is the area that I think we must focus on to improve our teaching.

P1 It is good to know these misconceptions. I have always known that my learners have misconceptions, some of which are in this mirror. I am fascinated with the number of misconceptions that I have seen here, they are a lot and I believe my students also have these issues. This knowledge is valuable I think because then I can anticipate the difficulties that my students might have and really prepare for them. This is good knowledge that we need.

P3 The knowledge of some misconceptions that learners have beforehand is valuable. At times you teach thinking you are doing well, not knowing that you are actually creating some problems in the learners' conceptions of the ideas.

The way the new syllabus is organised is problematic. The old NSSCH was organised in a much better way. We would teach Chemical Energetics and Chemical Kinetics before chemical equilibrium so that we had the prior knowledge that we need. But as I said before I didn't teach the topic this year, it was taught at the regional office. In addition the order of the objectives can be problematic, particularly for new teachers but with experience, you will know you can play around with the syllabus as well as scheme of work and teach in the order that you think best suits your learners. Pertaining to the order of objectives I am not sure of the order to use and may follow what they give in the syllabus.

T Are you still writing regional exams, where students are tested based on the content you are expected to have covered according to the scheme of work? Wouldn't that [rearranging the topics] affect your learners in the exams?

P3 We haven't written those exams in a while, maybe due to COVID, but yes that would affect the learners because the exams are set following the schemes of work.

T P4 couldn't attend this workshop today and we miss her valuable contribution. In the interview she said that chemical equilibrium is now taught to younger learners in Grade 10 and they are finding it very difficult.

P3 Yes, the new curriculum has a number of issues. There are large gaps in content between grade 9 and grade 10 and these are causing us problems in teaching. In particular, teaching these difficult topics to younger students is causing misconceptions that are making our jobs even more difficult. We are hoping that in future when we review the curriculum we might look at some of those issues, but right now we don't really know how to handle it.

T What we have done so far is the questioning; trying to understand the problems in our teaching practise; look at the mirror and see what it tells us about how we are teaching. Now we want analyse our teaching using the triangular model of the activity theory. What we are looking for mainly are the personal dilemmas that we encounter in teaching. I have given a few examples that I extracted from the interviews. You can look at those and see if you agree. Our main task is to find the main contradiction or to rewrite all of them as one sentence and capture everything.

P4 mentioned that students struggle with language as one of the main problems. The challenge is that we are not language teachers and devoting time to teaching students language may be problematic.

P3 The idea of experiments for this topic is new to me; I do not know what experiments one can do for Le Chatelier's Principle. In addition, I do not think we have the equipment at state schools to do the required experiments. We also have huge number of learners in the classroom, upto 45 learners and we have to prepare all those chemicals and do the demonstrations. We do not have the assistance of lab technicians.

T Can you please clarify if your issues are to do with the knowledge of experiments you can do in your teaching or the availability of the materials.

P3 Both!

T You have raised an important point that relates to division of labour in terms of support from the relevant officials I think it's worth exploring.

P1 The dilemma that I have has to do with giving formative assessments. In our school, the problem is that if an assessment is not for marks then the learners do not do the work. I want to be able to give assessments that learners can take home, to save some time, but the learners simply do not do the work if it is not for marks. Another problem is that the classes are getting big and 45 in a science class is a big problem. First we have the issue of having to deal with crowd control while at the same time having to teach the content. It's difficult! Another issue of the big classes is that when you give an experiment you want to be able to move around and provide help and guidance as the learners carry out the experiments.

P2 For me the main problem has to do with misconceptions however they arise and I think it is the one that we should focus on. You see, if the teaching is done well enough from the onset then most of these challenges simply disappear.

VIDEO TRANSCRIPT: WORKSHOP 2

T Just think within that example.

P2 Okay. That might of course, be the case as well. But, but as I'm saying, you know, when I was reading now in those essays of yours, those examples with adding an inert gas and all of that just is playing with the pressure. I mean, will they have those at AS level, those concepts? Or is that even as far as university level? As I said from the examples that come in past exam papers is usually the straightforward ones for IGCSE.

T Well, Yes. You're right there. But the other issue that we have is to do with, say, a practical activity and want to change the pressure? How do you do that?

P2 No those are the ones I think you can't really have that strong effects. I think in a lab you will be restricted to looking at temperature. I've got one practical that I inherited from XX where they have ….. Maybe P1 you will remember it as well, the one where you have iron three chloride and potassium thiocyanate that makes a complex. And for some reason, when you add more iron, and then you can see the colour change and it shifts. For some other reason, it doesn't work though if you add more of the potassium thiocyanate. Then it doesn't seem to shift, which it should, because you are increasing the concentration on the left. So I haven't quite figured out what the story there is. But there the challenge comes in, I think, because they will have not been taught about complex ions and all of that. It's maybe an example better for the AS level. Because I seem to recall, there was also something that when you add it, then sodium hydroxide that basically removed some of the product out of the equilibrium and then you could see it as well. But I stopped using that for the Grade 10s. I just quickly showed, if I add more iron, it moves that way. And I thought let me just put it away before someone gets the idea lets add more of the other stuff and see, and then I look red in the face.

P1 Is that the one that we did with the titration, where the potassium permanganate was in the burette.

P2 No. It was one of the things that previous teacher said: "Can I make some of the solutions I want to demonstrate XYZ" and I kind of watched it from the side but I never really used it myself. So you know, some of the things that I thought I need to do a read up a little bit more. Why the adding more chloride didn't work.

T Alright, guys, thank you so much for coming. It seems P3 struggling to get through. She said something about having to go somewhere. We'll just take the ideas through to the next one and P1 needs to leave as well. So we'll just make this session short.

What I have seen now is that in the analysis, we did not finish because we didn't agree on the problem that we have as the main problem that we need to solve. So maybe we are going to have to go backwards a bit and look at the ones that I have here, Find a way of describing that main problem that we want to solve as we model the new teaching methodology.

So I have captured what you have in your reflections and then I will add the ones that we had already, and probably find a way of phrasing the main problem that we have. And then we model our solution based on that one big broad statement. I do not know if we are going to be able to get that since we all have different problems. So from the examples that I had given from the interviews, there are five there... I don't know if you want to look at them again. The five problems:

- The first one is the time teachers required to teach and make use of all the teaching strategies is not adequate.
- The second one was the budget limitations to do with resources in general. And I've seen the issue of resources in the reflections as well, where the lab probably is not adequate. There's only one lab for all the classes, and the issue of the solutions themselves being available, and the time required for setup and to pack away. So that one came in as well, too, with the budget limitations, resources and everything, so I've captured that one together.
- The use of analogies and the misconceptions that they cause in student understanding, like the example that I've been given here of the seesaw analogy, reinforcing the idea of static equilibria.
- The school policy for assessments, we spoke about this one, is it a main problem or not.
- Le Chatelier’s principle being scientifically inadequate,

and now adding the ones that are coming from the reflections,

- There is the language barrier, where the learners don't understand the language used in the topic to understand the topic.
- There is the differentiated learning where the learners in the classroom are not at the same position and that becomes difficult now where we pitch the teaching,
- the order of the syllabus and progression of the topics
- Managing the large classes.

So basically, those are the problems that are coming through as the dilemmas that we have, or probably as the contradictions, I'll really put them nicely in terms of the CHAT theory itself as to where they actually appear. But for now, we just want to work with those ones and find what would say is the biggest of our challenges.

P1 So I think for me, the thing is that, you know, what I said in my reflection is that it depends like sort of what situation you're in at that time because when I was in different schools, I had different conditions, different things were a problem for me. But I think that, you know, I suppose that most of these things will be a problem, no matter what syllabus you're doing and depending on your circumstances, but I suppose the only time that perhaps inadequacies of the Le Chatelier’s principle is actually going to be relevant is when you're teaching this section, you know, because for other sections, they are maybe other things that you would focus on. And not all sections need as much background knowledge, maybe not all sections cover so many, you know that this is sort of like an umbrella that covers quite a few different topics in the syllabus.

T Okay, but here now, the understanding is we want to put everything together as one topic. And then try to … because generally what you want to get to is to model a solution that is going to tell a teacher what they are supposed to do as they teach. So like those suggested schemes of work from Cambridge. That's something that we want to come up with, saying at the beginning, do this, these are the activities that you do, this is the analogy that you use and here are the problems that you have that you might want to bring to the learners attention, as you use the analogy to capture everything.

P2 But for that it might well, if I remember, I think we all agreed that we should jumble the order of topics around, right. Where, with the Namibian syllabus, we said reaction kinetics comes after equilibria and it should be before, right? I mean, that should be an easy thing to solve. If they don't want to reprint the syllabi, or whatever, it doesn't matter, but just point that out in the scheme of work that you should have that concept or parts of that concept first. The same with the Cambridge for example, the IGCSE syllabus breaks up the organic chemistry in sections where they do some parts much earlier, like the fractional distillation. I think that you can kind of take out as a fairly easy concept without going into the whole chemical differences but we haven't done that, per se, yet. They are breaking up Stoichiometry which we do where we take that bit of formula writing and balancing, we put that into G9 and the more complicated calculations we can only do later in G10. So that is something where I think when you're not talking about finding a solution for all of that, I would think its maybe one way one can agree on a scheme of work and I think especially with AS level content, I'm quite sure there is a lot of teachers who will be new to having to teach at AS level. So I think that would be something that could be very helpful for that.

T Okay. If I read you very well, you are saying it is the idea of the misconceptions that appear or develop in the students' understanding as a result of the order in the curriculum not being accurate?

P2 Yes. I mean as P3 also said, an experienced teacher will find their own order, but for a non-experienced teacher, he will now follow the syllabus. And then the things are wrongly understood already before you get to a topic. Had they known that before that would have helped.

T Okay. P1, are you are you there in agreement? Maybe: the misconceptions that are generated as the result of the order in the syllabus - is our main problem here? So the learners are not learning the ideas well, early enough. And then that is actually bringing our learners to having misconceptions.

P1 Yes, I can go with that. Because I think that it's like P2 was saying it's difficult to know. Well, an experienced teacher will decide: Okay, now this time, I'm going to teach a differently to that time. but we wouldn't necessarily all even agree on what is the order we should teach it in. So I suppose this is just that variety and style is even going to lead to changing the order.

T Okay. There is a theory that I have given you there, we are not going to use it as of now, of the pedagogical content knowledge as something that's important and it talks about these things. As teacher's knowledge, the knowledge that the teacher has, as an individual, say personal PCK. And this one is different for all teachers, and the collective PCK. So it's the collective one that probably we want to get and say, let's get this knowledge, put it there, and then work from that kind of position.

So we focus on the misconceptions. And then there is this one, also, where we are using our analogies well, but they cause misconceptions. How do we factor that in? I go there well-meaning, I'm using the tools that are there, I get the analogy of the seesaw. But it causes misconceptions in the understanding of the learners.

P2 I think it also might come back to the general thing of they need to understand, well, what is a model - that it's just something that helps to illustrate certain ideas. For example, I stumbled across that demonstration that we were talking about with a water canisters, where you move it from left to right. I read it in one of those articles where they said, while it illustrates nicely the dynamic nature of the equilibrium position, it can cause a misconception - thinking that reactants and products, they're happening in different places, because it doesn't nicely show that it's all in one system. I think that is one thing, one always needs to be aware of the shortcomings and just point those out. I think kids would be okay to then say, oh, when you said, hey, but what is wrong with the picture? Just be aware of that forward reaction and the backward reaction are not happening in two different containers that its actually all happening within the same container and so on. I read somewhere where they say they use the "Apple challenge", where there is the apple tree and the neighbour throws the apples over the fence, and the other one throws them back. So there as well you would have this kind of fence, which in a chemical equilibrium in a system, you wouldn't have anything separating now your left hand side from your right hand side.

T Okay, so Yes, that's perfect. I'm just going to structure the double bind, or the main problem. And then I'll share it with you as you do the reflections for this session.

Now, there's this one that I want us to look at briefly. We're using it as a tool now for modelling. It is the pedagogical content knowledge one. So if you have it, then I've put a lot of words there just to have the theory itself working. But I'm still going to pick up on a few things. So we have this theory of pedagogical content knowledge that was started by Shulman in 1986. So basically, his idea was that a teacher is a professional, who knows his work very well. And then there are two things that are involved there. We have the SMK, which is the content knowledge, and possibly this is what a chemist would know, in industry, for instance, or in manufacturing, as an example., who knows some of these things like a Haber process. You've a factory that actually produces ammonia and we've a specialist there. All they have is what they call the content knowledge or the subject matter knowledge, very important. And we have the PK, which is the pedagogical knowledge, which is knowledge of how to teach. So what Shulman did was to bring them together, and say, here is a new construct, which he called pedagogical content knowledge, that talks about a specialized knowledge of a teacher, where they transform the knowledge of the subject into a form that is understandable by the learner. So this is what distinguishes, a person in industry from a teacher. A professional would make it understandable to his class and that was his argument. So this idea has evolved and we now have what is called the refined consensus model, which is now on page two. If you can turn to page two with me, there is the representation there, where you have concentric circles. So right there in the middle, you have what is called the enacted PCK, which is the knowledge that you use in the actual teaching, when you teach a specific group of learners or a student in a particular setting and we are teaching particular concepts. So they call it the enacted. So this is the knowledge that you have available in a classroom, and it responds to the students that you have in front of you. So that's the one that they say is the most important, or is the central idea, the enacted PCK. And then we have what they call the pPCK, which is the personnel, knowledge which is cumulative and is dynamic. So this one is, I teach a class and my experience increases my knowledge of how to teach a certain topic also increases. So it's very dynamic and it's different from teacher to teacher and from context to context. So this is the second level of that knowledge, which is the personal PCK. Now this one, when we interact every day, in our teaching, you talk to a certain teacher, they tell you something, you are developing your personal PCK. And the one that they say is the most important one is the reflection; where you leave your classroom, and then you reflect on your teaching and say, there I could probably have done it this way. So they say it develops.

The last one is the cPCK, which is the broad knowledge that we basically want to develop here in general, where we are saying, let's come together, let's develop this broad knowledge, and then we contribute our ideas into this pool and then we come up with something that we can use. Obviously, our pPCK and our ePCK when we leave this program is probably going to be the same, but it will be different probably after just 10 minutes of teaching the specific topic depending on the learners that we have and the context you are in. And then in the model, they add the learning context which I've explained there, and the general knowledge bases like the content knowledge, you need to have the content knowledge and then you develop your PCK from that the pedagogical knowledge - how to teach, knowledge of students, curricular knowledge and assessment knowledge. So, this is generally the theory of the knowledge of a teacher, when we talk about the knowledge of a teacher we are discussing that.

The one that is important for us and the one that we are going to zoom in on is the topic specific pedagogical content knowledge, where we are saying PCK has three grain sizes where it can be topic specific: where when you teach chemical equilibrium, you know the techniques that you need for that topic, when you teach rates of reaction, the techniques would be different. And then they have the discipline specific PCK for the subject chemistry in general would be taught in a slightly different manner to history, for instance, so the history teacher will teach in a certain way, and then the chemistry teacher would teach in a different way.

So, the one that we want there is the topic specific. We are targeting chemical equilibrium now, and then there are five concepts that we need to know for this one. We need to know, the learner prior knowledge, curricular saliency, what is difficult to understand, representation and conceptual teaching strategies. And just to give a brief, which is right on the last page, the student prior knowledge refers to students' preconceptions and misconception - what do the learners bring to the classroom? So as we thinking of the way to model, we want to have that in mind, how do we check their knowledge? Do we have an understanding of their misconceptions or their preconceptions or just the knowledge in general? So that's the first one. So any teaching would have that as central? What do learners know, and what misconceptions do they have?

Then they is the curricular saliency, which deals with the identification of the main ideas, what are the big ideas in chemical equilibrium, like we've been saying the reversible reactions, then dynamic equilibrium, then Kc, Kp, then Le Chatelier's principal then industrial applications as the main ideas. That is what they refer to as curricular saliency, as well as how do we sequence those, what's the best sequence as well as what topics should be taught before we teach chemical equilibrium?

What is difficult to understand as the gatekeeping concepts when we go to the classroom, what is difficult to understand and representations which are analogies, illustrations, examples, demonstrations used to support an explanation? Finally, conceptual teaching strategies is now trying to combine all these four and try to find which methods would be best suited when these are the misconceptions that students have - what is the best method when this is the prior knowledge that students have, which is the best kind of strategy to use or when we identify this saliency whatever we agree on what would be the best strategy. So the presentation of this TSPCK is that in teaching we should kind of make use of all the five in the one lesson try to capture all say when I'm teaching today check the student prior knowledge - what they know, what misconception and the idea of the order should also come through and all that. So basically, this is the kind of theory that we want to use as we generate our model as well as to make use of the materials that I've shared with you already. There so what are your views?

P2 Yes, I know we mentioned before with a student prior knowledge when we had our interview right when I also said we kind of rely on the fact that we taught before what we thought were the necessary foundation. Sometimes you not necessarily double check if they actually have those prior concepts available. We just assume that they should be there because we taught them before. Maybe one needs to have a strategy that you actually double check that whatever you think they should be knowing that. In fact, it is their or kind of have a mechanism to activate that prior knowledge again that they see the connection that they do not start all afresh with an empty mind.

T Yes. And then it also connects nicely with a point that was raised in the reflections, where there was the idea of differentiated learning, whereby we have learners of different abilities then at times, we rely on the brighter student. And for this, when we check the prior knowledge, we are using the brightest student, when in fact, probably we should be using the other student, on the other side, because they say, when you measure the strength of a string, you check the weakest point.

P2 Yes, I mean, it is sometimes also, sometimes it's not necessarily the about weaker ones and the stronger ones - sometimes it's the more outspoken and the shy ones. And I mean, sometimes it's goes hand in hand, that outspoken ones are the ones that are confident and understand. Whatever you're doing well, it's not to say that all the shy ones don't understand. But it's still sometimes when we need to be reminded to get them out of their reserve to actually see whether they are now just quiet because it's just their personality, or whether they are quiet because you lost them completely in the process. And I find especially funnily now with COVID, when half their faces hidden behind the mask, some it's sometimes difficult to catch the nonverbal cues that they are now having difficulties.

T Yes, that that's that one is one thing that we had to learn different, because we normally use their facial expressions to judge if things are working. But now because after face is hidden now we don't know, which is something that is very significant, and probably requires a change in teaching strategies.

P1 It was difficult online as well, because online, a lot of them chose not to have the camera on. Or even if you ask them to have the camera on, especially like early in the morning, some of them are still in their pajamas, so they might not be appropriately dressed. So I think at home, they're more distractions, and because they don't necessarily have the camera on. Or you ask a question, and it's like, you're there by yourself, so I found that the interaction was way less online than it was in in person interaction.

T Thank you so much. So we get that another zoom and actually go into the actual modelling. Because here we were just mainly focusing on the analysis, try to understand the problem in that manner. So before we go there in the modelling, the ideas that really came out, in so far, where curricular saliency, it's something that has been spoken about in detail. Misconceptions have been discussed, but what I haven't seen coming up nicely is 'What is difficult to understand'. This for me has not come out in our discussion so far. Do you have anything that pops up for you or something that is there quickly, to be something that is difficult to understand? Like, the gatekeeping concepts?

P1 With this we spoke about in a previous one was that, you know, it's difficult for them to understand the concept of how the things are changing when it's going backwards and forwards. And because most of it, they can't actually see, so just the fact that it's abstract.

And as P2 mentioned earlier on, that the backwards and forwards are happening at the same time, I think that's difficult for them to understand.

T So here the concept is I want to just get it nicely. The concept there is at macroscopic level, nothing is changing. But we want to convince them that there are reactions that are happening, but we can't see those changes. Okay?

P1 Yes, I hear that. Yes. And it's happening simultaneously in both directions.

Yes, this is one of the notes that you gave us, if I just can show you the kind of graphs? Is this is difficult for them to understand. And it's difficult to explain it. Yes, how you want it. But the graph is almost going backwards of what you would like to think it should.

T Okay graphs - Graphs and interpretation of the graphs. Yes, I noticed that, in general, our learners struggle with reading graphs. Just one simple graph - they don't understand what it means. Now, we are putting two graphs at the same time makes it very difficult.

P3 we are just discussing what is difficult for learners to understand as per this document that I shared, that I brought to you. We are just on point number three there - What is difficult to understand - as one of the main concepts of TSPCK. In teaching, we want to know what the learners find difficult.

P1 So while she's thinking is the next session going to start immediately after this one.

T Yes, immediately.

T. Can you hear us saying we just looking at what is difficult for learners, so I'll just give you what we have so far probably be to just bring your teacher out quickly. There was the first one, which was about the learners understanding that at macroscopic level, we don't see any changes. But at microscopic level, there are reactions that are taking place. So this they find very difficult to understand, because in Grade 8 when we talk about a chemical reaction, we tell them chemical reaction is the one where we see some of these changes. So there is a change in colour. That's how we know chemical reaction or a chemical change from a physical change. So a new substance is produced and we see this by changing colour. Now, at this point, we are saying there are no changes in colour, but a chemical reaction is taking place. So that was the first one.

Then there's the next one about graphs and interpretation of graphs, they were saying learners struggle to interpret graphs, particularly where you've got two: the one for either concentrations of the reactants going down while concentrations of the products increasing, and the one of the rate, where, the rate of the forward is decreasing, while the rest of the backward is increasing. So they [learners] find very difficult to interpret those graphs. And then I have one more here that I thought of just now the idea of position of equilibrium, find it very difficult to understand probably related to that misconception of static equilibrium. Can you think of anything that your learners find difficult to understand?

P3 I think not right now. I think I will just refer to that 'position' thing because to just talk about position is really [difficult] and the kids are wondering; "what are you talking about?" Yes, so I will think of some as we go along.

T That's okay, that's fine. I can think of another one from the marking where learners struggle with making predictions. Here, they're applying Le Chatelier's principle. They probably know that the reaction will shift to whatever direction but then to bring that in terms of the colour changes, or the observational changes is something that they struggle with, they can apply Le Chatelier's principle nicely. So they predict reaction is going to shift to the right. They do that nicely. But when you say: "What do you observe?" Then they fail to answer. So I will put that one as well: observational changes or changes to observations. Okay. Okay, I'm still thinking about what's difficult for learners?

You are saying what's difficult for learners. We have added position of equilibrium, and making predictions in terms of the observations that the learners make, they find it very difficult, like the colour fades, or the yellow solid is going to increase, things like that, after they've applied probably Le Chatelier's principle correctly. But to then put that in terms of the observation is something that they struggle with. Anything else?

P1 I think it's the things that link in with like stoichiometry some children already struggled with stoichiometry. And now added to that they must add that additional concepts to Le Chatelier's calculation or question. Also, I think reaction kinetics, some of them struggle with understanding, you know whether it was going to be exothermic or endothermic direction which way it will move. So, I think it comes back to I suppose, like the their background knowledge and the misconceptions they might have.

T Your contribution there is very loaded. If I read it very well, I got stoichiometry there, as something that's very basic. But then I also read you saying the balancing of the equations in there as well. And you spoke about the calculations. And yes, I agree with this one a lot that the learners struggle with the calculations, they normally think there is a simple relationship, arithmetic relationship between the reactants and the products, and they want to take stoichiometry ideas, and then push them into chemical equilibrium. Yes, that's very strong there.

P2, is there anything that you have noticed the students struggling with?

P2 Yes, I think you mentioned the exothermic and endothermic concept where you know, the fact that exothermic is giving out heat, but now, you looking for the reaction that is actually taking that heat away. I think they're quite fine with the concentration and seeing how that is shifting [the reaction]. But for the temperature, that sometimes takes them a little bit of a moment to get around - to get their head into the fact that it's then going into the other direction, not into the exothermic. I think, that is where then, because they had now just learned about kinetics, saying, heating up, speeds up the rate of reaction and all of that and now you're telling me heating up actually decreases the yield, so something has to be wrong. I think they get the idea that heating is generally a good thing, because heat speeds up things. I know with the Haber we then talk about the compromise but I think initially it takes a moment to get there that yield and rate of reaction are two different things.

T So there's this statement, which says, to get as much as possible, as quickly as possible. So they combine them. I've seen this statement in question papers or something where they say, you want to get as much as possible and as quickly as possible. So you're saying the rate of reaction and the idea of the yield. So it comes back to the language as well doesn't it? To say, the language of yield, the language of position is not accessible.

Now, there's something that you brought in there that I liked the idea of the concentration. But you kind of brushed it aside is something that they quickly understand, but I've noticed that learners struggle with this. When the questions become a little bit more, what can I say, more abstract, and they really want to ask something difficult, particularly when they leave products, and then they focus on the reactants. Let me give you an example. So it's a reaction that has two substances, A and B. And then they add A. So the basic question is what happens to the position, we know it's going to shift to the right, the amount of products are going to increase. But they'll ask now the question: "what happens to the concentration of A at equilibrium?" or "What happens to the concentration of B at equilibrium, the new equilibrium position?" Is it going to be the same as the original? Is it going to be more? Is it going to be less? For A is it going to be the same as the original, is it going to be more or is it going to be less? I think that one is something that learners also find very difficult to work with. That one is a very nice one.

P2 Yes. I see that. And I guess that's when the calculation part comes in finding the concentrations but maybe I am lucky there because at IGCSE they don't ask that.

T You have not been unfortunate to get into that situation, you'll get there!

P2 I have not been unfortunate. For me, at the level it was… There they are actually just fine with saying, Okay, you can change the concentration, by adding more or by taking something out also changes the concentration. That's where we the Haber now, for example, when it comes in that as you're removing the ammonia out of the system, you're actually shifting the equilibrium as well. So as I said, we could keep it simple enough that they don't ask about the individual concentrations yet. But I can see where this becomes a problem, when you then use the calculations and equilibrium coefficients and all that.

T Okay, so we now want to kind of start with our model. But I will refer to this later on. But for now, what do you think is the first thing that we should start with when we are teaching this topic? So we've got the big ideas which is in the curricular saliency, as well as we have the order of those main ideas; probably if we can start with that. What do you think? Where do you think we should start?

P1 Can I just clarify? So, are you going to give us a model as a suggestion or are we coming up with a model?

T We are coming up with a model. We are making the model now. So what we are saying is now how are we going to teach chemical equilibrium? We have seen these problems, we know what they find difficult, and we know the misconceptions. Now, how do we teach chemical equilibrium? You have a class next year of Grade 11. They might want to revise the chemical equilibrium they've done at 10. Or you have the Grade 12s who are going to learn the AS chemical equilibrium, which is basically our main target. We are saying if we learn to teach AS we can water it down to teach at Grade 10 or Grade 11. So that's where we are now. But probably to start this one is not very good, I think, in my view, because it doesn't capture everything that we need. But we might use this one: "The teaching and learning of chemical equilibrium; Chapter 12." If you have your notes on the file, if you can get to Chapter 12: The teaching and learning of chemical equilibrium" because I want to refer to the order that they have given in their "Suggested teaching approaches".

P2 Which one are we on now. What do you say chapter 12? The new handouts?

T No, not the new; in the old one. The topic is the Teaching and Learning of Chemical equilibrium. You found it?

P2 I found it.

T Okay. And then we ignore the first leaf, the entire first leaf, we ignore it. On the next page we want to go where it says "Suggested teaching approaches" Then on the next page, they have a short paragraph there that we don't need. We then go to the next page where it starts with "Introducing reversible and incomplete chemical conversions."

So basically, this is the order that they suggested and the activities that they suggested there, we are just going to have a look at them briefly and think how we can apply it in our situation. So for them, these authors, their first one was to introduce reversible and incomplete chemical conversions. So in terms of the big ideas, we have reversible reactions and we also have incomplete chemical conversions. So for them, they are saying for this topic, 'reversible reactions' is the main one followed by incomplete chemical conversions. This is what they are saying it -this is what you need to introduce first. And then second, you then talk about dynamic equilibrium - still on the same page in italics. Then the last one is teaching Le Chatelier's principle. So that's what they have there as their order.

For the first one now of introduction, I'll ask you to ignore the first paragraph. And then the second paragraph now is the one which I found important where they say "we address the reversibility of chemical reactions and use a simple chemical experiment that demonstrates reversible reactions."

P3 Sorry where are we?

T "Introducing reversible and incomplete reactions" Are you there? We ignore the second paragraph. And then we go to the next one that says "first of all…"

So there the suggestion is, we want to talk about reversibility first and we want to use a simple chemical equation or experiment to actually demonstrate it. To say this actually happens; we have reactions that are reversible. P3, you spoke about the copper sulfate, hydrated and anhydrous copper (II) sulfate. So it's a suggestion, maybe, if it works very well, where we dehydrate by heating, make sure we trap the water somewhere towards the mouth of the test tube and then we also put the water back and we go back to blue. Maybe?

P3 Yes, I think that is the easiest because copper sulfate is available.

T P2, reversibility?

P2 I think it is a nice one to demonstrate. It is a nice visual because you can you can see the colour change. But yes, you would have to, because we show them when we do the test for water - the chemical test for water - we use it there. But there I think we don't trap the water, we just evaporate it all off and then we add it back on from your wash bottle. So Yes, that is a nice one to actually consider condensing it at the mouth of the test tube and then letting it run back in. I think we would have to be a bit careful though. When you now say I want to talk about the closed system and P1 will remember with a grade 11 practical exam that you find then the student that heats a test tube with a stopper on and you know, oh my word, are they trying to blow things up in their face. But then again, in the sense of that it needs to be a closed system, you would have to do it.

T That's the issue that I have, probably with that one now where we say now how do we have the closed system there? And how do we convince, maybe, the learners that it's water that we drove out, and we are putting it back? When we're heating we're driving out the water, and then now it's the water that we are putting back to get that blue? So it's something that's actually worth considering?

P1, can you think of an experiment that we can use at this point? Any suggestion? or maybe you're fine with the same one?

T It should be the same as the cobalt chloride one, isn't it?

P2 Yes

T So they say the first thing there we start with the demonstration, or as an experiment, and then you have that but be aware of some of these challenges.

Now, the next one, they suggest there is a discussion now where you, you are now discussing the experiment, bringing the idea that this reaction is reversible. But we need to get to a point where we have the incompleteness of a chemical conversion as an empirical fact. So probably, we might need to find another experiment that we can use there, that actually has both reactions taking place at the same time in a closed system. I tried the one of the same copper sulphate as dilute, but then we add concentrated sulfuric acid, I'll share with you videos, probably that would be fastest of these experiments being done, where you just add concentrated hydrochloric acid, it starts off blue, and then you add concentrated hydrochloric acid and then it becomes green because it's pushing towards the yellow copper chloride complex. And then you can add water again, and then it goes back more towards the blue. So I'll share that one. So it probably gives an idea of the system being closed. So this is just the suggestions from the literature, but we are still going to have to come up with our own.

So they say at this point, we need to emphasize the idea that the chemical reaction is not complete, we get to a point where you still have the products, but you still have the reactants, they are not in excess; they are all there but then the reaction is just not going to completion. We have everything present there as the first one.

And then number two, they suggest that we go to the idea of dynamic equilibrium, we bring in the idea of dynamic equilibrium. And this is where we use simulations and analogies or metaphors. So the analogy that they have given here is of people in a shop that are on the queue paying checkout, and then one person leaves and then another person joins the queue such that at the end of the day, the queue is still going to be there and it's going to be the same length as a suggestion of a simulation. And there's the large reservoirs the one that we're talking about P2, where you are moving water from one container to another and the misconception that arises from that would be important to show at that point. And there is the apples one as well, throwing apple from one side to the other. So there are a lot of analogies that can be used at this point. But the point they're using there is that we want to avoid misconceptions or be aware of the misconceptions that can arise from that.

I'm talking too much, so I'm going to, to leave it there and say: "is there any that we can think of as analogies that we can use?" Because for the analogies, they are saying the main thing, or the most important thing there is, it should be something that is in their [learners] day to day lives?

P2 I think that's where the escalator one and the treadmill.

P1 How do they work?

P2 With you going up with you are going up the wrong way on an escalator; you're trying to get up an escalator that is coming down. So you're moving, and the escalator is moving, but from looking on it from the outside, it looks like there is no change. But both movements, the one could represent the forward and the other the backwards reaction. Same on the treadmill, you're running forwards, but the treadmill runs backwards. You are actually staying on one spot.

T Yes. So those are some of the analogies that they speak of. Thank you, P2, for explaining those ones and P3 we'll need more. I don't know if you can think of any analogy that we can use there as well. It's a bit difficult, but can you think of anything from our day to day lives? Because the idea they are putting across there is that it should be something that our learners actually experience from home and in their kind of day to day lives? Maybe the escalator one they will understand it or the treadmill but can we think of more situations from day to day lives? It's homework.

P2 There is one. I'm just trying to find it. I found it in one of the PowerPoints, where it's kind of these the image of a toddler emptying his toy box while his mom is trying to tidy up. So the one is putting the toys out and then the other one is emptying the box and you are throwing.

T I think it makes perfect sense also a good one. So at this point, we are there in that we use that. Because here they haven't put in the idea of calculations, position of equilibrium and things like that.

Personally, I would suggest this is where Kc and Kp goes in just after those analogies. Now, we talk about the position of the equilibrium. And we now introduce the idea of Kc the equilibrium law itself after which we then go to Le Chatelier’s principle. We are left with about eight minutes and we will be kicked out soon.

The next one would be Le Chatelier’s principle itself. What they are saying there is that, because of the problems of Le Chatelier’s principle, we break it down to statements. So we take the one for concentration, we talk about it separately. Because learners are required to know Le Chatelier’s principle we break it down like that. This is the suggestion from the text.

Then after that general idea, there is a bit of reading that comes through. The one that I liked, especially, is the next article there which talks about the analogies in teaching of chemical equilibrium. So they have a long list and then they give the ideas that are being taught and the alternative conceptions that arise with a misconception. So it's the next one.

So for people who like to read, that is a very good reading. They give a nice table there so that's the next one that we'll look at. After that is the conceptual change approach. That is the next article. Can you find the conceptual change approach? The article itself? I can't pronounce the names of the authors. But the heading is conceptual change approach. Can you find it?

P3 Yes. Okay.

P2 I see why you can't pronounce that name.

T Yes, it's a bit difficult. It's a very nice reading.

P2 Way too many consonants next to each other I know.

T The one that I found interesting in this article is on page 224 and 225. Those are the pages that I found very interesting; you might want to look at them. So they are saying this conceptual change approach; when you teach using this approach you come to class knowing/having a list of the misconceptions and you talk about the misconceptions first, or you ask questions. On page 225 they have an example of a conceptual change text and on page 224, they explain how you actually make use of this idea of the conceptual change.

The example that they have here is: "When does reverse reactions start in a reversible reaction?" So in teaching, the misconception they are addressing is learners think the forward reaction has to end before the reverse reaction starts. So when presenting it they are saying, the teacher is aware of that problem and then, in teaching, they ask that question, "When does the reverse reaction start in a reversible reaction". So if it's something that you feel we want to use in our teaching, we'll have to make the conceptual change texts ourselves. For each misconception that we find in our learners, like we said, we want to make this a collective that we are going to be using, and probably share with colleagues.

After this one, there is the last article there where we are using interlocking building blocks or building bricks, in hands on activities. This one is more of a game, where we think of a game that we give our learners to do and in that process they learn the idea. So, for this one which looks like the Legos, I think they are called that, were we put a mixture of them one person breaks them, de-assembler, and another person assembles them together, again. It is a game that we can use in teaching. We are running out of time, three minutes, I think I am talking too much.

P2 For that you can actually even use the MolyMod you build in ammonia.

P1 Sure we did something like that. I think we did some we had a kid making them and another person was unmaking them and they were trying to keep up with each other.

T Yes. You can use that one, but the challenge that I have with the use of the MolyMod kits is that the things would be physically different. The idea is they should be able to pick without looking, so if they're very physically different, there might be a preference for the bigger one, or a preference for the smaller one when you pick from there at random, I don't know if that makes sense.

P2 I've got tons of Legos at home.

T You do? Yes, we will ask for them.

P2 It's my pension fund.

T Oh, okay. So we'll ask for them and see how well that works.

P2 And we can try, we can try it.

T P3, can you think of a game that learners can play where the idea of, this equal concentration or the concentration being maintained? Any game?

P3 A game in the classroom?

T Because the idea that they're pushing for is, we have these games that we play at home? And can we find ways of having those same games that all learners are familiar with? But we can twist them a bit to suit chemical equilibrium - the topic?

Yes, it's also homework. We have given you a lot today. I can't think of anything, but it's those ones that we want to squeeze in there: Games that the learners are familiar with, but we can twist them to this idea of chemical equilibrium at any point, either calculating Kc or just reversible reactions, or the idea of dynamic equilibrium. Yes, P1, you can think of the game that the boys play. I can't

P1 Just thinking of something like pick-up sticks. You could have even just have matches/toothpicks on one side that someone makes an order and you got the other person making it chaotic; the one who's trying to organize it and one who's making it chaotic simultaneously. It would be something really simple

Reflective journaling: Workshop 2

Learning action: Modelling

Question 1: Where your ideas of the new model considered

P1 Yes, we interacted and collaborated well as a group.

P2 Yes, I feel my opinions where considered a coma especially since my background is very practical oriented karma meaning demonstrations and lab activities are used quite regularly in my teaching approach.

P3 I feel it can help both teachers and learners in the delivery and learning of this topic. The knowledge of content alone is not sufficient to help learning. The structure of the lesson does not a lot to help the learners follow through. The model discussed which I have partly used before helped in this regard.

Question 2: If not, were you satisfied with the ideas considered and how does this affect your willingness to make further contributions in the workshops.

P1 Yes, I find discussing these ideas and common problems with colleagues helpful and enjoyable.

P2 I am happy with the way ones ideas were considered and new learning models were explained and I'm willing to continue.

P3 Most of them were satisfactory, however in a minor or small way a lot of factors still come into play in the best delivery of the new model.

Question 3: How did you find the entire process do far, in terms of how it motivates (or fails to motivate) you to learn and make contributions in the discussions?

P1 Very motivating! It helped me consider aspects that I had not realised were so problematic with teaching LCP and keen to generate solutions.

P2 I really enjoyed the discussions and a more than willing to participate further in the workshops.

I appreciate being reminded of the common misconceptions that students form, it is really impressive to consider those.

P3 **I**t is a very eye-opening educational, informative and so much more.
The ideas and information being shared bring out so much that can enhance the teaching and learning of the topic.

Question 4: Describe any further reflections.

P1 I am looking forward to trying the proposed model with next year's students.

P2 It is very comforting to realise is that problems in certain concepts are a universal problem and not just specific to my individual experiences

P3 This workshop or the opportunity to be a participant help me to see me things or angles about this topic that I would have never seen by myself.

VIDEO TRANSCRIPT: WORKSHOP 3

T Coming up, we just want to critique and have a look at our, what do you call it? Scheme of work to say, what is it that we can or we should do in the teaching and what can we improve. So it's more like analysing the scheme of work and trying to find out how best we can teach the learners so that they understand. This is more of a new model: how we are going to teach. It's based mainly on the work that you gave me, P1. I've done for the first three or four lessons or so. And then because we had this discussion in the previous one, and then when I tried to, to bring everything together, I realized some gaps, especially just for the scheme of work, or the examining of the new model would give us an opportunity to also try to put everything else that we need. So this is what's there now. So let's start from the very first one, which is the short assessment at the beginning. This is from our PCK it is about student knowledge that is knowledge of students' prior knowledge. It is just here to set you off, to just get an idea of how much the learners understand.

So probably we can start from there to try to critique that short assessment. Will it work? Then having the 10 MCQ questions and how well will that work? And with this tool, here for the CHAT, is there any problem that we can envisage from giving those 10 multiple choice questions. At the moment the questions are not there but it's just the starting point.

P2 Take multiple choice questions. Yes, I think that's still not a bad idea or something.

T. Any possible problem from that? Is there anything? I've put time in there - that's 15 minutes just to get us started? Will that work?

P1 Who's going to mark it? Or are they going to mark themselves?

T That's a possibility. Do you think that works? Mark it themselves?

P1 If you're not counting it for marks and you just want to know what they understand, then they can actually just read out the mark and you record it so that you can just get a feel for it. Or, what I do sometimes, I just actually get them to put their hands up. So who got one wrong, who got two wrong … if you got five wrong and half the class put their hands up then you're like… okay.

T So, there is no other problem that we can see in there? As in probably the marking itself now that we have taken peer marking so it doesn't give you any load for marking.

P2 If you don't want it as recorded marks.

P1 Just to give you a feel for where they are at

T I am trying to get any other problem that we might experience.

P1 So there's this, it gives you the rest of the lesson, then you can maybe discuss the memo and see who's struggling and where they got something wrong then just elaborate a little bit more.

T So are there any other problems that would be possible? This peer marking really works very well. Is there anything else that you can think of? Where we could have a problem with that? For instance, the children are not going to be stressed when they start off with an assessment as a first thing for a new topic?

P2 It's up to you, you can make it clear as well that this is not for marks. As well, before we proceed, we need to go back to those questions include some of the typical misconceptions. They usually get it wrong, or maybe even give them one of those.

T And then embarrassment? Now that we are giving their peers to mark for them, is there a possibility that a learner might feel uncomfortable in the peer marking.

P1 I suppose it could be possible. I think you have to just see where your class is at. You have children who are... like today, they did a worksheet the other day, my Grade 11s and it wasn't for marks, but I recorded the marks just to see where they are at. It was group work and these two chaps got 4 out of 13 for group work. I said, why didn't you ask me if you were struggling? So now I would be hesitant to ask that class to read their marks out to me. And there's another child who's struggling. Because I am aware now that I have three children who are very weak so then I wouldn't want to embarrass them. Maybe I would let them, in a case like this, maybe mark their own and then just put their hand up.

T So I just wanted to find possible areas of problems. So I'm just using this tool to find all the possible areas where we can get problems.

So that assessment can be done in 15 minutes is fine, or it's going to be a challenge? Is it okay?

P1 it's fine.

T So, we then proceed with our lesson. Next, there is 'Reversible reactions and incomplete chemical conversions'. As we agreed in the previous workshop, that is we start with reversible reactions and incomplete chemical conversions. In terms of student prior knowledge, there is the misconception that all reactants are converted into products and this comes from balancing equations. When you balance equations first time you say balance everything, all reactants are going to be products. So you need to have same number of atoms on both sides. That is one misconception that comes out there that I could think of. Can you think of any other misconception?

P2 I think we need to be aware that somewhere we need to bring in the concept of a closed system. Because when you even look at your copper (II) sulfate and you are heating it you are actually fully converting all your reactants to products but because it's not in a closed system the water has gone off. So what I'm just thinking, this is something we need to be aware of, that if we are now starting with our copper sulfate that actually also still kind of manifests the idea that all reactants are converted because that's what you see. You cannot see the reverse reaction automatically and you don't see it going backwards.

T Yes, that makes perfect sense. So I have put that idea as conceptual teaching strategies under that section where that has to come up clearly and the explaining some of the problems that are coming through from that needs to be done.

The prior knowledge - so we are saying this knowledge that we have tested counts there as the prior knowledge. All the things that the learners already know: the chemical energetics, stoichiometry, gas laws and reaction kinetics and the misconceptions - we want to know the misconceptions early on.

P1 What do you do if a child says to you nothing is going on. How do we prove to them that it's going on? Like with copper sulfate, you can see a change in colour. For some of the reactions we can see change in colour but not where it starts to go back. And maybe the colour change is not that obvious, how do we prove to them? If they ask us, how do we prove to them that it's going backwards?

T When there is no colour change? Now, when there's no colour change then it is very difficult

P1 So we just use the ones with colours which helps us understand the concept.

T Until they have the concept and they have accepted it is as an imperial fact - that there are reactions that happen that way. And we also need an observation that we can make for that.

P2 Am I right in saying that most of those colour changes they all actually occur in the ones for when you're driving off the water of crystallisation?

P1 No, not all.

T There's the 'What's difficult to teach' under that section, and then we have the idea of incomplete chemical conversions. Our students understand particles as identical. So the idea that some are going to convert [to products] and some are going to remain is something that's difficult for them to understand. Can you think of anything at this point? Anything that's difficult to teach for the reversible reactions or there is nothing so far?

Now we have the representations to teach this. I have found this one respresentation from our previous discussion. there is the copper sulfate one that's reversible, the ammonia reaction and the KSCN reaction which all proceed in both directions. P2 you're ready for one?

P2 Yes. I think because it's copper sulfate, it's nice to see and I find it doubles up because they also need to know it as a chemical test for water. It's a very popular one and makes sense.

There are two ways you can do it: You can either do it in a test tube, or you can have it in a crucible or an evaporating basin, and it's quite quick. Right, so I'll just do it in the test tube now first. And you can let them, if you have the facilities, do it themselves. You can do it as a demo, or you can do it as an experiment. And I think the test tube is actually a little bit nicer because you can see the water vapour condensing. You can see that it's the water being driven off. You can obviously not make it a closed system, you can't put a stopper otherwise the glass will shatter. So you can see something is escaping out of the system. I can even hear it a bit. But one could stop here. And then just let it cool down. And if you are lucky you actually see the condensation running back down and then where it drips in it actually starts the reverse reaction.One of the tricky bits, they often forget, is that this is very hot. They can't add the water back straightaway otherwise the glass shatters. So they can leave it to stand there for a little bit.

Alternatively, you can do it in a crucible or in an evaporating basin, but it's a little bit slower. You can actually already see on the side where the water is creeping back down that it is reversing and you see the condensation here. So you were driving off the water the colour changed but once the water goes back into the anhydrous the colour changes back. It's beginning to change. It's changing here as well. I think I rather stop before I even decompose it.

If you looked closely, you could see a little bit of steam coming off. But the tricky part here, of course, is that you will have lost the water out of the system. So you have to physically put it back in. That might actually help at looking at those two reactions separately. If you're writing it, I find it sometimes also helpful to write them.... I do not only use the reversible arrow, but I actually write it down as two individual reactions.

T Okay, and then combine them afterwards.

Then there is the ammonium chloride. We'll leave this one. It says YouTube watch on the scheme because there are a lot of resources online for this one. Then, there is the $FeCl_3$ one, which I think works very well for Le Chatelier's principle. I think probably we can just have this one as the one that we will use demonstrate. It is fine for the reversible reactions - I think we can use this one. And then do a YouTube watch for the ammonium chloride. And we can use both of those; and the cobalt chloride because they both show how the colour changes nicely.

P1 So you could also do the cobalt chloride.

T Yes same thing, same concept

P2 And then you could show them if you have. I don't know, I'm not 100% sure about those $CoCl_2$ test papers, are they standard? Are they actually part of what we need, like your litmus paper is standard, we should have it. I don't have a look here. Hopefully, it's holding up. And then it comes nicely blue again.

T And then there is this nice simulation that I found, a computer simulation that shows a reversible reaction. So they start off with the reactant and on the other side there is nothing. Then the products now are going to be formed, that is the reactants converted into products. They have different colours for the reactants and products. Then, the products start getting converted to reactants and you can see both happening at the same time. That simulation works very well.

P2 I think that those PHET people from that university have done really well. You'll also find simulations for other topics. We actually found very nice simulations for Maths and Physics.

T is there any analogy that we can use for, for this concept, where we are using the learners' knowledge from their day to day lives, especially in social settings?

P2 I mean, you are talking now of seniors that are doing that. But maybe they still remember the days when they were building with blocks or when they were doing Legos or whatever. You had your idea, little blocks, you build something. But then they would have to clean up and they broke it all apart again.

T Yes, yes, yes

P2 Changed all your products back into reactants. Take the puzzle and you build it all together and then you break it apart again, without losing a piece.

T Building it and breaking it again. These analogies work very well. There are many good ones.

What could be the problems associated with this topic so far in terms of CHAT, using this way that we are proposing to teach it now? Is it going to be a challenge in terms of time? Is it going to be a challenge in terms of the rules set out by the school in terms of how we do our work? Or with the parents? Or with the division of labour? Gives us too much to do? What can be a problem there? Or anything or the children are not going to be comfortable doing some of these experiments? Or it doesn't help their learning - that it actually makes it difficult. Or that this introduces misconceptions?

P1 Maybe not all schools have access to internet. Good internet. So even though, you know, there's a YouTube watch, and this last bit simulation, but if you don't have a device that works on the internet to do it, then you want to actually use it.

T Yes, there's that problem. And also, do we understand how to make use of the simulations and make them work and how to interpret them. For the YouTube watch there was some concern about the accent that is used by some of the YouTubers, it's very difficult to understand. You can get your nice video from the east and then you can't hear what they are saying, or from the west. So I have that.

P2 Or from the North, sometimes it's difficult to understand as well.

T Yes, from the north as well.

P1 Yes, there's some Khan Academy, who have put out a lot of resources. But some of them have a very, very heavy accent. It is really difficult to understand all you know, maybe like a Welsh Scottish accent. It is just so different from how we speak.

T Yes. Okay, that's fine. So probably that could be one of the challenges that we have, particularly when you want to pick these resources that are online.

P2 But you know what might help them? I'm not sure if it's a setting you can put but I find many times you find the YouTube way it actually has the printed text, where they kind of read along. that might be something

T What do they call them?

P1 Captions

T Yes, closed captions, but sometimes they are not accurate when the accent is so heavy. There's actually double trouble because the system doesn't read them correctly as well...

Okay, so we can say the 'Reversible reactions' is fine. It looks like that! There's this conceptual idea that we agree that we want learners to accept incompleteness of a chemical reaction as an empirical fact. And then the idea of a closed system; we want them to understand that whatever we're talking about, it is in a closed system.

Next, let's move to dynamic equilibrium. So how much time do we think this will take and how they refer to and how would that work out in terms of the amount of time that is available to us? Is it going to cause problems or it's something that we can work out and we do it beforehand?

P2 Like the copper sulfate reaction has double value. I think it's actually valuable if they can actually do it themselves spend at least one period on it. I always think it helps, that they don't just have to believe things. Now go see that. Okay, now the reversible reaction has started, how do I know? How do I see that?

T I would believe that, learners ask questions like that: How do we know?

P1 If you let them do the prep for one lesson, then I think for the reverse reactions and incomplete reactions or for the two, I think you can do the rest of that in two to three lessons. It depends on how much detail you go into and how much the children seem to be struggling.

T Okay, so that one is good. Number 3 would be dynamic equilibrium: Position of equilibrium is the next thing that we teach. The prior knowledge that we would need obviously would be knowledge of reversible reactions and that other prior knowledge from stoichiometry and balancing equations, knowledge of basic mathematics, which comes with graphing - this one is a problem.

We have a few misconceptions that are there: The idea of static equilibrium was mentioned in the interviews and in the other workshops, compartmentalization of equilibrium where they put equilibrium into different compartments; the concept of oscillation as in the reaction goes first to the right and products are formed, then it starts going back; that concentrations are equal at equilibrium. I think you mentioned these in one of the workshops! Any other misconceptions that you can think of or challenges in dynamic equilibrium? Or any other prior knowledge the learners should have?

P2 I think it's also kind of a little bit difficult to understand that not every reaction achieves dynamic equilibrium. So how are they to know? Or how are you supposed to know which type of reaction this is applicable and for which is it not? Say your common reactions that you would have discussed: acid-base and metal and an acid. Those are not reversible reactions! Or a combustion reaction or whatever, you don't consider those! So you do consider some a big amount of the reactions as going to completion. Now all of a sudden, you're telling me some of them are not. That's what I have known for like five years in science. But I think that is the tricky part, actually. It wasn't all wrong but there are some reactions where it is reversible.

T What's difficult to teach for this part? I have here macroscopic properties - constant, but they are processes at microscopic level. I think that's what you were alluding to, the fact that we've been saying for all this time, that the reactions are going in one direction, and we see changes and that's what we associate with chemical reactions. And then now we want to say there are processes that are happening, but then you can't see anything. That becomes problematic! I've put that one down. Anything else?

P2 When you come from rate of reaction point of view; because you are also told me that once the graph is level you have reached equilibrium, depending on what you're measuring. Now you're bringing these funny graphs where there are two lines

T It's a tricky when there are two graphs: Is the equilibrium where they meet and cross or equilibrium is when they become flat? Well, that one is a good one as well. So yes, graphing is an issue.

So for representations, there is the analogy for a queue in a shop, the treadmill and escalator, I think you're the one who mentioned that one. And then there's the simulation now, where we have the water into buckets, and then the leaves or apple war, where people are throwing from one side and then the other side there are people throwing the apples back. However we look at it whenever get to a point where one side will not have any apples because these ones will continue throwing in these ones throw back even if the other one is slow, we'll still get to a point where we get equilibrium where the things are balancing out

P1 What if we use a leaves instead of apples?

T Instead of apples we can use whatever is workable in their contexts.

P2 You can even use one of those. I have used the toddler and his mum: the mum is trying to clean up putting the toys in a box and on the other side the toddler taking it the toys out.

T At the times the context might be difficult for some of the learners. Like they don't all have apple trees where they live and now thinking of an apple being thrown… it may be a little bit difficult to imagine. So, the analogy is the problem now because the analogies can reinforce the idea that …

P2 You can use another example. Like one person is digging a hole and another person is throwing the sand back in.

T These are nice analogies that we can use. But another issue there is that analogies can reinforce the idea that reagents and products are separated. There is that compartmentalization. Let me do this one for water in a bucket.

So we start with two buckets. In one there are reactants and the other one products. The reaction is reversible so either can be reactants or products. So I can choose which one I will use as the forward. It's just a question of reversible…

Eventually, we'll get to a point of dynamic equilibrium where the amounts transferred will become fixed and thus this reaction will never get to completion. That is, at some point we are going to get dynamic equilibrium where the amounts transferred become fixed.

Basically this one is simulation for dynamic equilibrium and reversible reactions as well, where we are saying the reactions never get to completion. So, that's one for me there!

All right, then this a good simulation, and probably we can add it to simulations for the first concepts, where we are trying to show the idea of incomplete chemical conversions. But the problem now is that the reactants and products are placed into different buckets.

P2 That's how it kind of shows two separated systems but technically this is all one reaction and can be thought of happening in one big bucket.

T And then once we are there, there is another one that I want us to look at, and might take us a minute or two: 'Modelling dynamic equilibrium with coins'. It looks like a nice one as well. Here we can use coins or anything small - They say that can be coins but it can be paper clips, it can be stones, it can be whatever.

Here I have small blocks of wood, and we want to model dynamic equilibrium. So what do first is we decide what our rate constant is for the forward reaction and what our rate constant is for the backward reaction. We do the experiments and record our results.

I start with these blocks, they are 48. I have decided that for the forward reaction I'm using a rate constant of ½. So half of the 48 blocks are going to be converted into products. So it's just a question of counting 24. And then the 24, go there (product side), and then the other 24 go there. So I just count nicely, then I get 24 - 24. And then I record that in the table, as shown there, the first row. So initially, the number of A to move is 24 they go there and for B representing the reverse reaction there is nothing because we didn't have anything.

From there, we go to the second one where we move half of the 24. So we move twelve. And then from the right hand side where we had 24, as well, we move a quarter (rate constant for reverse reaction is ¼). So we'll move six to the other side. So move six to the left side, and then move 12 to the right side. And then we now have new totals. On the left side, we now have 18 and on the right side we now have 30. Then we find ½ of 18 - we move 9. And they go to the left. We find a ¼ of 30 – we move 7. And then now we have 16 on the left and 32 on the right. The moment we get there, whatever we do our numbers now are maintained. The good thing with this one is it clearly shows that we have equilibrium, but the numbers are not the same. We have 16 on the reactant side, and then we have 32 on the product side, but still we have reached equilibrium. So it's one that we can also use as a nice simulation. And then it has also do calculations for Kp and Kc. I find it a very easy one because it uses readily available resources.

P2 You can also use the Molymod kits

T The Molymod kits, Yes that's a nice one. What problems can we find with this analogy? Besides the compartmentalization of equilibrium I have examples of some misconceptions there on the nice sheets that come from the teaching and learning of chemical equilibrium by Van Driel and Graber.

P2 I haven't taught at AS level and never taught Kp so for me, it stops where I'm saying the rate of the forward is equal to the rate of the backward. Then when you now will say you use half going this way but for this one only a quarter, but for me, I'm reading that there's a different rates.

T More of the rate constant, it's a little bit of a tricky one.

P2 So from rate to rate constants, I think we need to scaffold it carefully as well.

T Rate and rate constants, the concept is a little bit difficult

P2 Even when you go back with your water bucket analogy you used different sizes. That I would interpret as they are different rates but if you want, as I said, to use the same rate you will…… you get to this as well…

T What we are pushing for is that … because if you use the same size then they will have the same volume for both sides then it also adds to that misconception that equilibrium is when the concentrations are the same. so that's the one we were trying to avoid having equal numbers to try to have different numbers but still have the rate being the same…

Ok so this one it's now an issue of a tool and a subject (CHAT terms). That's a nice one as well.

Ok, so this one is done, now equilibrium law which is describing the position of equilibrium - Kc and Kp and calculations. So we are saying when learners come they want to have a good understanding of dynamic equilibrium and also the position of equilibrium; what we mean when we say position of equilibrium and then this one is now giving them the numbers to that description. So, what do I have here? There wasn't enough information in the scheme of work from our discussion to fill this one nicely. So what can we say there would be difficult to teach? I would put graphing there. Learners find graphs difficult to deal with and because they find it difficult we find it challenging also to get them there where we want them to be how to interpret a graph and….

P2 You find something when you say basic mathematics. I think even fractions is a challenge to some students so that when now your denominator increases that it actually decreases your Kp, like an eighth is smaller than a half.

T That conception is difficult for some learners. What analogy can we use? I have this one as a simulation “Coins for dynamic equilibrium”. If you read the paper nicely, you'll see how to do the calculation And it works very well. But what can we use this analogy for this concept? Or it's something that we might need some reflection when we when we chill at home? To find an analogy that we can use for this calculation or an experiments: experiments are many now, but for the calculation itd difficult need a lot of equipment, for an actual experiment where we can calculate concentration based on light transmittance.

P2 What I'm asking is “are there tables available where they can manipulate the numbers?” where you can…..

T So we are saying under conceptual teaching strategies, we need to find and give them a table of values where they can just work out and see how it works for different reactions. That's a good one.

What could be the problems for this one? Teaching it, time wise, where will the problems come from? For us, the teaching time and the usual one: language or those problems that we're talking about, such as division of labour - who does what?

P2 They all have calculators but they don’t always know where to punch in the values. If you have some brackets somewhere, but do not punch them in then your answers won’t be accurate.

T Yes. The tools (CHAT terms) as well. Yes, that one is very prominent. I've seen it in marking; these learners fail to get the correct answer because they don't know how to use the calculator. Everything else looks fine but when they get to the calculator they have issues. Now with this Maths, do we see any challenges with the other departments where we are saying we might get into some conflicts of some sort? For instance, the way we are teaching fractions, the way we are teaching graphing can be different from how they do it in the other department. I know with Biology we struggle, where we want a smooth curve, they want the straight lines.

P1 In Biology often, they join a dot to dot: depends what the curve of the graph is - if it's smooth, they can join it smooth. But I know with Physics, for example, they want it to go through the origin. And most of the time, they want it to be straight, and not all our graphs are straight lines. So that is confusing for the children that sometimes the expectation and what they need in Chemistry, Biology and Physics are not necessarily the same. It's all slightly different focus on how they want the graphs. I mean in Maths, you know, they tend to work with all four quadrants, whereas in Biology, Chemistry, Physics are mostly working just in the first quadrant.

T I'm seeing a challenge with the community now, the way we are teaching and the way they're teaching conflict a little bit.

Next one is teaching LCP. This one is everyone's favourite and is the difficult one. For students' prior knowledge we're saying they need to understand the position of equilibrium before they shift it. Kp and Kc are basically describing that position of equilibrium. Then, the order that we have taken clashes with the syllabus order, because the syllabus starts straight from saying Le Chatelier's principle,.... reaction then Le Chatelier's principle without describing the position of equilibrium, Kp/Kc. If somebody doesn't do that nicely it might cause a problem there, maybe with the rules (CHAT terms), that's how I'm looking at it - a clash between the rules and the tools I think.

Now, there are a lot of misconceptions. The Le Chatelier's principle is difficult to understand, we spoke about this one. Its language is difficult and we agreed we will break it down into smaller statements so that it's easier to understand for the learners. For instance, for the temperature we say an increase in temperature favours the endothermic reaction and then a decrease in temperature favours the exothermic reaction.

Now what's difficult to teach there in Le Chatelier's principle? The language is difficult because it's used for different purposes, particularly when they start talking about yield. And I've seen that this is where compartmentalization becomes a bit of a misconception where they now say endothermic side, rather than the left hand side or the right hand side, because they have compartmentalized and said reactants are the ones that endothermic and the products are the ones that are exothermic. I can put that under difficult to teach.

The understanding that when states are different and some substances have to be ignored. For example, when we are operating in the gas state and we have different substances, and we are counting moles, we ignore the solids and just focus on the gases. What analogy representation or simulations can we use? And what can be the problems associated with Le Chatelier's principle; the new way we want to present it, where we want to do all the experiments and representation?

So I'll start with the first experiment or demonstration, the one that I like uses Cobalt chloride. Hydrated cobalt chloride is pink. So we have our cobalt chloride solution here, which is pink. I'm just going to put a little bit there and a little bit there as reference. And then use the reaction to show Le Chatelier's principle. We saying, in solution, it [cobalt chloride] reacts with concentrated hydrochloric acid and forms that $CoCl_4$ complex, the one that is pink is the $[Co(H_2O)_6]$ complex. If I add hydrochloric acid that will push the equilibrium to one direction; to one side to form a complex. Initially it's pink and then I add hydrochloric acid and then it becomes blue. So the $CoCl_4$ complex has been formed. Now it's nice and blue. And then but to show the reaction is reversible, I can add water to that. And then it should go in the reverse direction. And become pink again. So the top part is getting pink as there's more water now, favouring the other direction. Okay, so this one is a nice one. It also works for reversible reactions. The first one where we say this one, we put it there, and then we go to the blue. We put water we go back to that one. But it also shows Le Chatelier's principle

P1 Do they stay separated like that.

T No, it's just because I didn't mix.

P1 But it's actually even nicer like this because you can see the two different ones. All at the same time!

T. I wanted to show just the top part so that I have that one [colour], but if we mix nicely then we will have this one [colour]. Still the same reaction! And when we add the same HCl we form that and it becomes blue again. It becomes nice and blue! So the equilibrium has shifted now to that direction [reverse].

Now I want to remove the chloride. I'm going to use silver nitrate to see what happens. So, silver combines with the chloride and then that white ppt. is forming. As you can see from the top we can start seeing the pink forming as well. It's turning more to the pink as the chloride is being consumed. You check the top part! It now has a pinkish colour there, because the chloride is being taken out by the silver as we form that white substance and then a pinkish colour there. Basically this is one of my favourites as well. The cobalt chloride works very well in showing Le Chatelier's principle, anything from you Le Chatelier's principle! I think this one works very well especially if you make it very dilute. Then you don't have to use a lot of solutions.

T Yes, to dissolve this I used just a spatula tip of Cobalt chloride. If it becomes too concentrated then you add lots of hydrochloric acid and lots of silver nitrate. There is your favourite compound! This might present as a problem in terms of time and in terms of resources but if we plan nicely beforehand it might be doable. When it comes to division of labour in the classroom who does what with the learners? Probably they are just used to coming in sit and listen, but now we are saying clear this area, help here and there, it might come in as a clash there. Then, I know the school will not like us in terms of resources when you do a lot of these experiments - they'll start talking about the budget.

P2 Nitric Oxide – it should be a mixture of the two gases, the nitrogen dioxide and the dinitrogen tetroxide, where the one is produced by an exothermic reaction and the other one by an endothermic one. I've got hot water in this one (beaker) which should shift it towards the end of right side and then you've got one with the ice water which no one can see. The way the one should get darker and the other one should get lighter and the one that doesn't change anything should be kind of in between when you see it. Did it stop?

T This one is becoming darker and that one is becoming faint.

P1 Can you lift it out of the ice a little bit. It's not as obvious but I think it's a little bit darker. Yes

P2 It's a bit difficult to judge how much nitrous oxide because you don't want to tap too much because then you're not sure that the ……

T it's not as obvious but it sure is getting a little bit darker.

P2 We're putting this now in here and vice versa

T To see the reverse

P1 It's just getting fainter, I think before you made for me this nitrous oxide in the bigger flasks. Maybe just more noticeable because then there was just more of the gas.

T And then probably need some time as well. We can leave it there. And then we can do the SCN one

P2 We can get this to be darker

P1 What is the blue at the bottom?

P2 That's just a bit of acid and that's how you should reduce the nitrate make it with a little bit of copper and nitric acid. I think this one does get darker.

T With higher quantities it gets better.

P2 It is losing the colour.

T And how much do you love your iron - The blood red experiment? I'm not a big fan of that one. But I see everyone talks about it. I've never used it in my life. So I didn't want to try it today.

T So that's the other one that I think works better. Well, also the FeSCN!

P2 Yes Iron... mixed with iron

T That one is my favourite when it's on video, yes it becomes a quick blood red.

T should be getting darker dark red, reacts quickly.

P2 Shifting equilibrium to the right side by changing the concentration.

P1 And then if you add more?

T You were saying sodium hydroxide can we retry it - sodium hydroxide that removes the Fe ions. Let me get the sodium hydroxide. Things are happening

P2 As we removing the Fe ions and then it goes back. Yay its working nicely adding more again!

T and it goes back again

P1 **B**ut if you add potassium thiosulfate does not make it lighter

T Potassium thiosulfate?

P1 Yes, does not make it lighter

T Would it make it lighter, it should make it darker? That might be a nice one as well

P1 Okay, sorry I'm having a moment!

T We see it's getting darker.

P1 So adding either of the reactants is going to push the equilibrium in the other direction.

P2 Here what we have done is to remove the iron ions and you see it easy and nicer. I don't know why the reaction happens instant than the other ones

P1 So what did you do to remove the iron ions

T We added sodium hydroxide to make that complex Okay, so that one is done and then we said in terms of resources

T Okay. And then there's the last part now, which is about the importance of compromise between equilibrium and reaction rates. This looks very straight forward, it doesn't appear in literature much in terms of misconception, but there is an analogy that I use. I don't know if it works for you. Where I use the balance between the stove setting when cooking; you want to cook well, so that the food comes out nicely. And then you also want to do it quickly. But you're not going to put that oven at 600 degrees Celsius so that it's very rapid. You find the balance point because then it doesn’t cook very well. I don't know if you have another analogy that you use. Like you want to make omelette, you want it very fast, but still you are not going to put your stove very high, you control the heat

P2 I usually approach it more from an economic angle that is the money. Even if you have it, you know what you want but you must balance it. They seem to have a good instinctive understanding that you can only have so much pressure that is feasible because …… Equipment you need ... some even have pressure cookers at home.

T That one works also, as the pressure cooker, which comes in as an analogy for the equipment.

P1 Yes, how much in atmospheric pressure does a pressure cooker cook at? To just think about it, the atmospheric pressure pushing on you is one - now think; if its two it's going to squeeze twice as hard. So imagine with thermal cracking it is supposed to be 70atmospheric pressure. Imagine how pressured that is! First of all, you wouldn't get that in nature and second of all, how big must your equipment be - how expensive must it be to enforce this. So as she says it's like that, you know, compromise between how long it's going to take, how much it's going to cost, how much atmospheric pressure is and how high the temperature is. Basically, which one is going to give you money, is going to be the most cost effective for the best yield? Because I think they understand that concept of: if you’ll have a business you want to make profit. You don't want to be running a business and you’re not making any money.

Reflective journaling: Workshop 3

Learning action: Examining and Testing

Question 1 What problems of the new model are salient to you and you feel they will give you problems in your teaching? (e.g. the new strategy requires much more time).

P1

- I am not familiar with the model showing the link between rules tools division of labour it is and tend to work more on the gut instinct in my teaching.
- I like the idea of modelling dynamic equilibrium in class. However, using coins foresee petty theft occurring and would rather avoid this scenario.
- Using small wooden blocks from physics is also nice however this equipment is seen as belonging only to physics. I would rather bring a paper punch from home and punch red and black circles to keep in envelopes for this kind of chemistry demos.
- A short at assessment in advance may intimidate learners especially those who are weak shy or not confident in their ability.
- No analogy is perfect for instance trying to demonstrate forward and reverse reactions often doesn't help students realise that both happen in the same container simultaneously.

P2

- Giving a formal assessment at the start of the topic could possibly backfire as you might be shocked on how little students have internalized from the topics you considered a foundation for teaching equilibrium. This might mean you have to go back to the drawing board and reteach some of the concepts you considered important, which will then constrain your time even more.
- Although using representations, such as heating of hydrated copper (II) sulfate comes at a cost to schools it should be included into the school's budget as I strongly feel it is a valuable experiment which students should be allowed to execute hands on. Especially for those learners who continue to go to AS or A level as they need to eventually write an advanced practical skills paper.
- A challenge can be though the shared responsibility between teachers and students and if the school lab assistant with regards to prepping and cleaning up as many labs are shared venues.
- At times requests for materials get sprung onto the assistant without notice i.e. getting a message the night before asking for material needed the very next day. Or the lab is left in quite a state as the teacher had to rush off to the next class without ensuring that the learners have packed up properly.

- What I mean to say here, is that it requires proper planning and organizing with colleagues should you need their assistance. If you are however in the lucky position of teaching in a lab and if you know your way around it, you can include the demonstrations ad hoc to illustrate the points you want to make.

Question 2: What problems were overlooked in the workshop that you envisage you will encounter when implementing the new model?

P1

- Theft of coins for as mentioned above.
- Sufficient access to chemicals and resources
- Not enough laboratory space or time for all science classes
- Did the mathematics required for chemistry is often taught after the mathematics was needed in chemistry. Science teachers do not have the time to teach maths background as well.
- Some schools have strict subject heads or Principals who will not allow the science teachers to change or adapt the work scheme according to the new model and insist it is completed as set out by the regional office.

P2

- I am still concerned that students will struggle to identify which reactions are reversible and which are not, it remains a challenge to find a simple explanation.
- While we now illustrate the concept of reversible reactions quite nicely, we should think of a way how we can teach the mathematics of the equilibrium constant so that students can feel more confident.
- Often basic fractions are not well understood i.e. one eight being smaller than one fourth etc, so it remains a challenge to understand how a change in concentrations affects the overall calculation…. (Not sure I am expressing this well)
- I find the concept of shifting the equilibrium to one side or another often makes sense if it only needs to be described qualitatively.

NO WORKSHOP: LESSON PLANS

P1

Goals of Lesson:

- to help students understand that many chemical reactions are reversible.
- that reversible reactions do not go to completion.

TSPCK

Notes	Plan
SPK: previous topics on stoichiometry energetics gas laws and reaction kinetics assessed through tests. Previous days lesson introduced the idea of reversible reactions as a concept Dehydration and rehydration of $CuSO_4 \cdot 5H_2O$ was explained previously and demonstrated. **WD:** bear in mind that this topic is difficult to grasp and not easy to see. I am to visually help them conceptualize their ideas. **CS:** the basics of reversible systems and equilibrium is taught before bringing in calculations and le Chatelier's principle.	**Introduction**: remind them of what we observed during the demonstration off dehydration of copper sulfate in the previous lesson **Explain** that the forward reaction must start before the reverse reaction can begin and that concentrations are not the same at equilibrium. **Demonstration**: use of LEGO blocks (provides a detailed description of analogy) **Points to emphasize**: • forward and reverse reactions don't start at the same rate; there does not need to be the same amount of both products and reactants. • forward and reverse reactions happen at the same time and in the same container. At the end of the demonstration, move reactants and products to a large see-through tub and let students continue at the same rate to complete the forward and reverse reactions. Also the use an analogy: the treadmill (provides a detailed description). Students will make notes from PowerPoint explaining the main concepts. **Homework**:

	Students must come up with their own analogies to help them understand this principle well.

P1

Lesson plan outline: Focus is on introducing the concept of reversible reactions

CS

Part 1:

Check students' prior knowledge on changes of states and how they can be reversed.

Discussion:

CTS

Observations made during phase changes of water.
Express the changes using the chemical equations:
H_2O (g) → H_2O (l) and H_2O(l) → H_2O (g)
Introduce the sign for the reversible arrow (⇌) as a new conceptual idea
Combine equations above to: H_2O (l) ⇌ H_2O (g)

Part 2:

Demonstration: burn a piece of paper
Discussion: physical vs chemical change, reversible reaction vs irreversible reaction)
Note: chemical reactions students had dealt with are not easily reversed
e.g. combustion, metal and acid reactions, decomposition reactions

Part 3:

Demonstration: Heating hydrated copper (II) sulfate in a test tube.
Observations: Colour change, water condensing at the mouth of the test tube
Discussion: the change required heating that is it is an endothermic process

After allowing the test tube to cool condensed water is allowed to drip back.
Observation: Colour changes back to blue, students can feel the test tube getting warmer an exothermic process
This can introduce the idea that some reactions are reversible when conditions are altered and also that the opposing reactions are different with regards to the energetics.

Part 4:

Students hands on activity: Heat a small amount of copper (II) sulfate themselves
this is a good and simple exercise to build their confidence in their lab skills, such as heating gently, lighting the burner, where to attach the test tube holder, small common mistakes that are often made are for example clamping the test tube at the bottom, so I would like to draw their attention towards correct techniques

Reflective journaling: No Workshop

Learning action: Implementation

P1

- There's so much information that can be covered and so many analogies or demonstrations to draw from. Although we have come up with a proposed work scheme, exactly what to cover or leave out in each lesson was tricky to decide upon.
- If you have recently had children you may have access to LEGO, otherwise it's not something you may have at hand.
- One can also use Molymod kits but not all schools or teachers will have access to them.

P2

- A challenge I am facing is the high demand on the laboratories which are shared between Chemistry and Physics classes over various Grades. This means I need to make absolutely sure that the lab is available for the lesson which I would like to use as an introduction to the topic. This might need negotiations with colleagues.

VIDEO TRANSCRIPT: WORKSHOP 4

T Thank you so much for pitching up, I know it's a little bit difficult. This is one of the challenges that we always have when it comes to professional development, in general, and worse off when it is research. People have their lives and they have a lot of commitments to attend to. And then you've got these to add to their lives, which is why I was saying, let's just keep whatever it is at a bare minimum, but you guys like writing it a lot. In the reflection I get a lot of information and I'm saying WOW.

P2 We just thought you can pick the best bits and omit the rubbish.

T All the information is very good in terms of the quality of the information, it's very good. It actually makes the research very, very rich, because everything is coming out and from all directions. So, thank you so much for that. This workshop, the very last one is just a reflection on the process itself. And then we also want to look at what they call "Consolidating and Generalizing. So it's something that's not meant to take a lot of our time, or a lot of our time, we just going to reflect on the process. You see, we've been reflecting throughout. But now it's a question of reflecting on the process itself and reflecting on the model that we came up with.

There is a little bit of reflection that I saw in P1's reflections on the process itself and on the model. So that's what we want to look at here. So the question that I have is: "What could we have done better for this entire process?"

Just to give an example, I will have preferred the face to face, especially when we are starting off with our chemical equilibrium issues, which would have helped a little bit a and made it more rich, I think. But the problem with face to face, like I have seen, is that the recording was not easy - it was not as clear as the zoom session.

P1 The benefit of a zoom is that you could be anywhere and kind of join the meeting quickly. You know, you don't have to be worried about traffic and travel time or your other engagements. It's easier to join the zoom with hectic schedules. I think that's one of the problems that you've had is just trying to find time when everybody is available.

P2 You know, especially with the colleagues from the other schools, on the other end of town, all of that is a challenge. So yes, so that's the advantage of zoom, then everyone can kind of join from the comfort of their home or wherever they are. And you don't need to plan an extra hour traveling back and forth into your schedule as well. As you said, it is already very tight for everyone.

T Then traveling would add a few minutes to that. There's another one that I would ask about. It has to do with the amount of information that you got, first of all about chemical equilibrium and then about the theories that were in use the TSPCK and the CHAT. How did you find that?

P1 I think that the amount of information was fine. I think that you really helped to slim down. You know, you went in and looked up some things for us and sort of pointed out what were the more important things and I did not have to go and study it for hours and hours. You had already whittled it down for us. But I am just not familiar with all those the new terminology that you were using. I think it is sort of quite different; it's newer than when I studied. Back in the olden days when I studied terminology was different. So I struggled with the new terminology, the educational terminology.

T Yes. And but I'd say for that one, we might need to just look at it a little bit, like the TSPCK one that just breaks down these things into what learners know, representations, conceptual teaching strategies, because then, for me, I think it just puts the teaching right there in front of you, and says, Have you looked at this? Have you looked at this? Have you looked at this? And have you looked at this in your teaching? So I thought that one is important, but the contradiction one, for the CHAT. I think that one is difficult?

And then probably something that was coming through again, in the reflections, we are supposed to look at the scheme of work, the model that we came up with, and say, Where could it create problems again, so we have been reflecting on this all along. But now we just want to sum it up and ask: Where could the problems be? In particular, we now want to focus on the other activities, like sports, that happen in the school. For instance, we might be asked to do our practicals in the afternoon, by you know who, saying: Let's do our practicals in the afternoon, so that I have time to prepare? And that can affect sports and extra murals, or things like that? Is there anything that we can think of in that regard? Or it's a model that's really fitting into nicely with your work? That also is a very good answer.

P1 Well, I don't know if it links up, specifically enough with what you are talking about but, for instance, now they're talking about the exams coming up, that they want the physics, chemistry and biology practicals; they want them to be in the afternoons. So that automatically takes away more of our time. And, you know, I think we're already just finding that the, we just struggling to get into the lab with all of our classes. And I would hope we wouldn't get to stage we would actually just need to do practicals in the afternoon, just to try and get everyone to have that experience.

T Yes, I think that is maybe where we are going really where we have to do it in the afternoon.

P1 Our resources are under pressure.

T What else can I think of? Basically, I think that is the main area of concern there where, because we have introduced this model that has a lot of activities in it. It tends to go into and encroach into other activities and create conflicts. Like you have said with the exams, and then the resources are stretched.

P2 No, I think we also mustn't forget, though, that we are in quite a privileged situation where we are. When I'm thinking of the challenges that P3 has, we you sometimes think we are, we are now complaining on a different plate. Where someone in a government school is like, might think, What is their problem now? They have their bread buttered on both sides and still find the challenge. So as I think it is also sometimes I find it difficult when we are now reflecting to put myself into the shoes of now a government school teacher with 50 kids in one class and, how will they cope with those that's implemented.

T That can be a bit difficult, which is why we needed P3 to be here but the marking that she had to do that made the process very complex. We wanted that that kind of aspect from that side. But you government schools particularly in the Namibian context, they do not struggle much in terms of getting the resources. Their problem comes in when it comes to the number of learners that they have in the classroom. But if they want resources, I think there is an open cheque there. Which is why when they Talk about buying chemicals for the exams, you'll hear them talking about ridiculous amounts being spent.

P2 I think it was that became apparent this year when, the Minister actually put it out and said; Schools, you need to calm down as to what you are asking. I remember Jane, I was asking me: “How much did we spend?” because she had seen these outrageous figures? I said: “no, we only had to order XYZ, because other things are already there: they are standard lab equipment - they are there. We didn't need to order more voltmeters, we didn't need to order more crucibles because we have them. sometimes it's just we use it often as a nice opportunity to stock up on, you know, get a few more burettes and get a few more pipettes. But it's not that we ever had to start really from zero, kitting us out for an exam.

P1 Don't you think I'm just speculating that maybe some of the schools didn't actually have enough equipment to start with? So maybe they're using the exams as an excuse just to get the equipment they need.

P2 They always put that on the REXO form that comes is that schools should not use this as an opportunity. I think it's more of a problem or of a challenge that there's no one really responsible or in charge of the equipment, it just goes missing afterwards. Or it ends up who knows where.

T What I've noticed is that, they just get the list as it is, they don't check what's in the lab, and then they take that to the suppliers. So it's easy for them, and they just buy everything. Ok, so basically, that's the story. And under consolidating P1 you mentioned that there now a lot of activities in the scheme and now you are spoilt for choice. Is that a very big problem?

P1 No I think it's just like trying to decide, now, what do I put in this one lesson. I think I've confused myself a bit. I think one just needs you know, we've got all this to choose from, you just need to know certain plan more carefully lesson for lesson because I think that, you know, how I would do it, maybe lesson for lesson might not be exactly how you would do it might not be exactly how P2 would do it. We all have our own personal choice and it might make sense for me to first do the copper sulfate and then something else and you do it the other way around. That's fine. It's just we just need a bit of time to do that. I think, you know, something I heard other teachers commenting about in another department that went true for me, is that I think a lot of us actually have quite heavy … you know, we including, I think you this year now you are spread over quite a few Grades. So because of that, you actually you've got so many different preps to do. So it's all wonderful having this but you actually still need time every day to actually, you know, get, you know, I still need time to tell P2, I need this. One, let's just check what I'm going to teach in tomorrow's lesson, I must actually be ready for tomorrow's lesson. And that's just one grade. But then sometimes you've got 2, 3, 4 grades to teach. So I think that's just a problem that a lot of us find ourselves in. It's like a little bit spread over too many grades. And that's not the fault of this model.

T The model is fine. Yes. And just watch. That's the issue there really where we are saying the motor is coming in to try to improve our work. But is it fitting nicely into our way of doing things or is coming in to cause other problems and that's a better relevant one way you said, We have one lab everyone now wants to do a little bit more practical activities and now we will not have enough resources. And then that's a conflict because now I will say the timetable is saying I'm the one on but you want to come in how well does that work? So that's a relevant one. Okay, so basically, with these I would say, Do you want to say anything P2 before I just sum it up.

P2 No, fine, it's fine. I'm speechless today,

T Which is perfectly fine. So I will just some it up and I'll send you that normal reflection. So you be reflecting on reflections that were reflections. So we are reflecting three time with the examples, like the examples that I put there that I said you could look at. I think they work very well here like where we have the Bursar's Department having their own systems that we want to pick into. Those ones will work or the drivers in the program and now we are saying go and buy these chemicals for us that we need for our practicals. So those are the kind of conflicts that will come through now. And because we now have a new model probably need more chemicals or resources.

P2 Yes, it was a real problem the other day when I just needed my deionized water refilled and then all of a sudden the bursar's office couldn't. Usually I would just give them the order and say can you check, can the drivers pick it up? And then it was the whole thing; no we're not allowed to give the drivers jobs anymore and this must now go to John Doe. Like can we make things more complicated?

T So that's the thing that's happening there in that we are changing our systems to suit our needs, and then there they are also changing their system, probably to suit their needs, then we have these two separate activities now clashing. And that is exactly what we call a contradiction. And that's how new things come through. And then they affect the neighbouring activities. So that's exactly a great example.

P1 We need the driver to go and do something, but you know, the school needs them to do something else urgent. And we are like no but we need them. Yes, no, I mean, I think now with COVID budgets are tight. So I think that they are less and less happy for money to be going out.

P2 Yes, that's for sure.

T So, ladies and gentlemen, this is done. We'll meet again. It's bye bye for now. I'll just send you those documents through. Just don't complicate it just to do 1, 2, 3 lines its fine. You have a lot to put down, which is perfect for me.

Reflective journaling: Workshop 4

Learning Action: Reflecting and Consolidating

Question 1 What are your reflections on the entire process?

P1
Very enjoyable to be part of the study and to help come up with a new model or work scheme as a team.

P2
I found a lot of value in the sharing of experiences with co-teachers.
It was great to bounce ideas around and to hear what works well from other people.
It was interesting to learn as well about one's own misconceptions and where one can improve upon.

Question 2 What do you think we could have done better?

P1
It is a pity it was so difficult to get everyone together for the Workshops.
I found the practical session hands-on extremely helpful.
However due to external circumstances beyond our control, our in-person meetings were more limited e.g. Exam paper leaks from other schools caused exams to be rewritten which delayed marking and effected availability of others to join workshops.

P2
Time constraints are unfortunately a sign of our times; it was a hard to fit the workshops in.
It was a pity that some teachers could not attend all the time, maybe having a bigger group right from the start might have helped to have a greater pool of experiences e.g. from government schools the challenges might have been quite different

Question 3 How will the new model impact other school activities, other teachers and staff? (For instance, we may have to do lab sessions in the afternoon and this will impact on extramural activities.)

P1
New model requires a lot of lab time which may lead to afternoon session since labs are already over-busy with full classes in high numbers of students taking science.
Staff already stretched thin which may cause conflict with colleagues and possible been out for us.
Extra murals may need to be carefully managed to fit in everything.

P2
I don’t think there needs to be major impact on other school activities.

Clashes might occur with regards to access to the laboratory and chemicals, but I would think if all the teachers are well trained and hey can autonomously handle lab activities and even bring the lab to the classroom if there is a double booking on the venues.

Appendix XI: Participants Scheme of Work

1. **Short Assessment (10 MCQ questions): Time: 15minutes**
   a) Chemical energetics
   b) Stoichiometry – balancing equations, state symbols, calculating moles & concentration
   c) Gas laws – gas pressure
   d) Reaction kinetics – effects of pressure, temperature & catalyst

   Take note of topics where there are gaps in knowledge, if any. Consider these gaps in planning and delivering subsequent lessons
2. **Reversible reactions and incomplete chemical conversions**
   a) Students prior knowledge
   Misconceptions: all reactants converted to products emanating from balancing
   b) What is Difficult to Teach
   Incomplete chemical conversions – students understand particles as identical.
   c) Representations
   (i) Experiments/demonstrations:
   $CuSO_4(s) + 5H_2O(l) \rightleftharpoons CuSO_4 \cdot 5H_2O(s)$ (demonstration)
   $NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$ (you tube watch)
   $FeCl_3 + 3KSCN \rightleftharpoons Fe(SCN)_3 + 3KCl$ (experiment)
   (https://www.ld-didactic.de/documents/en-US/EXP/C/C4/C4211_e.pdf)
   Khan Academy videos
   (ii) Computer simulation
   (https://phet.colorado.edu/sims/cheerpj/ideal-gas/latest/ideal-gas.html?simulation=reversible-reactions)
   (iii) Analogy
   Building and breaking Lego's or puzzles.
   Melting ice (vs frying an egg)
   d) Conceptual teaching strategies
   Discussion - so that learners accept incompleteness of chemical equilibrium as an empirical fact.
   Discussion – closed system
3. **Dynamic equilibrium & Position of Equilibrium**

a) Students prior knowledge
Knowledge of reversible reactions
Knowledge of stoichiometry – balancing equations
Knowledge of basic mathematics - graphing
Misconceptions: static equilibrium, compartmentalisation of equilibrium, concept of oscillation, concentrations are equal at equilibrium

b) What is Difficult to Teach
Macroscopic properties constant but there are processes occurring at sub-microscopic level – chemical change is defined in terms of changes in observable properties.
Graphing/ interpretation of graphing – point at which equilibrium is achieved

c) Representations

(i) Analogy
Queue in a shop
Treadmill and escalator

(ii) Simulation
Water into buckets, leaves or apple war, dig a hole – another fill the hole, mom and toddler with toys.

(iii) Experiments/demonstrations:
We could not find an experiment that can be done easily.

Analogies/simulations can reinforce the idea that reagents and products are separated (compartmentalisation of equilibrium). Analogies

d) Conceptual teaching strategies
Discussion

- so that learners accept that reactions occur but without any changes at microscopic level – a new conception.
- so that the learners accept that two reactions are occurring simultaneously

4. Equilibrium Law (Describing POE) – Kc & Kp Calculations

a) Students prior knowledge
Knowledge of dynamic equilibrium
Knowledge of basic mathematics – operations such as powers, units
Misconceptions: expression of K without the powers, using moles instead of concentration, concentration of solid, inclusion of substances that are not gaseous in calculating Kp, value of K changes with changes in the amounts of reactants and products.

b) What is Difficult to Teach
Calculations – overload the students' working memory
Failure to learn underlying concepts
Separate Kc from the position of equilibrium

c) Representations

(i) Analogy
Seesaw, fulcrum represents Kc. When Kc >> 1 Kc is to the right and balance is achieve when there are much more products than reactants.

(ii) Simulation

Modelling dynamic equilibrium with coins (or even better small pebbles)
Students use the pebbles in games at home and provides a good starting point.

(iii) Experiments/demonstrations:
Cobalt chloride (you tube watch)

d) Conceptual teaching strategies
Discussion: Conceptual change approach

5. Teaching LCP to account for changes of equilibrium

a) Students prior knowledge
Language used in LCP; e.g. yield, shift of equilibrium position, observation
Chemical energetics
Rates of reaction
Stoichiometry
Gas pressure, gas laws

b) What is Difficult to Teach
Language, the concepts,
Difficult to use experiments and demonstrations – it is difficult to change one variable and keep all others constant.
Card games can be used to simulate behaviour of equilibrium systems, then students and draw graphs. *The card games were found not to be particularly helpful – weaker students do not benefit – they struggle with drawing and interpreting graphs*

c) Representations

(i) Analogy
Participants could not come up with an applicable analogy during the workshops

(ii) Simulation
Modelling dynamic equilibrium using coins/ pebbles

(iii) Experiments/demonstrations:
Cobalt (II) chloride – add conc. HCl, heat, cool, add water, add $AgNO_3$
NO_2/N_2O_4 interchange. Heat and cool.
https://edu.rsc.org/experiments/equilibria-involving-carbon-dioxide-in-aqueous-solution/1728.article

d) Conceptual teaching strategies
Break down LCP into a number of rules, each with limited applicability. Use such statements at junior levels to avoid misconceptions.
The simple rules may be derived by the students themselves based on empirical data e.g. experiments or demonstrations.
Conceptual change approach

6. Importance of a compromise between equilibrium and reaction rate in chemical industry

a) Students prior knowledge
LCP
Chemical energetics

Rates of reaction
Stoichiometry

b) What is Difficult to Teach
The idea that equilibrium is independent from yield

c) Representations

(i) Analogy
Cooking – balance between rate of cooking and the quality of cooking. Highest rate is given by the highest temperature setting, but that may affect quality forcing a cook to prepare the food slower by using lower temperature settings.