Faculty of Education

The effect of an intervention on experienced chemistry teachers' pedagogical content knowledge of environmental sustainability

by

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Declaration

I declare that this doctoral thesis entitled: "*The effect of an intervention on experienced chemistry teachers' pedagogical content knowledge of environmental sustainability"* which I hereby submit for the degree Philosophiae Doctor at the University of Pretoria, is my own work. I further declare that I have not previously submitted this thesis for examination to this or any other institution.

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Dedication

I dedicate this thesis to:

- My mom, Judy Groening. You raised me with love and made me see the value of hard work and perseverance. Thank you for your continuous support; you never stopped believing in me.
- My children, Milano and Hannah. Thank you for understanding when mummy spent long hours at her computer doing her work. May this achievement inspire you to fight for your dreams and motivate you always to do your best.

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Abstract

Providing proper education and making learners aware of environmental sustainability issues may be an effective way to help citizens deal with sustainability challenges. Teachers, however, have not been sufficiently trained on how to teach with sustainability concerns in mind. The simultaneous teaching of chemistry and environmental sustainability requires knowledge of the concepts of Education for Sustainable Development and the components of pedagogical content knowledge (PCK). The current study explored experienced chemistry teachers' personal PCK about environmental sustainability when teaching about the extraction of metals as a Chemistry topic. This investigation included an inquiry into the effects of an online intervention aimed at developing the teacher's PCK. Six chemistry teachers were purposively and conveniently selected. The data was collected in three phases; before, during, and after the online professional development intervention. Various data collection instruments, mainly based on the CoRe-tool, were used to capture the participants' personal and enacted PCK. The focus was on emerging patterns in planning a chemistry lesson with particular emphasis on the impact of mining on the environment. The data analysis entailed the use of a validated PCK rubric informed by the grand rubric. The focus was on teachers' knowledge about curricular saliency, student understanding, and conceptual teaching strategies. The intervention proved to be effective in the development of pPCK in chemistry teachers. However, the PCK developed to varying levels. Four participants showed a positive gain in the quality of their PCK on all three components of PCK, while two only showed a positive gain in two of the components. The difference in PCK development was attributed to the presence of amplifiers and filters that inform the knowledge transfer between the three realms of PCK. These results serve as empirical evidence that the presence of amplifiers and filters inform the PCK transitions between the three realms of PCK. The study contributes to both theory and practice, highlighting the need for research-informed continuous professional development of teachers in the area of education for sustainability and how to infuse sustainability into their teaching of chemistry.

Keywords: Pedagogical content knowledge, experienced teachers, extraction of metals, sustainability, online professional development

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List of abbreviations

BEd	Bachelor’s degree in education
BSc	Bachelor of science
CoRe	Content representation
cPCK	Collective Pedagogical Content Knowledge
CS	Curricular Saliency
CTS	Conceptual Teaching Strategies
EGCSE	Eswatini General Certificate for Secondary Education
ePCK	Enacted Pedagogical Content Knowledge
ESD	Education for Sustainable Development
PCK	Pedagogical Content Knowledge
PGCE	Post-graduate certificate in education
pPCK	Personal Pedagogical Content Knowledge
RCM	Refined consensus model
SD	Sustainable development
SGCSE	Swaziland General Certificate for Secondary Education
SU	Student Understanding
UNDESD	United Nations Decade of Education for Sustainable Development
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WCED	World Commission on Education and Development

CHAPTER 1
INTRODUCTION AND CONTEXT OF THE STUDY

"The importance of sustainability to chemistry and chemistry education is clear, the connections are real and significant... The challenge is for each of us as chemistry educators to find ways to bring that connection and context into our courses."

(Fisher, 2012, p.180)

1.1 Chapter Overview

This chapter introduces the reader to the study. It allows the reader to become familiar with the background and context of the study, define the problem that justifies the study and state the main purpose of the study. The research questions are followed by study's rationale and significance, and lastly, the researcher defines some of the terms and concepts used in this thesis.

1.2 Introduction

The world is facing many sustainability issues, and these issues are likely to worsen (Flower, 2015). Eswatini, a developing country in Southern Africa, cannot be excluded from this predicament. Issues of poverty, diseases, unemployment, resource depletion, limited supplies of drinking water and global climate change are among the many sustainability issues facing Eswatini (United Nations Development Programme, 2013). Sensitizing people about environmental sustainability issues and integrating these issues into school chemistry curricula would teach learners how to address these global issues and live responsible lives (Mckeown, 2012).

Teachers are at the forefront of bringing about change and innovation in education (Suh & Park, 2017). To integrate the concept of sustainability into their teaching, teachers need not only to understand this concept and the issues surrounding it, but they need to be able to translate their personal understanding of this concept into their pedagogy to make it accessible and understandable to learners. Teachers' knowledge and skills to translate content and make it understandable to learners are called Pedagogical Content Knowledge (PCK) (Shulman, 1986). PCK is not a mere overlap of subject content knowledge with pedagogical knowledge (Shulman, 1986); it is a separate knowledge base (Shulman, 1987) and an attribute that a teacher develops over time (Shulman, 2015). Considering the importance of sustainability in education, teaching that infuses sustainability issues should be an integral part of a teacher's PCK.

1.3 Definition of terms/ concepts

This section defines terms and concepts as they are used in the study.

A learner or student refers to a 16-18 year old school-going child attending high school and is in Form 4 or Form 5. Form 4 and 5 are the Eswatini equivalent to South Africa's government schools' Grades 11 and 12.

Sustainable Development (SD) refers to development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43).

Sustainability means "the human behaviour that does not irrevocably damage the planet" (Schultz, 2013, p.22). It encompasses limiting pollution, conservation of resources and preservation of the environment. In this thesis, the focus was on environmental sustainability.

Education for Sustainable Development (ESD) refers to the process of providing learners with opportunities that will allow them to gain the knowledge and understanding, skills and behaviours needed to live in a way that safeguards environmental, social and economic wellbeing, both in the present and for future generations (UNESCO, 2005). In this thesis, the phrase "education for sustainability" was used to mean the same.

Curriculum refers to the learning experiences provided to learners inside and outside the school. This school curriculum may include the course of study, timetables, syllabi, curriculum guidelines, learning materials, textbooks and assessment guidelines.

Syllabus refers to an official guiding document comprising the aims, assessment objectives and learning objectives (content coverage) of a particular course of study.

Physical science refers to a school subject in the Eswatini high school curriculum comprising physics and chemistry topics. Although the two disciplines are taught separately by either the same or different teachers, physical science is examined as a single subject.

Experienced teacher refers to a teacher who has been teaching for more than six years

1.4 Background

The role of education in sustaining the environment has been acknowledged for almost four decades (Jegstad & Sinnes, 2015; United Nations, 1992; United Nations Educational, Scientific and Cultural Organization, 2012a; World Commission on Environment and

Development, 1987). The Eswatini government has not excluded itself and has included sustainable development as part of its educational policy (Government of Eswatini, 2011).

1.4.1 Education for Sustainable Development

In 1983, the World Commission on Environment and Development (WCED) was formed by the UN General Assembly. The main focus of WCED was to bring countries together to pursue sustainable development (SD) in a worldwide cooperative manner. The role of WCED was to identify sustainability challenges, raise awareness about them, and suggest solutions and strategies for implementing the proposed solutions (Jarvie, 2016). Four years later, in 1987, the Brundtland report was released by the WCED. The report described SD as comprising three components: environmental protection, economic growth and social equity (WCED, 1987).

Following the Brundtland report, in 1992, world leaders convened for the Earth Summit held in Rio de Janeiro and later reconvened in 2002 in Johannesburg for the World Summit on Sustainable Development. The outcomes of these summits emphasised the significant role of education in achieving SD. Soon after that, the United Nations (UN) announced 2005-2014 as the Decade of Education for Sustainable Development (DESD).

1.4.2 Goals of ESD in Eswatini

In 2006 Eswatini launched the United Nations Decade of Education for Sustainable Development (UNDESD), and in 2009 an Education Sector Policy was drafted. In 2011 the Ministry of Education and Training launched the Education Sector Policy. The Eswatini Education and Training Sector (EDSEC) policy which was later revised and released in 2018, states that one of the medium to long-term objectives is to "strengthen the quality of education within the framework of sustainable development" (Ministry of Education and training, 2018, p. 12). Furthermore, the policy aimed to revise education and training from primary school through university to include a clear focus on sustainability (Ministry of Education and Training, 2018). Something worth noting is that during the revision of the EDSEC policy, the ministry of education and training moved the sector-wide policy issue of ESD from position seven to position one. This shows that the ministry concerned shifted priorities and regarded education for sustainable development as integral to the quality of education.

1.4.3 Concerns about Teachers' PCK of ESD

Despite the formation of these organisations and meetings held by heads of state to discuss sustainable development, the involvement of teachers in these meetings has not been established. Teachers have the potential to change the future by teaching for sustainable development (Mckeown, 2012). Nonetheless, according to UNESCO (2014), teachers are not prepared to teach for sustainability. They do not have much content knowledge surrounding the concepts of SD and ESD, and even less pedagogical knowledge on how to integrate ESD into their teaching (Burmeister et al., 2013). Although Swazi teachers support integrating sustainability issues into teaching, they lack familiarity with the concept of ESD (Dube & Lubben, 2011).

According to Shulman (1987), a teacher possesses a unique kind of knowledge. This knowledge differentiates a teacher from a subject specialist. According to Geddis (1993), a teacher who is a subject specialist is an exceptional teacher. Over the years, there has been a shift from general teacher education to teacher education for specific subject areas. This meant that the concept of PCK evolved from a PCK that was generalised to a PCK that was both subject and topic-specific (Shulman, 1986). A teacher's PCK can be observed by focusing on a single topic (Veal & MaKinster, 1999).

Before comprehending how a teacher carries out instruction, one needs to understand why a teacher teaches the way they do. This enquiry necessitates an understanding of a teacher's PCK. How the teacher teaches is influenced by a combination of what was learnt in their teacher education institution, in-service training, advice and examples given to them by senior teachers and their own experiences. According to Evens et al. (2015), interventions that contain PCK courses which aim at improving teachers' knowledge on what and how to teach can lead to development of a teacher's PCK. In the context of Eswatini, what a teacher teaches is mostly determined by the syllabus of that particular subject.

1.4.4 The Eswatini General Certificate of Secondary Education (EGCSE) Physical Science Syllabus

The secondary school science curriculum in Eswatini comprises a junior and senior science curriculum. The junior secondary science (JSS) curriculum is a three-year programme that uses a contextualised teaching approach. This approach attempts to link real-life situations to school science. This teaching approach is favourable to ESD as it uses real-life issues relevant to the learners' lives.

The Senior Secondary curriculum for the Eswatini General Certificate for Secondary Education (EGCSE), the focus of this study, is a two-year programme offered to learners in Form 4 and Form 5. In these two years, learners are taught five compulsory subjects and a minimum of three electives. The compulsory subjects are Siswati – either as a first or second language, English, mathematics, religious education and science. The compulsory science subject group consists of biology and physical science. The school administration is at liberty to decide which of the two sciences, biology or physical science, is compulsory and must be part of the curriculum for every learner. The science that is not made compulsory would then be chosen by only those who decide to have both sciences as part of their curriculum.

The physical science curriculum content comprises separate chemistry and physics sections. Candidates entered for EGCSE physical science study both sections as the national examination assesses both chemistry and physics within each of three papers written by candidates. Paper 1 is a short answer paper with a total of 40 marks. Paper 2 is a theory paper consisting of structured questions totaling 80 marks. Both Paper 1 and Paper 2 are designed to test students' conceptual knowledge and ability to handle information and solve problems. The third paper, a practical assessment, gives students two options on which to be evaluated. Option 1 is a practical test which assesses experimental and observational skills. Option 2 is the alternative to practical work and consists of a written paper designed to evaluate familiarity with laboratory-based procedures.

The curriculum content coverage is listed as part of the syllabus, guiding teachers on the structure and format for assessing the subject. According to the Examinations Council of Eswatini (2019), the chemistry section, which is of interest to this study, comprises the thirteen topics listed below.

1. Particulate nature of matter
2. Elements, compounds and mixtures
3. Experimental techniques
4. Physical and chemical change
5. The periodic table
6. Atomic structure and bonding
7. Stoichiometry
8. Chemical reactions
9. Acids, bases and salts
10. Metals
11. Electricity and chemistry
12. Non-metals, and
13. Organic chemistry.

An analysis of the physical science syllabus reveals that there is neither mention of sustainable development nor reference to sustainability. However, it is important to note that although these terms are not mentioned, three of the aims of the syllabus can be related to environmental sustainability. These aims are:

> *To develop skills and abilities that are useful in everyday life and applicable in domestic, environmental and industrial situations, ... stimulate learner interest in, and care for, the environment ... promote awareness that the applications of science may be both beneficial and detrimental to the individual, community and environment.*(Examinations Council of Eswatini, 2019, p.5)

In addition, there are topics where sustainability issues can be incorporated. It is, however, the role of the teacher to go through the subject content and identify topics with opportunities to incorporate sustainability issues and concerns into instruction (UNESCO, 2014).

1.4.5 ESD and Chemistry Education

The topic of "extraction of metals" has been identified as one that has opportunities for chemistry teachers to integrate environmental and sustainability content. As such, it allows the researcher to explore chemistry teachers' PCK about environmental sustainability. Figure 1.1 is an extract of the Eswatini General Certificate of Secondary Education (EGCSE) physical science (6888) syllabus, which shows the objectives of the chosen topic.

Figure 1.1

Extract from the Physical Sciences Syllabus showing the learning outcomes of the topic "extraction of metals

C11.3 Extraction of metals
1. describe the ease in obtaining metals from their ores by relating the elements to the reactivity series.
2. name metals that occur native including copper and gold
3. name the main ores of aluminium, copper and iron
4. describe the essential reactions in the extraction of iron in the Blast Furnace
5. outline the manufacture of aluminium from pure aluminium oxide using electrolysis
6. describe the importance of conserving resources
7. describe the environmental impact of the mining and extraction of metals on vegetation , plants, human beings and animals

(Examinations Council of Eswatini, 2019)

This extract shows that Objectives 6 and 7 provide a good opportunity for teachers to teach these scientific concepts and incorporate environmental sustainability issues. A concern, however, is whether chemistry teachers have the knowledge and skills to effectively identify these opportunities and use them to promote meaningful learning.

1.5 Problem Statement

Providing proper education and making learners aware of environmental sustainability issues may be an effective way to help citizens deal with the challenges of sustainability (Mckeown, 2002). ESD generally does not require a new topic on sustainability to be added to the curriculum but allows for an existing curriculum to be adapted to suit the needs of both the people and the environment (Burmeister et al., 2012). This implies that even though the EGCSE physical science curriculum does not explicitly mention sustainable development, sustainability issues can be integrated into some chemistry curriculum topics.

Inclusion of sustainability aspects into teaching requires the teacher to understand the concept of ESD and its principles (UNESCO, 2012b). In addition to the content knowledge (CK), the teacher must also understand the concept of SD that they wish to integrate, how it relates to the subject content, and the pedagogical methods which would be most suitable to integrate these concepts into the teaching of science topics.

The fact that the curriculum does not explicitly include sustainability as a topic may contribute to teachers not understanding their role as agents of change in our society (Lasker et al., 2017). The teachers themselves have not been sufficiently trained on how to teach with sustainability concerns in mind (UNESCO, 2014). This implies that teachers' pedagogical content knowledge (PCK) about environmental sustainability has not been developed. Nonetheless, teachers are expected to use their knowledge of sustainable development to identify content in the physical science syllabus appropriate for integrating sustainability concerns (UNESCO, 2012b). The focus of the current study is to therefore explore the effect of a professional development intervention (PDI) on the development of a teachers' PCK about environmental sustainability in the chemistry topic of *extraction of metals*.

1.6 Purpose of the Study

This study aimed to explore experienced chemistry teachers' personal PCK (pPCK) about environmental sustainability when teaching about the extraction of metals. This investigation included an enquiry into the effects of an intervention aimed at developing the teachers' pPCK. The research involved gathering information before and after the intervention from experienced high school chemistry teachers regarding their knowledge and skills through looking into their planning of a lesson on concepts about the extraction of metals related to environmental sustainability.

1.7 Research Questions

The primary research question for this study is as follows:

How does a professional development intervention (PDI) influence experienced chemistry teachers' personal PCK about environmental sustainability, revealed through their planning of a lesson on the extraction of metals?

The researcher explored the specific knowledge and skills used by chemistry teachers when planning lessons on the extraction of metals. The goal was to develop the necessary competencies in teachers required to identify opportunities for teaching sustainability issues in the curriculum and infuse them into teaching specific science topics. The teacher was expected to plan a lesson to develop learners' academic excellence and environmental, economic and social responsibility. This necessitated a PDI for enhancing the chemistry teachers' PCK about environmental sustainability. The researcher continued to explore how the PDI had impacted the teachers' pPCK by comparing their PCK before and after the PDI.

The secondary research questions are as follows:

1. What are chemistry teachers' views about sustainability and education for sustainability?
2. What is the nature of personal topic-specific PCK about the extraction of metals with big ideas related to environmental sustainability revealed in the teachers' planning prior to the PDI?
3. What is the nature of personal topic-specific PCK about the extraction of metals with big ideas related to environmental sustainability, revealed in the teachers' planning after the PDI?
4. How does a professional development intervention influence the development of an experienced chemistry teacher's topic-specific PCK on the extraction of metals?

1.8 Rationale of the Study

This study explored the PCK of experienced chemistry teachers. As an experienced chemistry teacher myself, I only learnt the concept of ESD when I did my Master's degree. I was intrigued by the concept and started researching the concept itself and, more specifically, what its implementation into teaching meant for teachers and teacher educators. Firstly, I was curious whether science teachers were familiar with the concept or if I were the only one left in the dark. Secondly, if teachers were unaware of the concept, would they be open to learning about it? I conducted my Master's research to answer these questions and to explore chemistry teachers' knowledge and perceptions about ESD and its implementation in teaching. Although the chemistry teachers were not familiar with the concept of SD, they were able to relate to its environmental aspect and believed that the subject of chemistry could be used to incorporate sustainability. Also, the teachers cited their lack of knowledge about ESD as one of their major challenges. These findings urged me to do more; how could I use my research to help develop teachers' knowledge about sustainability? Through conducting this current study, I could gain a clearer understanding of the unique knowledge held by a teacher as identified by Shulman (1987) and consider ways that the findings of this study could inform and support the development of in-service teachers' pPCK and ePCK about environmental sustainability.

Over the years, many studies have looked into PCK and its components. More recently, as the realisation grew that PCK is topic-specific, research has focused on developing a teachers' PCK for a particular topic. Some of the chemistry topics that have been researched are chemical equilibrium (Dharsey et al., 2006; Makhechane & Mavhunga, 2021; Mavhunga & Rollnick, 2013), physical and chemical changes (Bektas, 2015), stoichiometry (Makhechane & Qhobela, 2019), thin layer chromatography (Hale et al., 2016) and organic chemistry (Davidowitz & Potgieter, 2016; Davidowitz & Rollnick, 2011). Even though the topics that researchers initially preferred were those in chemistry that were viewed as being conceptually difficult, more recently, a number of other topics have been studied. This study has contributed to the literature by exploring the PCK of teachers in a topic not commonly researched, the extraction of metals. As mentioned earlier, the topic of the extraction of metals has been chosen because it has opportunities for chemistry teachers to integrate environmental sustainability issues. This makes the topic appropriate as the researcher intends to explore chemistry teachers' PCK about environmental sustainability. The environmental aspect of sustainability was chosen as many identified environmental issues have been associated with the chemical industry, and this study focuses on chemistry teachers. Also, in a study conducted by Dube and Lubben (2011), the majority of Swazi teachers regarded the environmental aspect of SD as most suitable for integration into science teaching. This study, therefore, contributes new knowledge in the area of PCK about environmental sustainability.

The knowledge that was contributed by the study added to the research literature on the three realms of PCK: collective PCK (cPCK), personal PCK (pPCK) and enacted PCK (ePCK), which were proposed in the Refined Consensus Model (RCM) (Carlson & Daehler, 2019). This study investigated the transfer of knowledge from an online intervention, which was informed by cPCK, to pPCK and later, the transfer from pPCK to ePCK. Although there have been studies on the development of pre-service teachers' PCK, the outcome of this study will add to the body of knowledge about the development of experienced teachers' PCK and the factors that influence this development.

1.9 Overview of the Methodology

The researcher used a qualitative approach and a case study design for this study. Since the researcher employed more than one teacher, each from a different school, the type of case study used was a holistic, multiple-case study. The sample for this study was drawn from a population of chemistry teachers teaching in the Hhohho region of Eswatini. The study focused on teachers who have taught both Form 4 and Form 5 chemistry, and who were yet to teach the topic of *extraction of metals*. The researcher used a questionnaire to screen the teachers and came up with a sample of six chemistry teachers, each from a different high school.

The study used various data collection methods to investigate how chemistry teachers reveal their personal PCK about environmental sustainability through planning a lesson on the extraction of metals. The data collection was conducted in three phases to examine the teacher's pre-pPCK, knowledge transitions and post-pPCK. The purpose of the first phase of data collection was to explore a teacher's initial pPCK about environmental sustainability as they planned a lesson on the extraction of metals. Phase 1 data was collected through a pre-PDI questionnaire. The responses to the questionnaire were analysed and scored using a validated PCK rubric. The chemistry teachers were exposed to an online professional development intervention during the second phase. Telephonic interviews were used throughout the intervention to collect data pertaining to the PDI content and the participants' views and experiences while undergoing the intervention. Data collected in the final phase was used to help the researcher understand the teachers' post-PDI pPCK. During the third phase, teachers were given back the pre-PDI questionnaires that they had responded to and asked to make modifications in light of the new information they had learnt. The participants were also asked to design a lesson to reveal whether they could draw on their pPCK and enact it. The post-questionnaire and lesson plan responses were analysed and scored using a PCK rubric.

1.10 Structure of the Thesis

The thesis comprises seven chapters. The first chapter is the introduction to the study. Chapter two reviews related literature and conceptualises the framework used to guide the study. The methodology is described in chapter three. Chapters four, five and six describe the intervention and findings of the study. Chapter seven presents the conclusion and recommendations. The chapters are further described below.

Chapter 1: Introduction and Context of the Study

This chapter is an introduction to the study. It starts by portraying the background and context of the study. It then moves on to describe the problem, state the study's main purpose and define the research questions that guide the study. The research questions are followed by the rationale and an overview of the methodology. The chapter ends with a summary of the structure of the thesis

Chapter 2: Literature Review

This chapter reviews the literature surrounding the construct of PCK and the concept of education for sustainable development (ESD), as this study focused on the teacher's PCK about environmental sustainability. Chapter two looks briefly at the different models of PCK that preceded the refined consensus model (RCM), which was the framework used to guide this study. It continues to review ESD, its principles and practice. The chapter ends with the conceptual framework and an elaboration of the PCK components that the researcher used to evaluate the teacher's pPCK and ePCK.

Chapter 3: Methodology

This chapter discusses the research methodology used in this study. The chapter presents the philosophical assumptions underpinning this study, the research method and design, research area and population. Since the sample was chosen through a screening process, the researcher described the criteria used together with the sampling techniques. Data was collected in three phases, the pre-PDI phase, the PDI phase and the post-PDI phase. The data collection instruments and procedures used during these phases are briefly discussed in this chapter as they are elaborated on, and the data analysis in the following chapters. Issues of trustworthiness and ethical considerations are also discussed.

Chapter 4: Pre-intervention Interactions

This chapter presents the pre-intervention pPCK of the participants. The findings of this research chapter are presented in two sections. The first section presents the data collected from the six participating chemistry teachers using the screening questionnaire. This was done to address, in part, the first secondary research question: What are chemistry teachers' views about sustainability and education for sustainability? The second section is a presentation of the data that was collected from the participants using the pre-PDI questionnaire. This was done to address the second secondary research question: What is the nature of personal topic-specific PCK about extraction of metals with big ideas related to environmental sustainability, revealed in the teacher's planning prior to the PDI?

Chapter 5: The Intervention

This chapter focuses on the PDI to which the participating chemistry teachers were exposed. It describes the design, structure, content and delivery of the intervention. The chapter then continues to present the data from the interviews conducted during the intervention. The data from the first interview provides evidence of the teachers' knowledge of the curricular saliency of the topic through the teacher's responses to the questions enquiring into the teachers' views about sustainability and education for sustainability.

Chapter 6: Post-PDI Interactions

This chapter focuses on the post-intervention PCK of the participants during and after they had undergone the online professional development intervention (PDI). The same questionnaire administered before the intervention was administered to the teachers after the intervention. The responses to this questionnaire and the interview questions, together with a lesson plan, were used to determine the teachers' post-PCK. The analysis of their responses was also used to determine whether the intervention contributed to the development of teachers' PCK about environmental sustainability.

Chapter 7: Summary, Conclusions and Recommendations

This chapter concludes the study by pulling together the findings and discussions from the previous chapters to answer the research questions. There is a discussion of the methodology and how it aligns with the refined consensus model of PCK, which was used as the framework for this study. There is a reflection on the methodology, the use of the grand rubric and the use of an online intervention. The study's limitations are acknowledged in this chapter, together with the contributions the study makes to both practice and theory.

1.11 Chapter Summary

This chapter introduced the study and discussed its background to help the reader understand the context of the study. Education has a major role to play in sensitising people about sustainability issues. Teachers are always at the forefront when it comes to the implementation of innovative forms of teaching and learning. Although the Eswatini education policy states that education should include a clear focus on sustainability, the teachers have not been prepared to take up this task. Education for sustainable development requires teachers to have a developed PCK about sustainability. This study aimed to explore experienced chemistry teachers' personal PCK about environmental sustainability before and after an online intervention. This was done by analysing teachers’ responses elaborating on how they would plan a lesson on the extraction of metals. The researcher chose the topic of the extraction of metals because the stated syllabus learning outcomes allow teachers to infuse environmental sustainability elements in their lesson planning. This study puts forward recommendations for curriculum material developers to create teaching and learning materials and provide learning opportunities that can assist teachers with new ways of teaching and the department of in-service teachers to explore different methods of enhancing PCK development. The next chapter provides a review of relevant literature as well as a description of the theoretical framework and its relevance as a methodological and analytic lens, enabling the researcher to answer the research questions introduced in chapter 1.

2 CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

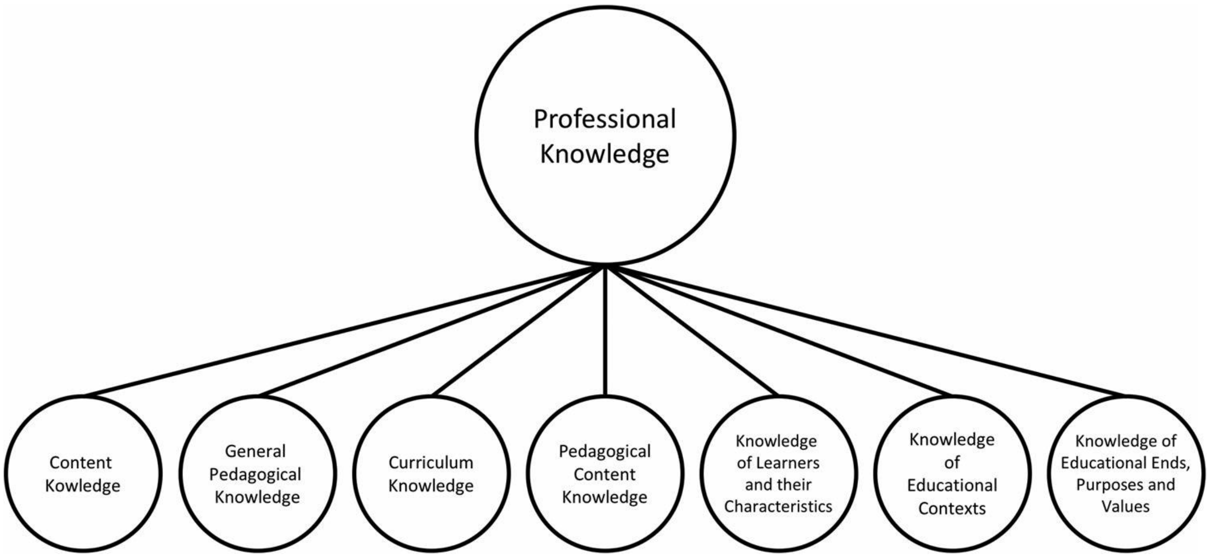
The past two decades have been filled with talks of sustainability and the use of education to achieve a more sustainable future. Furthermore, when discussing education, a construct that has gained ground in science education is pedagogical content knowledge, conceived by Shulman (1986). This chapter discusses a review of literature that relates the construct of pedagogical content knowledge (PCK) to the concept of education for sustainable development (ESD). The chapter starts with a brief history of the different models of PCK, which precedes an elaboration on the refined consensus model (RCM) of PCK. The RCM is the conceptual framework that was used to guide this study. The review continues with a discussion on the conceptualisation of ESD. In reviewing ESD, the researcher first discusses the events that led to the launch of ESD. This is followed by literature on the key competencies required and the key issues and challenges faced by educators in the implementation of ESD. The chapter ends with a review of the components of PCK, focusing on the understanding of teachers on the concept of sustainability and its place in the curriculum, the conceptual teaching strategies used when integrating sustainability into teaching and the difficulties students face when learning chemistry concepts infused with sustainability ideas.

2.2 Pedagogical Content Knowledge (PCK)

Shulman (1986, 1987) introduced pedagogical content knowledge (PCK). This was to draw attention to the fact that for a teacher to teach effectively in a manner that promotes students' understanding, the teacher must blend content and pedagogy. According to Shulman (1986), content knowledge is the knowledge about concepts and ideas that are relevant to your teaching. On the other hand, he referred to pedagogical knowledge as the methods and techniques used during teaching and assessment and the knowledge and characteristics of the learners. PCK, an “amalgam” of the two, is considered a separate knowledge base and represents an understanding of how content is taught. Figure 2.1 shows the different knowledge bases that constitute a professional teacher, according to Shulman (1987).

Figure 2.1

Teacher Knowledge according to Shulman



Shulman (1987)

Of all these knowledge bases, the one that is of special importance to researchers and educators is that of pedagogical content knowledge. According to Shulman (1987), the reason for this is that it is the only knowledge base that is distinctive for teaching. This body of knowledge will allow you to distinguish between a content specialist and a teacher. PCK is more than just a blend of knowledge of content and knowledge of pedagogy; it is knowledge of how the two are interrelated and represents "an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p.8)

Several attempts have been made over the years to provide more information and clarity on the concept of PCK. The one thing that most researchers agree on is that content knowledge, sometimes referred to as subject matter knowledge, is a necessary prerequisite for the development of PCK. The following section will look at some of the early models of PCK and how they led to the model of interest to this study, the Refined Consensus Model (RCM) of PCK.

2.2.1 Models of PCK

After Shulman's initial conceptualisation of PCK, Grossman (1990) developed a model to represent the knowledge bases of PCK. Following this, many researchers developed adapted versions of PCK models suitable for their research. For this section of the literature review, the researcher has chosen a handful of PCK models illustrating that the concept of PCK is dynamic and that there has been a change of focus from a multidisciplinary PCK to a PCK that is not just subject-specific but also topic-specific.

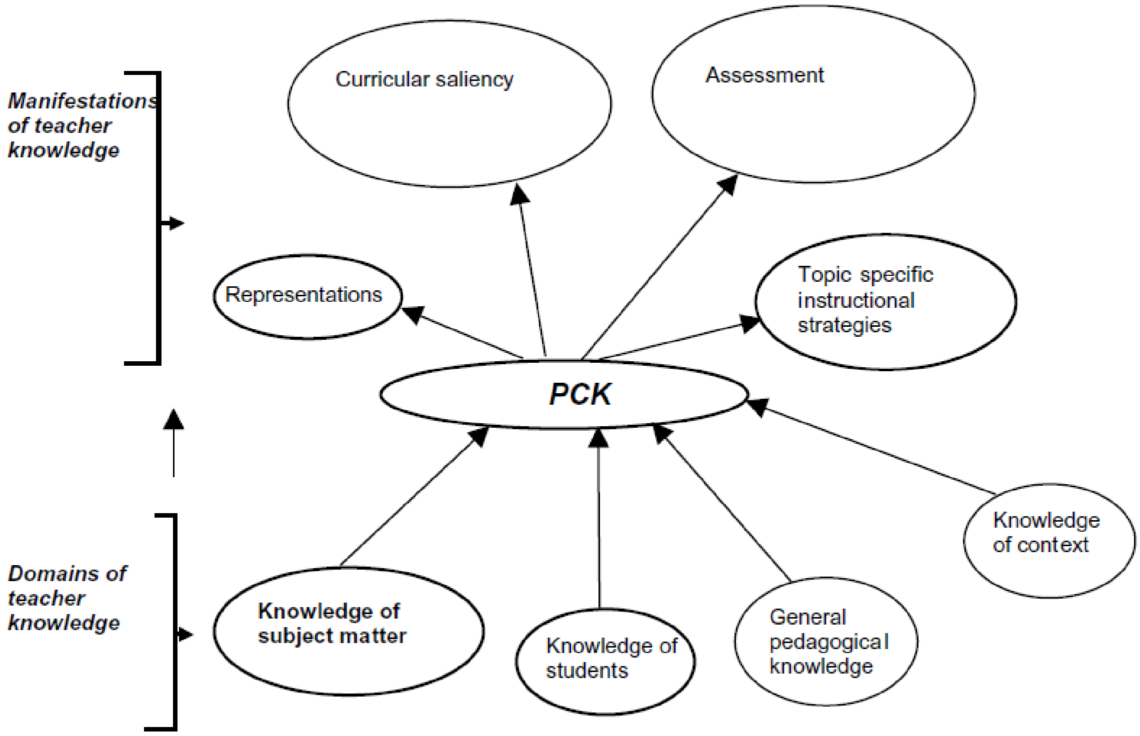
Grossman's (1990) model proposed that a teacher's knowledge is an interaction of four knowledge bases. In the model, PCK has the central position and the other three, pedagogical knowledge, context knowledge, and subject matter knowledge, occupy the periphery of the model. She suggests that the three knowledge bases are necessary for the development of PCK. Following this model, different authors made proposals that added new components or knowledge bases (Cochran et al., 1993; Morine-Dershimer & Kent, 1999), emphasised the importance of one knowledge base over another (Carlsen, 1999) or proposed that PCK is subject-specific (Abell, 2008; Magnusson et al., 2008).

When Magnusson et al. (1999) proposed that PCK was subject-specific, they formulated a PCK model for science teaching. In doing this, they added assessment knowledge to the original four knowledge domains of Grossman. In 2008, modifications were made to the model of Magnusson and his colleagues by including a sixth component which the authors called teacher efficacy (Park & Oliver, 2008). Later that year Abell (2008) proposed a model specific to a science teacher by integrating Grossman's and Magnusson’s models. Even though there were numerous models for PCK, researchers continued to explore this construct.

Empirical data from research carried out by Rollnick et al. (2008) confirmed that the knowledge bases needed for developing PCK manifest themselves during the teaching process. Figure 2.2 shows that these manifestations include representations, curricular saliency, assessment, and topic-specific instructional strategies (Rollnick et al., 2008).

Figure 2.2

A Tailored model for PCK



Rollnick et al. (2008)

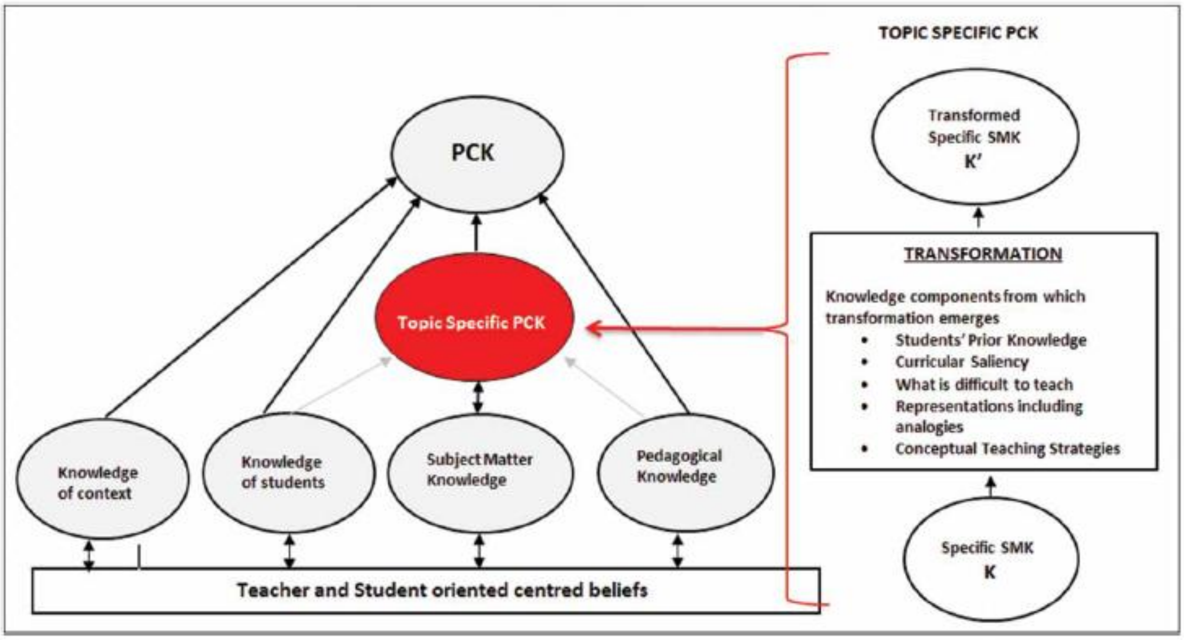
These manifestations were later seen in the topic-specific PCK model proposed and used by Mavhunga and Rollnick (2013) when investigating the development of the PCK of pre-service teachers (See Figure 2.3). According to Mavhunga and Rollnick (2013), topic-specific PCK is revealed when a teacher transforms subject matter knowledge (SMK) into units understandable for learners. This transformation of content knowledge takes place through the following five components:

- knowledge of content representations;
- knowledge of students' prior knowledge;
- knowledge of curricular saliency;
- knowledge of difficult concepts, and
- knowledge of conceptual teaching strategies.

The topic-specific PCK model, as seen in Figure 2.3, has combined the knowledge bases in the Rollnick et al.'s (2008) model (left-hand side) with a description of the transformation of CK to topic-specific PCK on the right-hand side.

Figure 2.3

A Model for Topic-Specific PCK



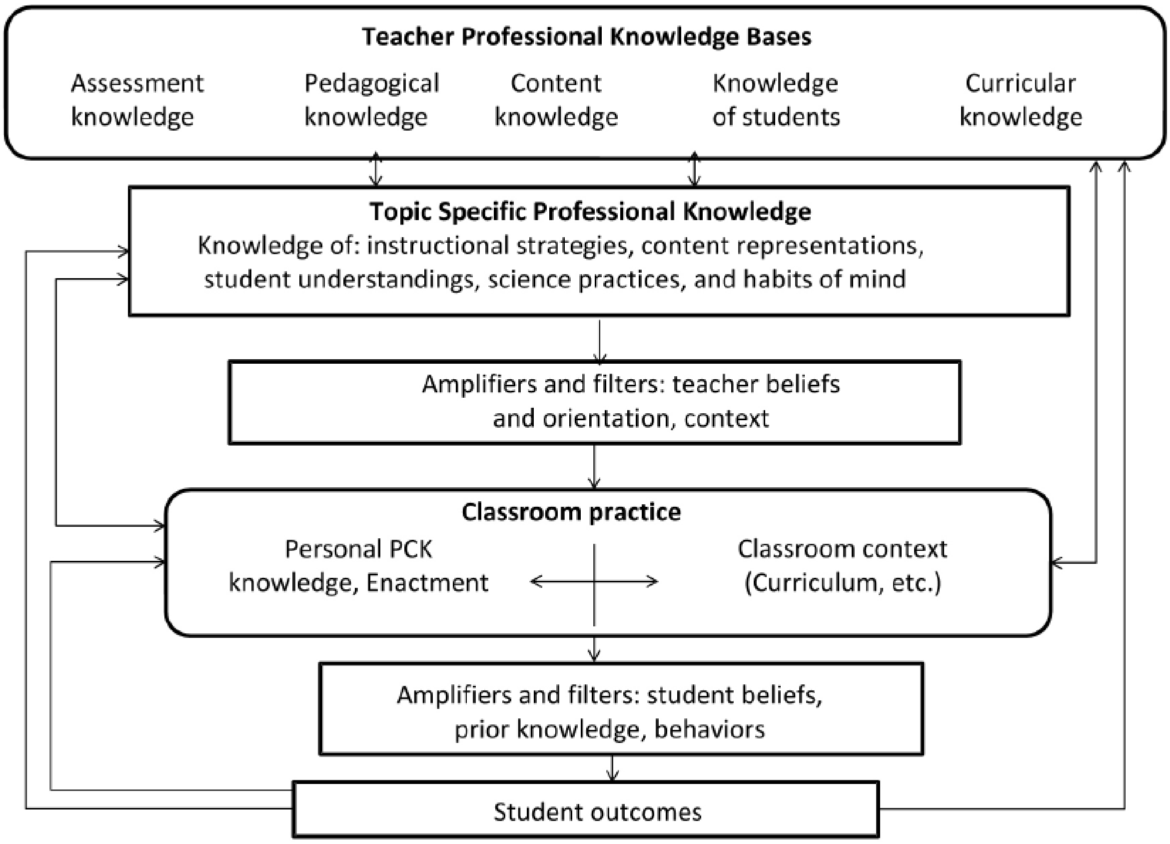
Mavhunga and Rollnick (2013)

Topic-specific PCK is the ability of a teacher to transform content, through these five components, into something more suitable for learning (Mavhunga, 2014). The dynamic nature of teaching rests on this premise, as each topic of content being taught has to undergo a process of transformation. According to Mavhunga (2014), the quality of a teacher's topic-specific PCK is determined by the teacher's knowledge of the five components and how they interact with each other.

With these different PCK models being altered and redefined, it became evident that there was a need for consensus on the definition of PCK and a framework that can support research. In 2012, a PCK summit was held where researchers gathered and developed a new model for PCK. Figure 2.4 shows the consensus model of 2012.

Figure 2.4

Consensus Model of PCK



Gess-Newsome (2015)

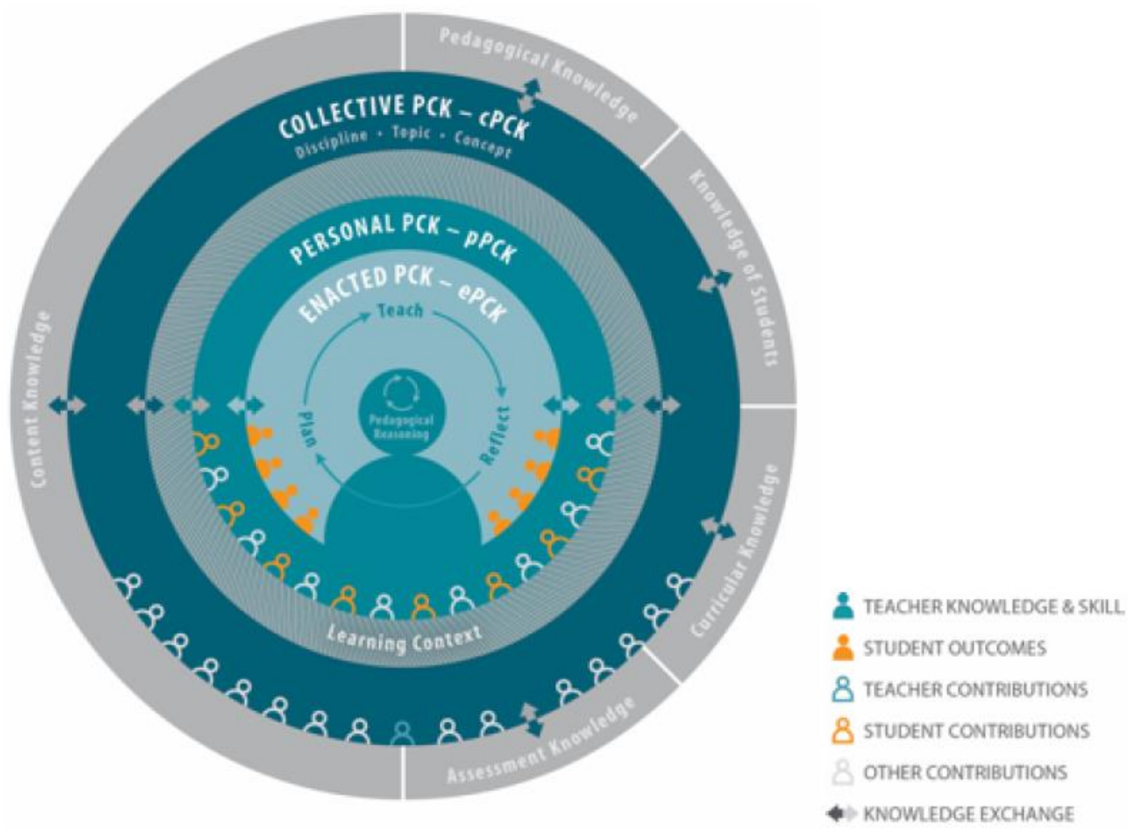
The consensus model emphasised that PCK was an interplay between knowledge bases, knowledge of a particular topic, teacher beliefs and orientations, and the context of teaching (Gess-Newsome, 2015). The result of this interplay yields a personal PCK enacted as the teacher plans, teaches and reflects on the lesson. This model was later revised due to the minimal detail that the model had about PCK in the 2017 Refined Consensus Model (RCM) of PCK. The RCM of PCK became the conceptual framework for this study.

2.2.2 The Refined Consensus Model of PCK

Although a consensus model was formulated in 2012, the model was complex with connecting arrows and component layers whose meanings and interactions were not described (Kind, 2015). Also, the model was not specific about the composition, sources and types of PCK (Kind & Chan, 2019). It needed to be revised because many researchers felt the model was unclear (Carlson & Daehler, 2019). This need led to another summit which gave rise to the Refined Consensus Model of 2017. The RCM focuses on the way science teaching occurs (Hume et al., 2019). Figure 2.5 shows the RCM of PCK.

Figure 2.5

The 2017 Refined Consensus Model of PCK



Carlson and Daehler (2019)

According to this model, five types of knowledge bases contribute to a teacher's PCK. These are pedagogical knowledge, student knowledge, curricular knowledge, assessment knowledge, and content knowledge. A culmination of all these knowledge bases feed into collective PCK (cPCK), which is shared among a group of teaching professionals. This means that cPCK does not refer to knowledge held by a single teacher but rather knowledge that is "public and held collectively" (Hume et al. 2019, p. 88). This cPCK can range from being discipline-specific to topic-specific to concept-specific, and this holds for the other realms of PCK, which we are yet to discuss.

The learning context, in this model, is represented by a circle between the cPCK and personal PCK (pPCK). This is important as the learning context informs the transfer of knowledge from the cPCK held by all educating professionals to a teacher's pPCK. Each teacher has their personal PCK that they possess, which is unique due to the context in which learning takes place. The pPCK can be influenced by teachers' beliefs and orientations, pre- and in-service training, interactions with other teachers, curriculum materials, classroom environments, and student attributes. These influencers also have an impact on the way the teacher thinks and behaves during the teaching process. During instruction, the teacher can draw on knowledge from their pPCK and use it. This becomes the enacted PCK (ePCK). According to the RCM, there exist underlying factors that can influence the transfer of knowledge between these three realms of PCK. These factors are referred to as amplifiers and filters in the RCM (Carlson & Daehler, 2019). Figure 2.6 shows the RCM of PCK with only the personal and enacted PCK.

Figure 2.6

The personal and enacted PCK- the knowledge and skills used by a teacher during the planning, teaching and reflection of a lesson.

The enacted PCK (ePCK) refers to the knowledge and skills used and displayed by a teacher during the teaching process. It is worth noting that the ePCK is not only seen during the interactive phase of teaching ($ePCK_i$) but also during the planning of instruction ($ePCK_p$), which happens before teaching, and during the reflection on instruction and student outcomes, which takes place after teaching ($ePCK_r$). This model is appropriate for the current study as it places the teacher at the centre of the teaching process. It also shows the dynamic nature of teaching, which makes every lesson unique. During the three phases of teaching, plan, teach and reflect, the teacher is constantly making decisions on how the content can be transformed into units the students can understand. This process of continuous decision-making and justification of instructional moves is known as "pedagogical reasoning".

The 2017 Refined Consensus Model of PCK identifies three distinct realms of PCK – collective PCK, personal PCK and enacted PCK. This study draws on cPCK to design an intervention. It investigates the transfer of knowledge from cCPK to pPCK, and the final transfer from pPCK to ePCK, looking at possible amplifiers and filters.

2.2.3 Influences on Teachers' Enacted PCK

According to the Consensus Model, underlying factors exist that can influence and impact the teachers' enacted PCK. These influencers can help us understand the link between what a teacher knows and does (Gess-Newsome et al., 2019). These factors, referred to as amplifiers and filters, are teacher- or student-centred. Although the learning context is not the focus of the study, the researcher is aware of its potential role in a teacher's ePCK. For this reason, teachers' beliefs and orientations, classroom environment and student attributes will be discussed briefly.

Teacher beliefs and orientations have been seen before as a PCK component in the models of Grossman (1990) and Magnusson et al. (1999). According to Magnusson et al. (1999), a teacher's beliefs and orientations refer to the "teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" (p.97). According to the RCM (Carlson & Daehler, 2019), the level and quality of knowledge transfer between the cPCK and the pPCK, and between the pPCK and ePCK, depends on how amplifiers and filters act in the teachers mind. These could be the learning context (Carlson & Daehler, 2019), a teacher's values, self-efficacy, commitment, emotions, knowledge, beliefs, micro-politics (Hong, 2010), enthusiasm (Sorge et al., 2019) and self-regulatory skills.

The classroom environment is another factor that influences the teacher's ePCK. Some examples include the location of the school (rural or urban), the number of students in the classroom, the infrastructure, interactions among students and between teacher and students, curriculum materials and even the rules that govern students' general behaviour. Kennedy (2010), suggests that forces that the teacher does not have control over factors such as lack of resources and school interruptions that have a greater effect on student learning than the quality of a teacher's PCK.

Student attributes such as age, gender, class level, subjects they have or have not studied before, background knowledge and skills, and social and cultural background greatly influence the teachers enacted PCK (Hall & Kidman, 2004). According to these authors, this knowledge will allow a teacher to identify the strengths and weaknesses of the students, and aid in the planning and delivery of content. A teacher, therefore, needs to be familiar with their students' attributes to make informed choices that will make the teaching and learning process more effective.

2.2.4 Methods Used to Capture a Teacher's PCK

Over the years, many studies have looked into PCK and its components. Over the last ten years, there has been a shift in focus to the topic-specific nature of PCK and the development of a teachers' PCK concerning a particular topic (Bektas, 2015; Dharsey et al., 2006; Drechsler & Van Driel, 2008; Makhechane & Qhobela, 2019; Rollnick & Davidowitz, 2015),how this PCK can be improved (Makhechane & Mavhunga, 2021; Mavhunga, 2014, 2019a; Mavhunga & Rollnick, 2013; Pitjeng-Mosabala & Rollnick, 2018) and how a teacher's PCK can be measured (Chan et al., 2019; Mavhunga & Miheso, 2021; Schultz et al., 2018).

From some of the studies mentioned above, I must highlight the methods used to capture teachers' PCK. These studies served as a basis for the data collection methods used during this study. In Dharsey et al.'s (2006) study, interviews and observations were used to explore two chemistry lecturers' enactment of PCK. Drechsler and Van Driel (2008) used interviews to investigate the PCK of nine experienced chemistry teachers about acid-base chemistry. In a study on organic chemistry, Davidowitz and Rollnick (2011) collected data using interviews and observations. With these data collection methods, the researchers could capture teachers' knowledge about curricular saliency, interactions with students and explanations, representations and topic-specific strategies. Makhechane and Qhobela (2019) used questionnaires, interviews and observations to understand how teachers transform subject matter on stoichiometry into units understandable to learners.

Mavhunga and Rollnick (2013) conducted an intervention with 16 physical science teachers using Content Representations (CoRes) to capture the teachers' PCK. A CoRe is a tool that was developed by Loughran et al. (2004) to capture a teacher's PCK using prompts. The first step to developing a CoRe is to identify the key concepts in a topic, called “big ideas”. Teachers then collaborate to develop responses to prompts such as, “what do you intend the students to learn about this idea” and “difficulties/limitations connected with teaching this idea” (Loughran et al., 2004 p.376). For this study, the researcher adapted some of these prompts to form the base of some questions in the Professional Development Intervention (PDI) questionnaire.

These topic-specific studies in science education are important to this research, as this study investigated chemistry teachers' topic-specific PCK about the extraction of metals, focusing on ideas related to environmental sustainability.

2.3 Defining Education for Sustainable Development (ESD)

Enhancing the quality and relevance of a curriculum for sustainable development requires understanding the concept of sustainable development (SD) from which ESD was derived. The literature reviews SD and how it evolved into ESD, which is the concept of interest in this study.

2.3.1 The Concept of Sustainable Development (SD)

Due to the nature of Sustainable Development (SD), a broad concept encompassing many aspects, there are various versions of its definition. The most commonly used definition is the one released by the Brundtland Commission, formally known as the World Commission on Environment and Development (WCED), in 1987. The Brundtland Report definition states that sustainable development “meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WCED, 1987, p. 43). Sustainable development is based on the three fundamentals proposed in the Brundtland report: economic growth, environmental protection and social equity (WCED, 1987). From its beginning, the concept of SD has been based on these dimensions of economy, environment and society (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2005). These three dimensions are seen as overlapping and interconnected and can be represented as pillars, embedded circles or overlapping circles (Adams, 2006). All representations emphasise the importance of the three dimensions of economy, environment, and society to sustainable development. While there is consensus regarding the contribution of all three of these factors to sustainable development, the economic aspect has been seen to carry more weight when it comes to the decision-making processes of a nation. This has resulted in the increased success of economic endeavours at the expense of societies and the environment (Borgstein, 2017). Environmental sustainability has fast become one of the most urgent challenges faced by the human race. Societies are now aware that the Earth's natural environment has been damaged as they seek economic stability.

This study gave particular attention to environmental sustainability due to the severity of the current state of our natural environment. Many, including the researcher, are concerned that future generations would be left to face the challenges associated with a polluted environment and a lack of natural resources. Also, many identified environmental issues have been associated with the chemical industry, finding relevance to this study as it focused on chemistry education and, more specifically, chemistry teachers. Environmental issues related to the chemical industry arise during the extraction, refining, manufacturing, consumption, and degradation of raw materials (Schultz, 2013). In a study conducted by Dube and Lubben (2011) on Swazi teachers, fifteen of the sixteen teachers interviewed regarded the environmental aspect of SD as most suitable for integration into science teaching. The link between chemistry and the environment cannot be disregarded; therefore, the researcher chose to focus on the dimension grounded on environmental protection.

2.3.2 Integrating Sustainable Development into Education

Increased awareness of the importance of sustainable development, and the essential role that education could play, led to the development of the concept of Education for Sustainable Development (ESD). Education is the key to creating awareness about sustainability issues and enhancing the ability of citizens to come up with solutions to the environmental, economic and social problems that the world is facing. ESD is the process of equipping students with the knowledge and understanding, skills and attributes needed to work and live in a way that safeguards environmental, social and economic wellbeing, both in the present and for future generations (Longhurst et al., 2014). ESD is, therefore, a means of empowering learners so that they can contribute to sustainable development.

According to UNESCO (2012a), the implementation of ESD involves providing quality basic education, including sustainability in educational courses, and increasing awareness and understanding of sustainable development, its principles and practice through public awareness and training. Of these four "thrusts" of ESD implementation, the relevant and direct concern to educators is that of including sustainability into current curricula. Including sustainability issues into curricula, referred to as "reorienting curricula" to include sustainability, is one of the basic priorities of ESD. Reorienting a curriculum to address sustainability requires the inclusion of the principles, skills, values, issues, and perspectives related to sustainability's environmental, social and economic domains. Appropriately reorienting a curriculum and ensuring the successful implementation of ESD requires teachers to have pedagogical content knowledge about sustainability (Perry, 2013). This means that a teacher should have adequate knowledge and skills about ESD to integrate concepts related to sustainability into their teaching effectively.

According to the United Nations Economic Commission for Europe [UNECE] (2009) the effective integration of ESD requires it to be cross-curricular. This means that it should be integrated into all school subjects. This approach allows learners to think more critically and embrace the holistic nature of ESD (Walshe, 2017). In light of the interdisciplinary approach to ESD, Walshe (2017) studied geography students to find the effect of using poetry to develop their understanding of sustainability. Data collection made use of students' drawings, questionnaires and interviews. The study found that the students could develop an appreciation for the three domains of sustainable development. The students were also encouraged to engage more critically and affectively. Chemistry has many opportunities to improve sustainability as many environmental issues stem from the chemical industry. The chemistry teaching can be tailored to incorporate sustainability issues and educate future chemists on sustainability. One suggestion made by Juntunen & Aksela (2014) was the incorporation of sustainability issues and student-centred pedagogies into chemistry course books. The key sustainability issues, such as climate change, sustainable production, consumption, loss of biodiversity, poverty, clean water and sanitation, need to be addressed during teaching.

2.3.3 Teacher Competencies in the Implementation of ESD

One of the biggest challenges for the future of ESD is the preparation of the teachers (UNESCO, 2014). Science teachers are lacking in the knowledge of both the theory of ESD and its pedagogies (Burmeister et al., 2013). The preparation of teachers is mostly perceived to be the responsibility of higher education institutions (HEIs). It does not only focus on the initial preparation of teachers but also on the continued professional development of the teachers in the field. According to UNECE (2009), sustainability issues need to be incorporated into teacher training and in-service training programmes so teachers can engage in ESD. HEIs have become increasingly eager to integrate sustainability into their teaching, and although some universities have tried to infuse sustainability into their curricula, there have been some challenges. One of the greatest challenges HEIs face is that the educators lack knowledge about environmental issues, where and how to obtain relevant information, and how to link it to their discipline (Thomas, 2004). This was highlighted by Hopkins (2015) who stated that the challenges faced by HEIs were "lack of financial resources, lack of awareness or support, and lack of human resources" (Hopkins, 2015, p.3). The human resources are the teacher educators who understand ESD and can be at the forefront regarding reorienting the curriculum and teaching processes. Understanding ESD not only focuses on the knowledge, issues, perspectives, and skills central to ESD but also involves understanding sustainability values. Once the teacher can identify these aspects in each of the three components of SD, then effective integration into the curriculum will take place (UNESCO, 2014).

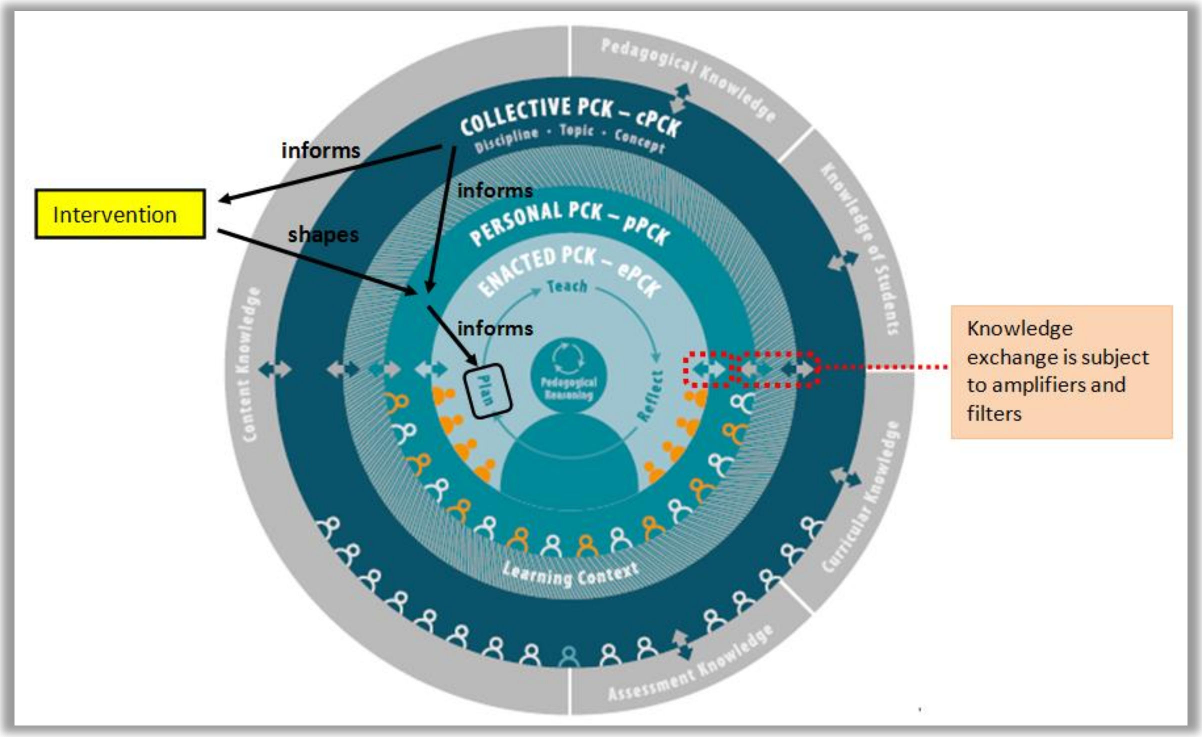
According to Burmeister and Eilks (2013), knowledge of content and suitable teaching strategies is required to infuse SD into teaching. A teacher's content knowledge affects their ability to plan and conduct a lesson in a way that will help the students better understand the concept being presented (Magnusson et al., 1999). This means that for a teacher to prepare for and present lessons on concepts related to sustainability, a teacher must be knowledgeable about both the concepts of chemistry and sustainability. It is worth noting that although content knowledge is necessary and important, it is not a sufficient pre-requisite for developing quality PCK (Gess-Newsome, 2015). According to Bertschy et al. (2013), for ESD implementation to be effective, a teacher must have an in-depth understanding of both content knowledge and pedagogical content knowledge (PCK). PCK is a conceptual framework that has been found to play an integral role in developing teachers' competencies (Shulman, 1986). It has become an important knowledge base for teachers, researchers and teacher education institutions.

2.4 Conceptual Framework

The conceptual framework that guided this study was the refined consensus model of PCK (Carlson & Daehler, 2019). A key aspect of this model is its description of the three different realms of PCK: collective, personal and enacted PCK. This study explores the transfer of knowledge from the cPCK to the pPCK, and from the pPCK to ePCK. Collective PCK forms part of a broader knowledge base for teaching from which a teacher draws their pPCK. In this study, the cPCK, a collection of information and resources from science educators and researchers, informs the intervention that the teachers are exposed to and has a role in developing a teacher's pPCK. This pPCK becomes a pool of knowledge that teachers can access and utilise, becoming their ePCK. Throughout the knowledge exchange between the three realms of PCK, amplifiers and filters can affect the development of a teacher's PCK. Figure 2.7 illustrates how the RCM was used as the conceptual framework for this study.

Figure 2.7

Diagram Illustrating how the RCM was Used as the Conceptual Framework



The intervention carried out in this study exposed the chemistry teachers to PCK about the topic through the five components of PCK that were proposed in the grand rubric (Chan et al., 2019). The main focus of this study was to determine whether a professional development intervention would affect a chemistry teacher's pPCK. This was done by capturing the teachers' pPCK before the intervention and the pPCK and ePCK after the intervention. Questionnaires and interviews gave the teachers opportunities to reveal their pPCK. According to Carlson and Daehler (2019), a teacher draws on knowledge from their personal PCK during the planning, teaching and reflection of a lesson, and the experiences gained during the process of instruction provide feedback which further develops the personal PCK. This implies a constant knowledge exchange between the pPCK and ePCK during the teaching process. The enacted PCK has three phases: planning teaching and reflection. For this study the researcher looked specifically at the teacher's ePCK during the planning phase.

The PCK components, namely curricular saliency, conceptual teaching strategies and student thinking, are important to this study as they were used to examine the teacher's pPCK and ePCK. These components are discussed in more detail in the section that follows.

2.5 Components of PCK

According to Mavhunga and Rollnick (2013), the quality of a teacher's personal and enacted PCK about a topic is influenced by the level of their knowledge about the components of topic-specific PCK and how they interact with each other. A teacher's ePCK can be seen through their choice of instructional methods and representations, their ability to consider multiple factors, such as knowledge of students, curricular saliency and knowledge of assessment when reasoning and their ability to explain why they teach the way they teach (Carlson & Daehler, 2019). These *components* of a teacher's ePCK are incorporated in the design of the grand rubric for measuring a science teacher's pedagogical content knowledge (Chan et al., 2019). The discussion amongst the authors led to the following key PCK components (Chan et al., 2019, p.11):

1. *Knowledge and Skills related to Curricular Saliency*: appropriate selection, connection, and coherence of big ideas; accuracy of content.
2. *Knowledge and Skills related to Conceptual Teaching Strategies*: selecting and using appropriate instructional strategies; using multiple representations.
3. *Knowledge and Skills related to Student Understanding of Science*: identifying and acknowledging variations in student learning and eliciting and assessing student difficulties and misconceptions.
4. *Integration between PCK Components*: monitoring and adjusting teaching practice based on student feedback and learning of the big ideas as well as the classroom context
5. *Pedagogical Reasoning*: providing a rationale for teacher decision-making and actions within the context of their teaching situation.

These components of PCK interact in a complex and dynamic way. A teacher with a well-developed PCK should be able to understand that each component cannot exist on its own but are rather integrated. There is interplay between and amongst these components revealed during a lesson's planning, teaching and reflection.

The first three components of PCK refer to the "Knowledge and Skills" that a teacher possesses. The researcher chose to focus on these three components as they draw directly from the personal PCK of a teacher and can be revealed through the teachers' planning of a lesson on the extraction of metals. Integration between PCK components was not included as the researcher felt that this component can be best identified when focusing on dynamic PCK, which pertains to ePCK in the interactive teaching phase. This would have been better revealed during lesson observations, which were not done in this study.

These knowledge components are important to this study as they constitute the lens through which the researcher investigated chemistry teachers' personal and enacted PCK. In this study, the researcher chose to examine how teachers choose their *instructional strategies and representations*, what they understand about *students' prior conceptions and learning difficulties* and the role that their *curriculum knowledge* plays during the lesson planning. The topic chosen for this study was "extraction of metals" as it contains two learning outcomes that can be linked to environmental sustainability, conservation of resources and environmental impact of mining. The exact outcomes can be seen in the EGCSE syllabus extract in Appendix A.

2.5.1 Knowledge and Skills Related to Curricular Saliency

Knowledge of curricular saliency is a teacher's knowledge about the concept being taught, how the sub-ordinate ideas can be sequenced, the concepts that must be understood before teaching the key idea, and the importance of teaching that concept. According to Magnusson et al. (1999), it includes a teacher's knowledge of the curriculum itself, the goals and objectives for teaching it, and knowledge of relevant instructional materials and resources. Students will perform better if the content is relevant and is supported by relevant instructional materials such as textbooks (UNECE, 2009). This component includes knowledge of what students have learnt before and what they will learn after (Grossman, 1990). In the EGCSE physical science syllabus, the topic of the extraction of metals falls under a broader topic of metals. The topic on the extraction of metals is preceded by the reactivity series of metals and followed by the uses of metals. This knowledge gives teachers an understanding of the concepts that must be taught to make the topic easier to understand and the time that must be spent on each concept.

The sources for knowledge of the goals, objectives and even concepts that need to be addressed are normally found in documents written by the government or school. For a teacher to be effective they must be knowledgeable about these documents, as well as the activities and materials that can be used to achieve these goals (Magnusson et al., 1999). In the case of the chemistry teachers in this study, the document we are referring to is the

EGCSE physical science syllabus. This document lists the general aims of teaching physical science and the outcomes for each topic. The aims of the syllabus of interest to the study are those related to environmental sustainability.

This component also includes a teacher's knowledge and understanding of the importance of teaching a particular topic (Park & Oliver, 2008). This means that a teacher with a developed PCK should be able to answer the question, "*Why is it important for students to know this?"* (Loughran et al., 2004). Although there are seven outcomes under the topic of extraction of metals, this study focuses on the two outcomes related to environmental sustainability. A teacher should know why it is important for students to learn about these sustainability issues and the impact of mining on the environment and conserving resources.

2.5.2 Knowledge and Skills Related to Conceptual Teaching Strategies

This component refers to a teacher's ability to select specific teaching strategies, including activities and representations, to make content understandable to learners (Chan et al., 2019). A teaching strategy consists of multiple phases of instruction aimed at supporting conceptual change or conceptual development (Magnusson et al., 1999). A teacher's knowledge of this component, therefore, depends on their awareness of student pre-conceptions, misconceptions and the concepts they find difficult. A teaching activity, on its own, is a mere pedagogical method. Teaching activities include "problems, demonstrations, simulations, investigations or experiments" (Magnusson et al., 1999, p.18). A teacher's knowledge of this component includes their knowledge and skill regarding using questioning to assess students' understanding and the use of appropriate assessment methods. It also relies on a teacher's knowledge of the curriculum.

Chan et al. (2019) considered knowledge of appropriate representations an important part of this component. A teacher's knowledge of representations refers to their knowledge of ways to represent specific concepts to make them understandable to learners. It also includes a teacher's knowledge of the strengths and weaknesses of specific representations (Magnusson et al., 1999). Representations include illustrations, examples, models, metaphors, analogies, equations, and tables.

Integrating sustainability issues requires shifting from the traditional teaching approach to participatory learning (UNECE, 2009). Participatory learning allows the students to interact with the content, fellow students and the teacher. ESD, therefore, challenges the "dominant pedagogical discourse" that educators have used for many years (Sandri, 2020). As opposed to traditional lecturing, ESD advocates for pedagogical approaches that challenge students to participate actively, think critically and reflect (Seatter & Ceulemans, 2017).

When teaching for sustainability, Borg et al. (2012) used group discussions, interactive lectures, group work, interdisciplinary work and class debates. Jeronen et al. (2017) broadly believed that teaching methods in which students worked in groups and participated actively in learning processes were most suitable when teaching for sustainability.

ESD pedagogies should encourage students to ask questions, analyse situations, voice opinions, think critically and make informed decisions (UNESCO, 2012b). Quality sustainability education requires interactive, exploratory and transformative learning, allowing students to develop responsible behaviours. Examples of such pedagogies are issue analysis, class discussions, storytelling, debates, and simulations. Another example of such pedagogy entails going out into the field to study and experience a particular issue and allowing the student to develop their social and interpersonal skills (Owens et al., 2015).

Since some higher education institutions have started implementing ESD, it is worthwhile to mention some findings regarding their teaching methods. Some university lecturers have been found to teach sustainability through class discussions, papers, readings, projects, guest speakers, and case studies (Natkin, 2016). At the same time, others are using the same traditional approaches, such as lectures, tutorials, and discussions, they would use when teaching content unrelated to sustainability (Christie et al., 2013).

2.5.3 Knowledge and Skills Related to Students' Understanding

This component of PCK includes two categories; knowledge of the student's prior knowledge of the student's difficulties. Shulman said a teacher should have an understanding of:

- the conceptions and preconceptions that students of different ages and backgrounds bring with them to learning
- what makes the learning of specific topics easy or difficult (Shulman, 1986, p. 9)

This knowledge will allow teachers to choose teaching strategies that are best suited to reorganise students' understanding (Shulman, 1986). Student prior knowledge includes pre-concepts that constitute sound content knowledge and misconceptions that a student brings into the learning environment. Knowledge of this component is integral to teaching as it informs the teacher's selection of instructional strategies, representations, and questions to access understanding and assessment. With this knowledge of students, the teacher can design instruction to become meaningful to the students and possibly bring about conceptual change.

According to Morgil et al. (2009), a misconception is a false or non-scientific idea about a scientific phenomenon. Misconceptions may arise due to wrong or incomplete knowledge that students get from their own experiences, misinformation from parents, teachers or media, and misunderstanding of concepts. The researcher noted a gap in the literature regarding the misconceptions and difficulties that students have about "impacts of mining" and "conservation of resources", and this research could be a start in filling that gap.

Apart from the knowledge about misconceptions in the topic, a teacher must also be knowledgeable about the science topics and concepts that students find difficult to understand and why students find them difficult. This knowledge will help the teacher during the planning of instruction. Knowing what is difficult for students is useful when allocating time to spend on the different concepts, as those that they find difficult may need more emphasis (Shulman, 1986). The researcher puts forward three reasons students find science topics difficult: very abstract concepts, students' inability to comprehend and solve problems, and misconceptions.

When reviewing literature about student difficulties in understanding environmental issues, it was found that some of these difficulties are caused by the new and challenging terminology used to name and explain scientific concepts. According to Stanišić and Maksić (2014), students do not have a clear picture of their role and possible contribution to the conservation and enhancement of the environment. This could lead to students being unprepared to participate in desirable ecological actions. Some difficulties could be a result of students having a low environmental awareness (Abd Rahman et al., 2018).

It was also found that some student difficulties could be linked to teacher difficulties. According to Ham and Sewing (1988), difficulties faced when teaching about environmental issues are caused by conceptual constraints and teacher competencies. These difficulties include a teacher's lack of content knowledge which leads to their inability to adequately explain environmental terms and issues, as well as being unable to provide examples that are relevant to the students. When teachers are unfamiliar with the content and lack pedagogical knowledge, it makes it difficult to decide on the teaching strategies that will make the content more accessible to the learners. Abd Rahman et al. (2018) found that there was a general lack of support from school administrators in promoting environmental conservation programmes and practices.

2.6 Chapter Summary

This chapter reviewed literature related to the construct of PCK and the concept of education for sustainable development (ESD). For PCK, I discussed the different models of PCK, including the refined consensus model, which was also the framework that guided the study. I continued to review possible influences that could amplify or filter knowledge transfer between cPCK and pPCK, and between pPCK and ePCK. I ended the section on PCK with a review of methods used by other researchers to access teachers' PCK. Regarding ESD, I reviewed the literature on the concept of sustainable development and how it was integrated into education. In addition, I reviewed teacher competencies in the implementation of ESD. The chapter ended with a discussion of the conceptual framework used to guide the study and the components of PCK. In the discussion of PCK components, I merged what is known about ESD with the body of knowledge that describes PCK. In the following chapter, I discuss the research methodology. I continue to demonstrate how the chosen conceptual framework informed the methodology and the design of the professional development intervention that was implemented to develop the teachers' PCK necessary for sustainability into chemistry instruction.

3 CHAPTER 3
METHODOLOGY

3.1 Overview

This chapter discusses the research methodology used in this study. The chapter initially presents a brief account of this study's philosophical assumptions. The research method and design are then identified, followed by the research area and population. The sample of participants for this study was chosen through a screening process; therefore, the researcher described the criteria and sampling used during this process. Data collection took place in three phases; before the professional development intervention (PDI), which is referred to as the pre-PDI phase. The period during the PDI is referred to as the PDI phase and the period after the PDI as the post-PDI phase. The chapter also deliberates on the instruments and procedures used during these three phases of data collection. Information about data collection is followed by a discussion of the data analysis procedures, trustworthiness issues, and ethical considerations.

3.2 Philosophical Assumptions

At the start of the study, the researcher made assumptions about the nature and origin of knowledge. These assumptions were captured in the purpose and research questions, allowing the researcher to align the research with a particular paradigm. A research paradigm is a set of beliefs that guide the thinking process and behaviour of the researcher (Jonker & Pennink, 2010). The philosophical position underpinning this study is that of the interpretivist worldview. An interpretivist paradigm is associated with the idea that individuals seek an understanding of the world they live in, and researchers rely fully on their participants' perceptions of the situation being studied (Creswell, 2014). These perceptions are subjective and can be altered by contextual or social factors. Interpretivists recognise that humans create their reality through interactions with contexts and other people (Wahyuni, 2012). This is relevant to this study as teachers are social beings constantly interacting with students, fellow teachers, parents and community members. Their conception of the construct of sustainable development is influenced by their social, environmental and economic context (Purvis et al., 2018).

3.3 Research Approach and Design

Based on the philosophical position, research purpose and specific research questions, the researcher chose to use a qualitative approach for this study. The researcher used this study to explore a phenomenon and develop a detailed understanding of a situation (Creswell, 2018). Literature alone could not adequately address the problem and give the researcher a complete insight into the situation. A qualitative study enabled the researcher to understand the phenomenon without imposing any pre-existing expectations on the participants and the research as a whole (Patton, 2002).

The study employed a case study design. According to Yin (2012), a case study is a method where the researcher investigates a contemporary phenomenon within its real-life context. For this study, the researcher investigated the phenomenon of how chemistry teachers use their personal PCK about the extraction of metals in planning a lesson with big ideas related to environmental sustainability. The researcher found a case study to be the most appropriate design for this study. A case study allows an investigation to take place in a real-life context, retaining the natural environment of the investigation and safeguarding the contextual characteristics of the teachers' PCK. Secondly, it allows multiple forms of data collection, improving the findings' reliability and trustworthiness. For this study, the researcher has chosen to use questionnaires, interviews, and lesson plans.

Yin (2012) further asserts that a case study can be either holistic or embedded, single-case or multiple-case study. For this study the researcher focused on the PCK of experienced chemistry teachers and therefore treated them as a holistic case. This meant that embedding novice chemistry teachers or teachers with a different teaching subject into the analysis would not reveal the relevant information about the phenomenon under investigation (DePoy & Gitlin, 2016). Since each chemistry teacher was selected from a different school, the type of case study used is multiple-case study. A multiple case study allowed the researcher to find a more in-depth understanding of a chemistry teacher's personal PCK before, during and after the PDI, as it explored the same phenomenon across several different cases. According to DePoy and Gitlin (2016), a multiple-case study is preferred when the researcher wants to repeat a study to strengthen theory. During the data collection and initial analysis, the multiple cases were treated as separate to highlight unique features of interest and then combined to highlight any overlaps.

3.4 Research Area

The study was conducted in the Hhohho region of the Kingdom of Eswatini. Eswatini is a small, landlocked monarchy in Southern Africa that shares boarders with Mozambique to its northeast and South Africa to its north, west and south. The Hhohho region is one of the four regions of Eswatini. It is located in the north-western part of Eswatini and runs southwards to the centre. The administrative centre is the national capital of Mbabane.

Figure 3.1

A Map of Eswatini highlighting the Hhohho Region

3.5 Population of the Study

The population of the study refers to a group of individuals with the same characteristic (Creswell, 2018). The group of individuals to whom the findings of this study apply is chemistry teachers teaching the EGCSE Physical science syllabus. There are 59 high schools in the Hhohho region of Eswatini (Ministry of Education and Training, 2013). Science is compulsory in all high schools; the sciences offered are biology and physical science. Physical science combines physics and chemistry. The researcher’s population, therefore, consists of at least 59 chemistry teachers.

3.6 Screening of Participants and Sample Selection

3.6.1 Sampling

The researcher chose to use a non-probability sampling method, so the participants were not chosen by chance procedures. The researcher used purposeful sampling as only teachers with certain attributes were selected. The researcher employed a screening process to select the participants of the study. Screening ensures that the participants are suitable for the study (Yin, 2018). The screening process used is described in detail in the following section.

3.6.2 Screening Process

The screening of participants is a method used when the researcher is interested in finding participants with the right combination of attributes that make them suitable for the study. This means that the researcher has to define some relevant criteria or participant attributes to use to reduce the number of possible participants. In this section, the researcher describes the screening process, the instrument used for screening and those attributes that the researcher thought would make the participants suitable for this study.

(a) Screening Procedure

The researcher used a two-phased screening approach. According to Yin (2018), this approach is used when the number of possible participants is large. The identification of the possible participants took four days. The first phase of the screening process consisted of collecting records for all the possible participants. The researcher called the department of in-service teachers at the University of Eswatini to find out if they had the records of science teachers in the Hhohho region. Once the records were confirmed, a letter was written to the department head asking permission to use those records. Once permission was granted, the records were released into the hands of the researcher. On receiving the records, the researcher picked all the chemistry teachers from the physics and chemistry teachers group. The researcher contacted all the chemistry teachers, introduced herself and the study, and confirmed whether they were indeed chemistry teachers. Once there was verbal agreement between the teacher and the researcher, the screening process continued. Questionnaires were hand delivered or sent via email to the teachers.

(b) Screening Instrument

A screening questionnaire (Appendix B) was used to screen the teachers. This questionnaire consisted of both close-ended and open-ended questions. The data collected from the questionnaires allowed the researcher to reduce the number of participants. The questionnaire used for screening the chemistry teachers consisted of three sections.

Section A solicited teachers' demographic information. This information included their gender, qualification, teaching experience and teaching subjects. This section was of importance to the study as the researcher was looking for participants who were experienced chemistry teachers. In this study, an experienced teacher is one who has been teaching for more than six years because they would have taught the two-year EGCSE physical science course at least three times.

Section B used a 5-point Likert scale to assess teachers' knowledge on sustainable development (SD) and education for sustainable development (ESD). The researcher chose to use a rating scale instead of open-ended questions since the focus was on measuring the teachers' knowledge and not their views and perceptions. Closed questions can generate frequencies and allow comparisons to be made (Cohen et al. 2018). This allowed the researcher to compare the teachers' knowledge on SD with that of ESD. In 2012, UNESCO published an ESD sourcebook to help teachers, teacher educators, and mid-level decision makers responsible for education, integrate ESD into the school system. The researcher used this book in conjunction with the Sustainable Development Goals (SDGs) when constructing statements that would capture the ideals and principles that underlie sustainability. This is the same book given to the participants before the start of the intervention as part of the resource pack. Figure 3.2 shows a few of the SDGs that were captured in the statements about SD.

Figure 3.2

Some of the SDG Issues used when constructing statements in the Screening Questionnaire

(modified from the UNDP SDGs Booklet of 2015)

Section B also had open-ended questions to elicit the teachers' views on the relevance of sustainability to their teaching and whether they thought it was important for students to learn about sustainability. Their responses to these questions were used in the later stages of screening. Teachers who responded to all these questions were chosen over those who did not. The responses of the six chosen participants for this study to this section were analysed and used to find their views about SD and ESD before they took part in the professional development intervention (PDI).

Section C asked the teachers to describe how much of the physical science syllabus they had covered and if they would agree that their lessons on *extraction of metals* could be observed during the pre-PDI phase. The questions in this final section of the questionnaire assisted the researcher in selecting participants who would be teaching the topic *extraction of metals* during the data collection timeframe and were also willing to be observed. However, schools were closed due to the COVID-19 pandemic, and a national lockdown restricted face-to-face interactions. In March 2020, His Majesty King Mswati III of Eswatini declared COVID-19 a state of national emergency. This press release was followed by the closing of all border gates and a national lockdown, bringing the education system to a halt. All schools were closed, and the researcher could not collect data from the participants. When schools did resume four months later, only classes due to sit for their external national examinations were allowed back in schools. As it was already close to examination time, teachers were more focused on the revision of content than on teaching. The researcher was consequently unable to carry out classroom observations as planned.

(c) Suitable Attributes

For this study, the main reason for screening was to determine teachers' eligibility for participation in the study. The attributes of the important target participants are:

(i) Teaching subject;

(ii) Knowledge of the chemistry section of the Physical science syllabus and syllabus coverage;

(iii) Willingness to be observed during their lessons; and

(iv) Familiarity with the concept of sustainability.

In the following sections, the researcher elaborates on these attributes to clarify their importance for the suitability of a participant in this study.

(i) Teaching Subject

The researcher was looking for teachers teaching chemistry to Form 4 students at the time of the screening process. A student in Form 4, in Eswatini, is in their eleventh year of a formal schooling system. Form 4 would therefore be the equivalent of year 11 or Grade 11 in other countries. As mentioned in Chapter 1, physical science, which consists of chemistry and physics, is a two-year course that runs from Form 4 to Form 5. This was important during participant selection as the topic the researcher investigated is normally taught during the first term in Form 5. This process ensured the researcher that the teacher still had to teach the topic of the *extraction of metals* in the following year (Form 5).

(ii) Knowledge of the Chemistry Section of the Physical Science Syllabus and Syllabus Coverage

For a teacher to have the potential to make informed decisions and give insightful information regarding the chemistry section of the physical science syllabus, that teacher needs to be well versed with the details of the syllabus. According to Chan et al. (2019), five components make up a teacher's PCK: knowledge and skills related to curricular saliency, knowledge and skills related to conceptual teaching strategies, knowledge and skills related to student understanding of science, integration between PCK components and pedagogical reasoning. This means that the knowledge and skills related to curricular saliency are integral to a teacher's PCK. Knowledge of the curriculum, which includes the syllabus, allows a teacher to make the appropriate "selection, connection and coherence" of key concepts (Chan et al., 2019, p. 263). The details that are important to the researcher are knowledge regarding the topics and general content coverage, the order in which the topics are presented and the assessment objectives. Knowledge in this area allowed the teacher to render prompt and accurate feedback regarding the relevance of sustainability to the syllabus and opportunities for the integration of sustainability issues. Knowledge of the syllabus also allowed the teacher to make a reasonable estimate regarding when the actual teaching of the topic of the *extraction of metals* was likely to take place.

It is also important for the researcher to be aware of the topics that have already been taught. Firstly, the topics that have been taught are related to the component of PCK that deals with the teacher's knowledge and skills related to student understanding of science. This means a teacher must be able to access and assess a student's prior knowledge, difficulties and misconceptions. Secondly, teachers may not follow the order in which the topics are presented in the syllabus. This means that a teacher might have already covered the topic of the extraction of metals, which is important to the study.

(iii) Willingness to be Observed during Lessons

The informed consent for participation in the screening process of the study did not cover the actual collection of data used for the research. As voluntary participation is of utmost ethical importance, the researcher asked teachers whether they would be willing to be observed during their lessons on the *extraction of metals*. Once the teacher agreed and was chosen to participate in the study, a separate consent form was to be given to the teacher, and further consent would be required from the parents of the students as the lessons would be videotaped.

Although this was part of the screening criteria, as explained earlier, lesson observations could not occur as planned.

(iv) Approach to the Concept of Sustainability

A teacher's knowledge about a specific subject area can be linked to teaching behaviours as it affects how a teacher prepares for and conducts the lesson (Magnusson et al., 1999). The teacher must have some knowledge on how to educate for sustainability to ensure that the lesson is well executed and students can relate to and understand the concept of sustainability. A teacher's familiarity with environmental sustainability can help the teacher identify other topics besides the extraction of metals, which are relevant to sustainability. A teacher's knowledge of sustainability and educating for sustainability, however, is not the only factor that will influence a teacher's personal and enacted PCK. As mentioned earlier, a teacher's knowledge and skills related to curricular saliency, knowledge and skills related to conceptual teaching strategies, knowledge and skills related to student understanding of science, ability to integrate the PCK components and pedagogical reasoning are important when assessing the quality of a teachers PCK.

Other factors such as professional development, beliefs, attitudes and motivation can also influence a teacher's personal and enacted PCK. Teachers hold a range of beliefs about topics that are part of the curriculum and those that are not part of the chemistry curriculum. The beliefs that teachers bring into the classroom environment may influence how they portray a certain topic. Teachers' attitudes and beliefs about a concept can therefore influence their teaching behaviours (Fives & Buehl, 2014). A teacher's attitude towards sustainability can influence their ability to implement ESD (Burmeister & Eilks, 2013).

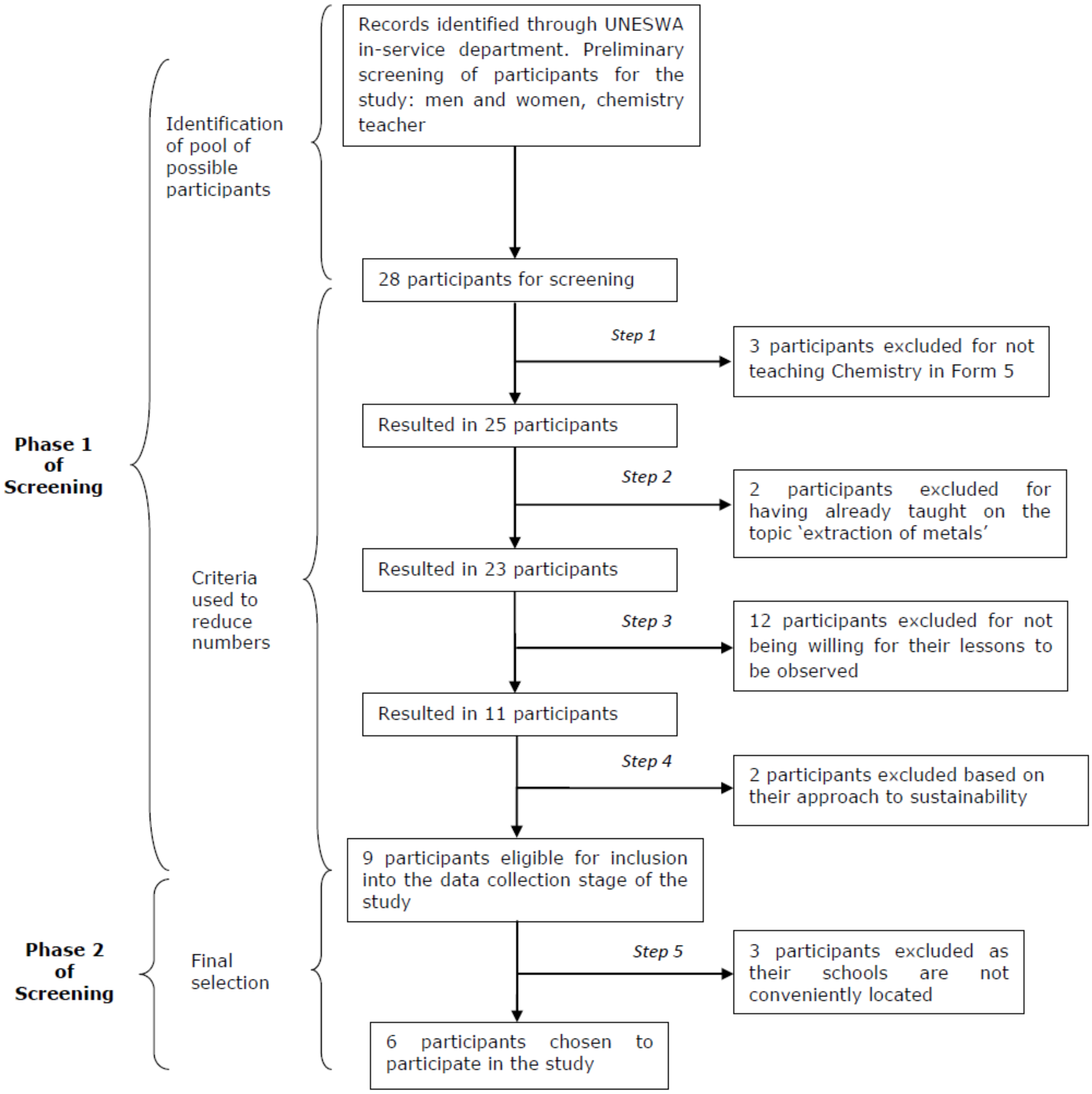
Although the researcher was not specifically looking for teachers that were knowledgeable about SD and ESD, a teachers approach to a possibly familiar or unfamiliar concept could play a significant role in whether a teacher may or may not use the opportunities in the syllabus to integrate sustainability issues into their teaching. In Step 4 of the screening process, two teachers were excluded based on their failure to respond to questions in Section B of the questionnaire. As mentioned earlier, this was important to the study as the responses of those teachers chosen to participate were later analysed.

Once the first phase of the screening process had taken place, the researcher was left with nine participants. These participants were chemistry teachers who fitted all the criteria required by the researcher for participation in the study. Since the chosen sample size for this study was six participants, the researcher used convenience sampling for the second phase of the screening. Six participants were chosen from high schools which were easier to access. This method is fast, easy and cost-effective (DePoy & Gitlin, 2016).

The flow diagram in Figure 3.3 summarises the screening process. It shows the procedure, the criteria used for the selection of participants and the number of participants before and after a selection criterion was used.

Figure 3.3

Flow diagram showing participant screening and selection



3.6.3 Sample

As explained in the previous section, the sample for this study was drawn from a population of chemistry teachers teaching in the Hhohho region of Eswatini. The sample for this study comprised six chemistry teachers from six high schools in the Hhohho region of Eswatini. A small number of cases has been chosen so that the researcher can have enough time with each participant, soliciting information that can give the researcher an in-depth understanding of teachers' personal and enacted PCK before, during and after a PDI. Below is a table showing the background data of the six participating chemistry teachers. As mentioned earlier, the background data was collected from the responses that teachers gave in Section A of the screening questionnaire. The profiles of the teachers are based on their gender, qualification, teaching experience and teaching subjects. For anonymity, the researcher used pseudonyms and codes for the teachers.

Table 3.1

Chemistry teachers' profiles

Teacher	Codes	Gender	Qualification	Teaching experience (years)	Teaching subjects
Mrs Zikalala	TB	Female	B.Sc + PGCE	6-15	Mathematics and Chemistry
Mrs Dlamini	TA	Female	B.Sc + PGCE	≥ 16	Chemistry and Science
Mr Mavuso	TE	Male	B.Ed	6-15	Mathematics and Chemistry
Mr Cele	TD	Male	B.Sc + PGCE	≥ 16	Mathematics and Chemistry
Ms Dube	TF	Female	B.Sc + PGCE	6-15	Biology and Chemistry
Mr Fakudze	TC	Male	B.Sc + PGCE	6-15	Biology, Chemistry and Science

3.7 Data Collection Instruments and Procedures

The study used several data collection methods to investigate the effect of a professional development intervention on chemistry teachers' PCK about environmental sustainability. The study focused on the teacher's personal and enacted PCK revealed through planning a lesson on the extraction of metals. As mentioned before, during the initial design stage of the study, it was intended that lesson observations would be done for all six participants as the researcher was focused on capturing the teachers' ePCK in the interactive phase of teaching ($ePCK_i$). However, the schools were closed due to the COVID-19 pandemic, and the researcher could not collect data from the participants. This also implied that face-to-face interactions between the researcher and participants and participating teachers and their students were no longer safe. This necessitated the decision for the researcher to reconceptualise the study and change the focus of the study from capturing the teachers' ePCK in the interactive teaching phase to capturing a teacher's ePCK in the planning phase of teaching ($ePCK_p$).

Data collection for the study was done in three phases. Each phase used its own instruments to examine the teachers' pPCK before, during and after a professional development intervention, as well as the $ePCK_p$ after the intervention. Since the study focused on the intervention's effect, the data was collected with the PDI being the central focus. The three phases were: the pre-PDI phase, the PDI phase and the post-PDI phase. The PDI's content was contributed by expert and experienced teachers and from research and other resources. It is therefore considered to be collective PCK (cPCK). Collective PCK was described by Carlson and Daehler (2019) as an amalgam of various science educators' contributions that can be shared and discussed amongst themselves and other professionals. The data collection procedures and instruments for the three phases are discussed below.

3.7.1 Data Collection in Phase 1- The Pre-PDI Phase

This phase comprised all the interactions between the researcher and the participants before the start of the intervention. This phase, therefore, included the participant's responses to the screening questionnaire, giving the screening questionnaire a dual purpose. The first was its use in the selection of participants, and the second was in revealing the participants' views about SD and ESD before they were exposed to the intervention.

A pre-PDI questionnaire (Appendix C) was also used to collect data in this phase. The data collected in this questionnaire was used to help the researcher gain an understanding of the teachers' initial pPCK. The questionnaire later helped the researcher determine whether there was a difference in the teacher's pPCK before and after the intervention. The questionnaire was sent to the participants via e-mail. This questionnaire was part of an email sent out to the participants before the commencement of the PDI. Before the email was sent, the researcher made telephone calls to all the participants to explain the changes in the study and the data collection procedures that would take place in each phase. The researcher also asked the participants whether they were still willing to partake in the study in light of the changes.

The questions in this instrument were modified from the CoRe-tool developed by Loughran et al. (2012). Since the researcher was looking at the teachers' PCK about environmental sustainability, the big ideas were taken from the learning outcomes already found in the EGCSE physical science syllabus, under the topic *extraction of metals,* as these were outcomes that were related to environmental sustainability. The big ideas were "*conservation of resources"* and "*impacts of mining"*. The questions were such that the researcher could draw out specific knowledge about some of the PCK components, namely, curricular saliency, conceptual teaching strategies and student thinking. The reader may refer to Appendix C for the full questionnaire.

3.7.2 Data Collection in Phase 2- PDI Phase

The main focus of this phase was a professional development intervention sent to the participants via e-mail. Telephonic interviews were used throughout the intervention to collect data pertaining to the PDI's content and the participants' views and experiences while undergoing the intervention.

(i) The Professional Development Intervention

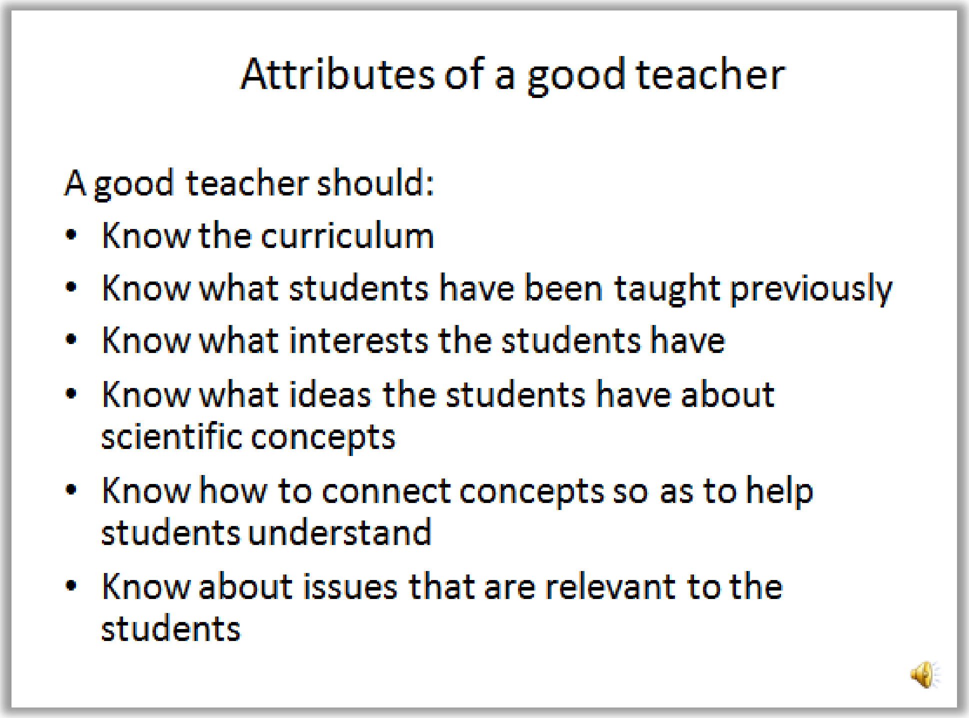
The PDI was collective PCK (cPCK) as it was an amalgam of contributions by different researchers regarding education for sustainable development (ESD), knowledge of students, curricular knowledge, pedagogical knowledge, assessment knowledge and content knowledge. Once the researcher had developed the tool, it was reviewed by an expert in the field. Once feedback was received, some changes were made to the tool. The tool was then piloted. Details on the piloting process of the PDI are discussed later in the chapter. The reader can view the slides used in the final PDI in Appendix D.

The PDI used four 20-minute-long narrated PowerPoint online presentations sent out to teachers via email. This asynchronous form of online learning was used because of issues that the country faces in terms of network connections and expensive data bundles. Each session had a particular focus, and telephone interviews were conducted throughout the intervention. Below is a brief description of what was included in each session.

Session 1 – This session started with an introduction which included the welcoming remarks, the purpose of the training session and the objectives that the researcher hoped to achieve by the end of the session. This session also introduced the participants to some attributes of a good teacher which were derived and modified from the components of PCK. The researcher made the deliberate decision not to use the terminology used for the PCK components in PCK research. This approach ensured that the teachers would not be overwhelmed by unfamiliar terminology. Figure 3.4 shows a slide from the PDI discussing the attributes of a good teacher.

Figure 3.4

A slide from Session 1 showing some attributes of a good teacher

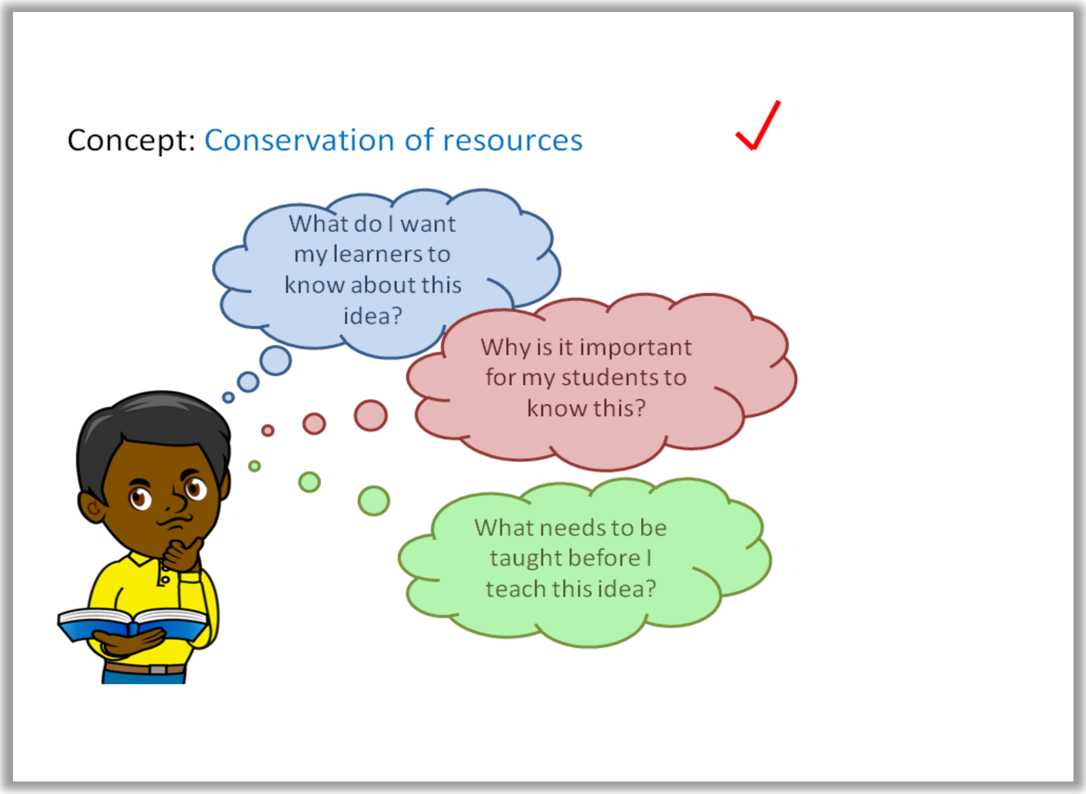


This session also made the participants aware of some general global sustainability issues that are relevant to their students and then went on to discuss specific environmental sustainability issues that could be discussed during a lesson on the *extraction of metals*.

Session 2 – This session was based on the first PCK component, knowledge and skills related to curricular saliency. It started with a brief overview of the concept of education for sustainability, what it is about, why it is important, its fundamental characteristics and how it can be integrated into the teaching and learning of chemistry. It also looked at how chemistry teachers could use their existing syllabi to identify opportunities to discuss environmental sustainability issues and how to expand on them by asking themselves some basic questions. Figure 3.5 shows the slide from the PDI, which gave the teachers an idea of the questions they should ask themselves during the planning of a lesson on the *extraction of metals*, with a particular focus on the learning outcome related to the conservation of resources. The session went on to assist teachers in answering each of these questions.

Figure 3.5

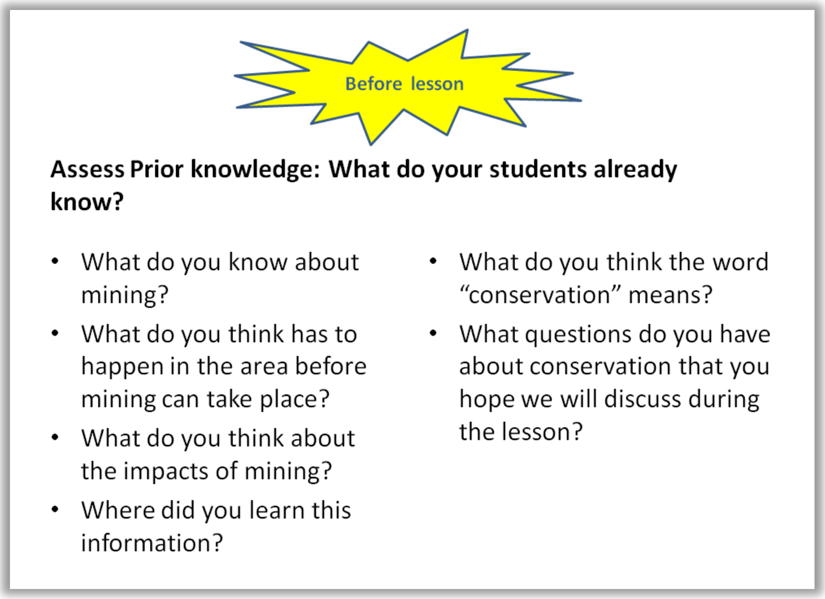
A slide from the second session showing some fundamental questions that a teacher should ask themselves during the planning of a lesson



Session 3 – This session focused on the third and fourth components of PCK and how they can be applied to the planning of a chemistry lesson. The main emphasis of the third component was on a teacher's knowledge and skills pertaining to student learning and thinking. This also includes a teacher's ability to identify variations in student learning and elicit student difficulties and misconceptions. In this session, the teachers were made aware of the importance of knowing what a student is thinking and how to use questioning throughout a lesson to elicit and assess student thinking and understanding (Figure 3.6).

Figure 3.6

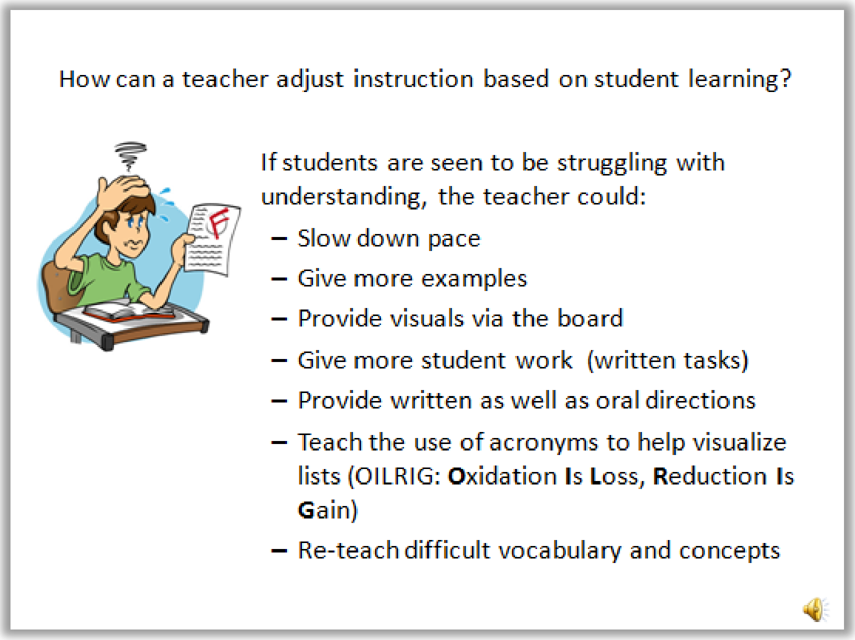
A slide from Session 3 showing questions that could be used to assess students' prior knowledge



According to the fourth component, a teacher should be able to adjust their teaching practice based on student thinking and the feedback they get from students during instruction. Figure 3.7 shows some instructional moves that a teacher can make if they realise that a student is finding it difficult to understand a concept.

Figure 3.7

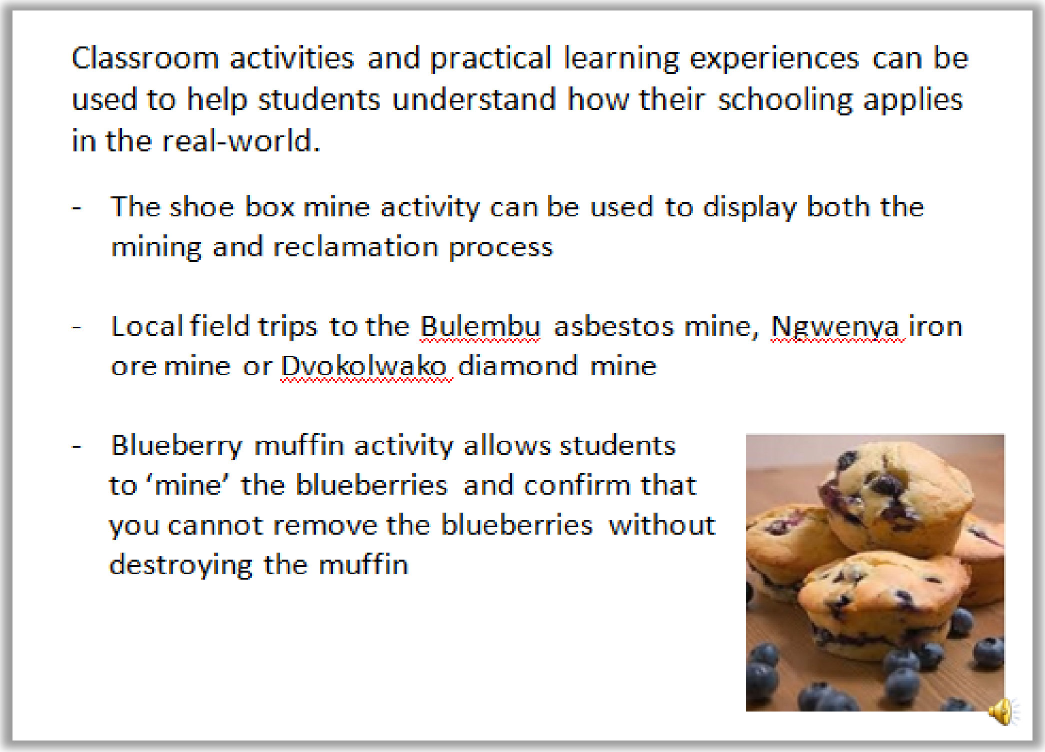
A slide from Session 3 showing how a teacher can adjust instruction



Session 4 – This was the final session of the PDI and included the second and fifth components of PCK. The second component focused on a teacher's knowledge and skills concerning teaching strategies and representations. The session gave teachers several examples that could be used during a lesson on the impacts of mining. Figure 3.8 shows some of these teaching strategies.

Figure 3.8

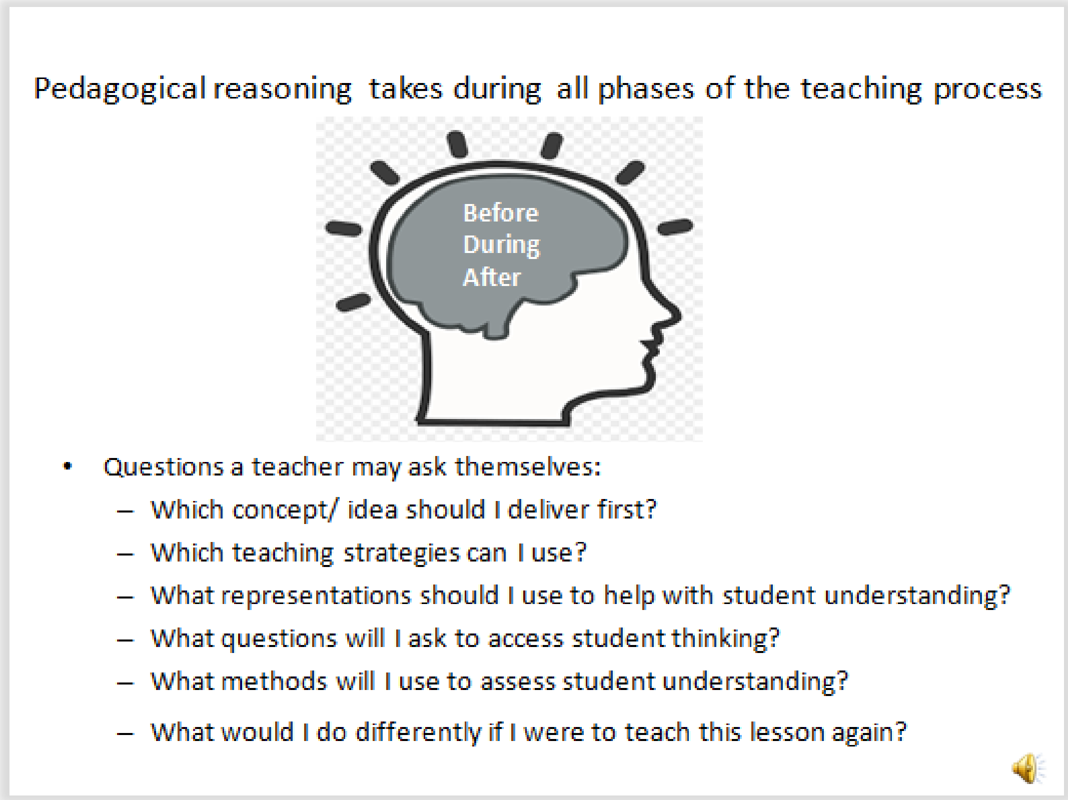
A slide showing teaching strategies that could be used when teaching on the impacts of mining



The fourth session also looked at the concept of pedagogical reasoning and how it occurs throughout all phases of teaching. The session ended with a revelation of how the attributes of a good teacher as discussed throughout the PDI, are linked to the concept of PCK and its components.

Figure 3.9

A slide showing how pedagogical reasoning takes place before, during and after a lesson



Throughout the training, there were opportunities for teachers to interact with the material in a short activity or reflection. Figure 3.9 shows one of these activities. For this short activity, the researcher reminded the teacher that “remembering” is the lowest level in Bloom’s taxonomy, and command words from this level are used when a teacher wants to assess if students can remember or recall information. The researcher then asked the teacher to come up with a question, related to the impacts of mining or conservation of resources using any of the command words in the list. This activity was also done for the levels of “application” and “analysing”.

Figure 3.10

A slide showing an example of one of the short activities found throughout the PDI

As the PDI was the focus of data collection, a chapter will be dedicated to the intervention, how it was developed, its content and how it was carried out.

(ii) Telephone Interviews

The researcher set up three telephonic interviews with each of the six participants, which were audio recorded. The telephone interviews were chosen over face-to-face interviews as the researcher wanted the participants to feel safe throughout the data collection and did not want to expose themselves or the participants to the COVID-19 virus. The researcher also chose telephone interviews as they are cost and time-effective (Tracy, 2020). Furthermore, these interviews were chosen over online, face-to-face methods, such as Zoom and Google meet, as they do not rely on an internet connection, which can be difficult to access.

The first interview (Appendix E) was conducted once the first session of the professional development intervention had been sent out and watched by the teachers. The interview was semi-structured as the researcher wanted to discuss the Session 1 presentation. This discussion included the teacher's views on the importance of students learning about sustainability issues, the need for teachers to undergo professional development on educating for sustainability and the relevance of sustainability issues to the subject of chemistry.

Once the first interview was done, the researcher sent out another email which contained the second and third PDI sessions. The researcher kept in touch with the participants through WhatsApp to follow up on their progress. The second interview (Appendix F) was conducted after the teachers had watched both sessions. The main focus of this interview was to determine whether teachers found the PDI's content relevant to their teaching and whether the information they had received would impact their lesson planning experiences. The second interview also asked the teachers for their experiences and views on using digital technologies as a professional learning and development tool to enhance teachers' knowledge and skills. On completion of the second interview, the fourth and fifth emails, which contained the fourth PDI session, the post-questionnaire, and a lesson planning template, were sent to the participants.

The third interview (Appendix G) was conducted once all four sessions of the PDI had been completed. This interview was semi-structured as the questions from the first section were structured and those from the second section were unstructured. The questions in the first section aimed to determine what new knowledge teachers had gained concerning ESD and being a good teacher and their general feeling about the whole intervention. The questions in the second section were formulated after the researcher had looked through the participants' questionnaires and lesson plans. The purpose of these questions was to help the researcher clarify some of the questionnaires' responses and the lesson plan.

3.7.3 Data Collection in Phase 3 – Post-PDI phase

The main purpose of data collection in this phase was to help the researcher understand the teachers' post pPCK and $ePCK_p$. This data helped the researcher determine if the PDI had or had not developed the teachers' topic-specific PCK about the extraction of metals when planning lessons with ideas related to environmental sustainability.

(i) Post-intervention Questionnaire

The post-PDI questionnaire emailed to the teachers after the PDI, was identical to the questionnaire given before the intervention. Before the PDI, the teachers were required to fill in the questionnaire using a different colour font from the font colour used in the questions.

After watching all four sessions of the PDI, the participants were asked to re-answer the questionnaire by adding, deleting or modifying their initial responses. These responses would reveal the elements of the cPCK that were transferred to the teacher's own pPCK. These new modifications were done in a different colour from the first responses.

(ii) Lesson Plan

In addition to answering the post-intervention questionnaire, the participants were asked to use a lesson planning template provided by the researcher to plan a lesson on “the impact of mining” which is a sub-topic under the “extraction of metals”. An analysis of the teachers’ lesson plan revealed the teachers’ $ePCK_p$ about environmental sustainability as they plan their lessons on the extraction of metals. Particular attention was paid to learning outcomes, instructional strategies and resources, teacher and student activities, and assessment methods. This was because these aspects are directly linked to the first three components of PCK: knowledge and skills related to curricular saliency, knowledge and skills related to conceptual teaching strategies, knowledge and skills related to student understanding of science, which the researcher used to determine the quality of the teacher’s $ePCK_p$. The information in these documents was triangulated with the data from the post-questionnaire.

3.8 Piloting

Piloting an instrument increases the reliability and validity of that instrument. In this study, the researcher piloted the questionnaire, the PDI tool and the interviews. This helped the researcher to refine these instruments and ensure that data collection would yield the desired results.

3.8.1 The Questionnaire

Before the researcher sent the questionnaire to participants, the questionnaire was piloted. According Cohen et al. (2018), piloting should focus on gaining feedback on the content and format of the questionnaire. This is extremely important because it not only helps the researcher identify grammatical errors but also allows the researcher to see whether the participants understood the wording in the questions to give the most informative answers.

The researcher contacted four pilot teachers telephonically to describe the study and explain the piloting process. The teachers chosen to pilot the questionnaire were chemistry teachers who had participated in the screening process but were not chosen to be part of the final six participants. The teachers participating in the pilot were asked to send the researcher their email addresses via WhatsApp, after which the researcher emailed the questionnaire to the pilot teachers. Once the pilot teachers had responded to the questionnaire and the researcher received the responses via email, the researcher made telephone calls to the pilot teachers for feedback.

The questionnaire piloting revealed that the teachers were unfamiliar with the term "representation". To help the participants, the researcher edited the questionnaire to include examples of representations. The researcher knew that content around representations would be covered during the PDI. During the telephone interview, one of the pilot teachers commented that some of his responses to the questions were the same because he normally taught on the ideas of *conserving resources* and *impact of mining* in the same lesson. The researcher was aware of this but chose to separate some of the questions based on the big idea they focused on, as this would elicit more specific information from the teachers.

3.8.2 The Professional Development Intervention

The researcher decided to utilize one of the teachers who helped pilot the questionnaire in an effort to keep the pilot study as similar to the final study as possible. The teacher was asked to look at and give feedback on the intervention's content and structure, as the researcher wanted the intervention to be accessible to the chemistry teachers.

The teacher used to pilot the PDI was a female who had been teaching high school chemistry for eight years. This teacher was one of those excluded from the sample of participants as she was not currently teaching a Form 5 class. Although the teacher was not currently teaching a form 5 class, she had previously taught that class and was familiar with the entire chemistry section of the physical science syllabus. She also possessed a BSc degree, majoring in biology and chemistry, and a post-graduate degree in education. The teacher's experience was important as all the participants in this study were teachers with more than six years' experience.

Initially, the intervention was as a single 75-minute presentation with four sections. The pilot teacher commented by saying there was a lot to take in, and even though she remembered the term PCK from her teacher education, she had forgotten about it. She also commented on the lack of information on the concept of sustainable development. Once the researcher had received feedback from the pilot teacher, changes were made to the PDI. One of the most significant changes was that the presentation was then divided into four 15-20 minute sessions spread out over time. An experienced educator and expert in the field were then asked to review the PowerPoint presentations and afterwards suggested more changes. Each of these sessions were again reviewed by the experienced educator. Once the final sessions were approved, they were piloted, using the same teacher who greatly appreciated the shorter duration and the use of visual representations. The duration of the development of the tool was five months.

3.9 Data Analysis

Data analysis involves gathering the many bits of data collected and bringing them together to form more general conclusions (Spaulding et al., 2013). The process of data analysis requires the researcher to organise and scrutinise data to identify themes, patterns and relationships and later make interpretations (Hatch, 2002). As there are no cut-and-set data analysis methods and procedures in qualitative analysis, making sense of data can be daunting. This study focused on identifying chemistry teachers' pPCK and ePCK as they are revealed through the planning of a lesson on the extraction of metals. A PCK rubric (Appendix H) and model answers with a master CoRe (Appendix I) were employed to facilitate the analysis.

The RCM of PCK (Carlson & Daehler, 2019), which was the study's conceptual framework, was used to guide the analysis process, and components of PCK provided a lens for the investigation and organisation of the data. The components of PCK were referred to continuously to inform the data analysis and make the findings more meaningful. Data analysis was done as soon as the data was collected. This improved the quality of the research as it allowed the researcher to make decisions for future data collection based on the findings.

3.9.1 The PCK Rubric

As mentioned in the section above, the researcher used a PCK rubric to analyse data. The researcher used an adapted version of the grand PCK rubric template (Chan et al., 2019). The grand rubric suggested five components of PCK: knowledge and skills related to curricular saliency, knowledge and skills related to conceptual teaching strategies, knowledge and skills related to students' understanding of science, integration between PCK components and pedagogical reasoning. Since this grand rubric served as a template, the researcher decided to modify the rubric to suit this study. This study explored chemistry teachers' pPCK and ePCK about environmental sustainability during the planning of a lesson on the extraction of metals. Adaptations were made regarding the fourth and fifth PCK components proposed in the grand rubric. Firstly, the component of PCK "Integration between PCK components" was not included in the study's rubric. According to Chan et al. (2019), this component is based on a teacher's ability to monitor and adjust instructional moves based on student learning. The reason for its exclusion was that no CoRe prompts could be linked to this component, and this component can be accessed more effectively when a teacher is being observed in the classroom. The second modification was with regard to the component of "Pedagogical reasoning". Although these authors agreed that pedagogical reasoning is an important part of PCK, they could not agree on where the component should be placed in the rubric, within each row of the rubric or as a separate component. In this study, questions prompting teachers to explain their teaching occur within the other components; therefore, the researcher chose not to place this component separately.

Since the grand rubric has no set number of levels of competence, the researcher chose to use the four-point scale (1 for "*Limited*" to 4 for "*Exemplary*") that was used by Park et al. (2011). These levels were used to score teachers' responses in the questionnaire and lesson plan, which correspond to the components of PCK.

3.9.2 Model Answers and Master CoRe

The researcher, in collaboration with teacher educators, designed a master CoRe and also came up with model answers for those questions that could not be uniquely linked to the CoRe. These were an important part of the analysis of data. When scoring, the researcher did, however, include the three questions from the model answers under curricular saliency. The reason is that the topic of *extraction of metals* is the vehicle for exploring teachers' pPCK about environmental sustainability. Teachers are expected to have knowledge about the *extraction of metals* before going on to teach the big ideas.

It is worth noting that although the researcher's model answers are extensive, they are not considered to be the complete list of possible answers. For this reason, the researcher treated the teachers' responses on a case-by-case basis.

Since the researcher chose to use several tools in this study, a large volume of data was collected. The data was presented in three chapters to make the presentation of the findings most efficient. Each chapter included a more detailed description of the data analyses.

3.10 Validity of Instruments

The participants' responses to the pre- and post-PDI questionnaire were analysed and then rated using the PCK rubric. The responses were rated using a four-point scale with scores 1 for *limited*, 2 for *basic*, 3 for *developing* and 4 for *exemplary* (Park et al., 2011). This method has been widely used by PCK researchers (Makhechane & Mavhunga, 2021; Mavhunga, 2019b; Mavhunga & Rollnick, 2013). Since the researcher was scoring teachers under three components– curricular saliency, conceptual teaching strategies and student thinking– averages were calculated for each component. This method of using averages was also used by Mazibe et al. (2020), as it allows for smaller changes in the scores to be detected.

Before the scoring commenced, the researcher and two science education experts reviewed and discussed the rubric. Those discussions led to changes being made to the rubric. The scoring process began with the researcher giving scores for one participant. These scores, together with the rubric and questionnaire, were then sent to the science education experts, who reviewed the researchers' scores and proceeded to score the participants' responses themselves. Discussions on the three sets of scores led the researcher to work on how the rubric could be streamlined to ensure that the categories were distinct. Once further changes were made, the scoring process started again, and more discussions followed. Throughout the scoring process for all participants, the rubric was constantly adjusted and scores reconsidered. Eventually, the final rubric was agreed on and used to do the final scoring of the participants' responses.

3.11 Issues of Trustworthiness

A researcher enhances the trustworthiness of a study by ensuring that the instruments measure or test what they are supposed to measure or test. According to Creswell (2018), the strategies used to improve the trustworthiness of qualitative data are member checking, triangulation of data and external audits. Merriam (1998) also recommended that experts in the field of research should review research instruments. In this study, the researcher asked subject experts and experienced educators to review and comment on the questionnaires, interview schedules, lesson plan template and the PDI used for this study. The researcher created model answers to some of the questions in the pre- and post-questionnaire, and designed a master CoRe. To enhance the validity of these analysis tools, the researcher asked experienced chemistry teachers, who were not part of the study, and teacher educators, to add, remove or change the responses suggested by the researcher. This can therefore be considered collective PCK. Experts in the field were asked repeatedly to review the study and its instruments.

Triangulation came from the use of different methods of data collection and different analysis strategies. In this study questionnaires, telephone interviews and a lesson plan were used to access the PCK of the chemistry teachers.

3.12 Ethical Considerations

Observation of research ethics is important as it helps protect the research participants' rights and promote the research's integrity (Israel & Hay, 2006). The researcher applied for ethical clearance and waited for the clearance to be granted before seeking permission from the Ministry of Education and Training in Eswatini (Appendix J) to contact teachers and collect data. According to Creswell (2018), research participants must be informed before they are approached for data collection. The participating teachers in this research study were given consent letters (Appendix K) which contained summarised information about the research, the purpose of the study and the role of the researcher and the participant. The information and consent letters were provided by the researcher before data collection started.

Due to the COVID-19 pandemic, the methods of data collection were revised. The researcher amended the ethics application and re-applied for approval of data collection. On approval, the researcher notified the chemistry teachers that the data collection methods had changed, that participation was voluntary and that they were allowed to withdraw from the study at any time. If teachers decided to withdraw, they would not be asked for reasons or penalised in any way. Emails and telephone interviews were chosen over face-to-face interactions as the researcher did not want to expose herself or the participants to the COVID-19 virus. The researcher wanted both herself and the participants to feel safe throughout the data collection process. With the revised data collection method, the participants and researcher faced no risks in implementing the study.

The researcher also promised the respondents anonymity. This means that the researcher did not reveal the name of the schools or the chemistry teachers in the report on the study. This would “enhance the validity of the research findings by increasing the participant’s truthfulness in responding” (Passer, 2014, p 78). For this study, the researcher used both codes and pseudonyms for the participants.

3.13 Chapter Summary

In this chapter, the researcher elaborated on the different aspects of the research methodology. This study aimed to explore experienced chemistry teachers PCK of environmental sustainability, before and after an online intervention, when teaching about extraction of metals. The study employed a multiple, holistic case study. The sample consisted of six chemistry teachers from six schools in the Hhohho region of Eswatini who were purposively and conveniently selected as participants. The data collection for this qualitative study took place in three phases; before, during and after the online intervention. A screening questionnaire, pre- and post-professional development intervention (PDI) questionnaire, interviews and a lesson plan template were used to capture the six participating chemistry teachers' pPCK and ePCK. These instruments focused on obtaining findings that were revealed through planning a lesson about the syllabus topic *extraction of metals*, with a particular focus on the impact that mining has on the environment and conservation of resources. The data analysis used a validated PCK rubric, model answers and a master CoRe. The PCK components of curricular saliency, student thinking and conceptual teaching strategies constituted the lens through which the researcher investigated the personal and enacted PCK of chemistry teachers. Issues of trustworthiness and ethical considerations, such as permission, informed consent, voluntary participation and privacy and anonymity, were also discussed. Next, I discuss the data collection process followed to establish the participant teachers' initial views about sustainable development and education for sustainable development, and PCK about environmental sustainability, prior to exposing them to the professional development intervention.

4 CHAPTER 4
PRE-INTERVENTION INTERACTIONS

4.1 Overview

The focus of this chapter is to present and analyse the data collected before the professional development intervention (PDI) took place. This data collection was done to understand the initial pPCK of the six participating teachers. The chapter briefly describes the instruments used to collect this data and how the data was analysed. The summary of the background information of the six chemistry teachers, who were the key participants of this study, follows. As the chapter continues, the focus turns to these participants' responses to the screening questionnaire. These responses described their views about sustainable development (SD) and education for sustainable development (ESD) before they started the intervention. This survey was done to address the research question: What are chemistry teachers' views about sustainable development and education for sustainable development? The final section presents the data collected from the pre-intervention questionnaire and attempts to establish the teacher's initial pPCK. Each teacher's data was treated separately, and each case was discussed under the components of PCK about environmental sustainability during the extraction of metals. The chapter closes with a comparison of the teachers' initial topic-specific PCK and ends with a summary.

4.2 Data Sources for this Chapter

The instruments used to establish the initial understanding of the teachers' PCK about environmental sustainability were questionnaires. The first questionnaire, referred to as the screening questionnaire (Appendix B), was administered to a larger number of chemistry teachers (n=28) and used to select the final sample of the six teachers. Only the data from the final six participants chosen to participate in the study were used for further analysis. The second questionnaire, referred to as the pre-PDI questionnaire (Appendix C), was administered only to the six participants and focused mainly on developing an understanding of the teachers' pPCK.

4.2.1 The Screening Questionnaire

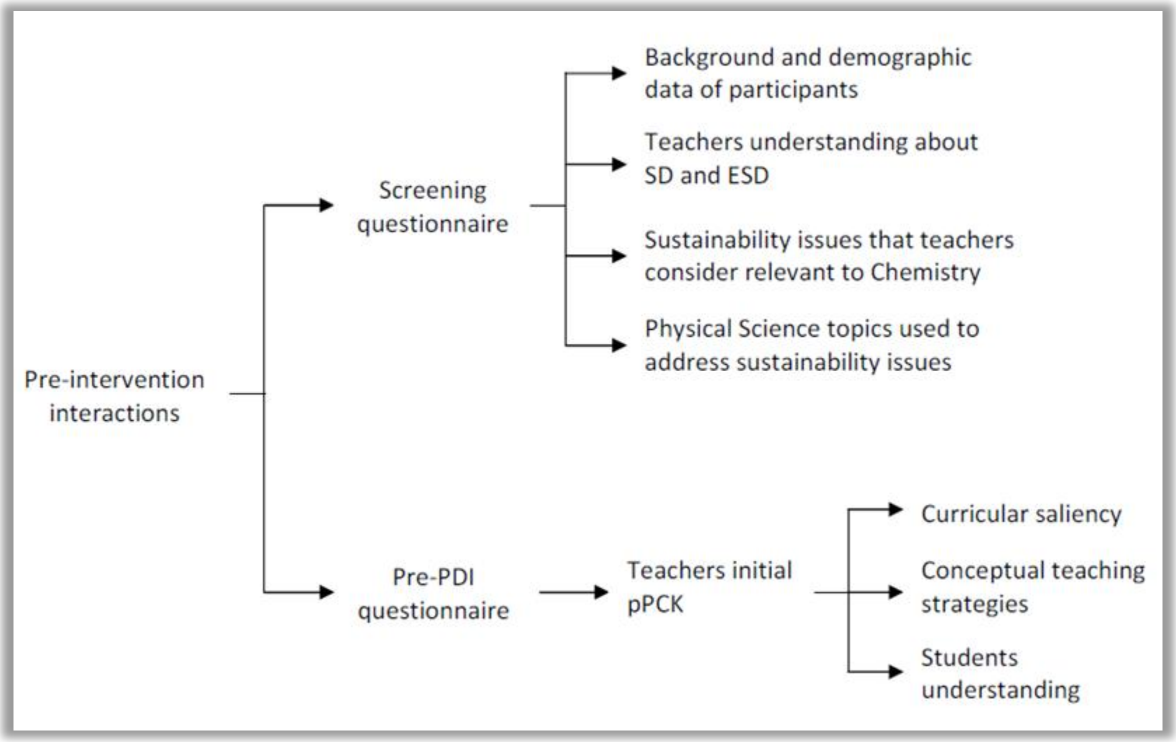
The screening questionnaire consisted of three sections. The first section solicited the teachers' demographic and biographical information. The second section used 5-point Likert scale items to assess teachers' understanding about SD and ESD, and open-ended questions to find out teachers' views on sustainability and the teaching of chemistry. The third section asked for information which was solely used for screening purposes. Only the data on the six participants collected from the first two sections of this questionnaire is discussed in this chapter.

4.2.2 The Pre-PDI Questionnaire

A Pre-PDI questionnaire was used to capture the six participating teachers' initial pPCK. The questionnaire used to capture the teachers' PCK about teaching environmental sustainability was constructed by adapting the CoRe-prompts suggested by Loughran et al. (2012). When adapting the CoRe- prompts, the components of PCK, as proposed in the grand rubric by Chan et al. (2019), were considered as these would play a major role in determining the quality of the teachers' PCK. Figure 4.1 below summarises the pre-intervention tools and the data collected from each tool.

Figure 4.1

Flow diagram showing the instruments used and the data collected during the pre-intervention data collection phase



4.3 Data Collected from the Screening Questionnaire

Before the initial data collection stage, personal and telephonic interviews were conducted with the In-Service Department at the University of Eswatini. These calls aimed to find the list of the chemistry teachers who had last attended an in-service workshop at the University of Eswatini. This exercise gave the researcher access to the telephone numbers of some of the chemistry teachers. The researcher was then able to contact several chemistry teachers, introduce them to the study and ask if they were willing to respond to a questionnaire (screening questionnaire). Those chemistry teachers who were willing became the screening sample of the study. The researcher made these chemistry teachers aware that answering the screening questionnaire was the first of two steps in the data collection stages of the research. Before the researcher could enter schools to meet with the teachers, permission was sought from the Director of Education's office (Appendix J). On receiving confirmation from the Director's office, the researcher set up appointment dates on which consent forms (Appendix K) and screening questionnaires were hand-delivered to each of the teachers. Before the teachers could answer the questionnaire, they were asked to read through the consent form in which the researcher promised anonymity of both the school and potential participants. Consent forms and screening questionnaires were sent to some teachers via email or WhatsApp.

The analysis of the screening questionnaire took place on three levels: firstly, the characteristics of the participants (gender, teaching experience, professional qualification and teaching subjects); secondly, an interpretation of the views of teachers about SD and ESD by consideration of frequency levels shown by participants when agreeing to statements on SD and ESD; and lastly, patterns of similarity when listing sustainability issues that are relevant to their teaching of Chemistry and the topics found in the EGCSE Physical Science syllabus in which those sustainability issues could be integrated. The analysis results allowed the researcher to select six chemistry teachers that satisfied specific requirements. These teachers from six high schools in the Hhohho region of Eswatini became the focus sample of the study.

The background data (Table 4.1) for the focus sample constitutes the responses the teachers provided in Section A of the screening questionnaire. The profiles of the participating teachers are based on their gender, qualifications, teaching experience and subjects. A pseudonym has been provided, in Table 4.1, for each teacher to protect their identity. Unique codes, e.g. TA for Mrs Dlamini, are used to help the reader identify to whom a response belongs when the data is presented.

Table 4.1

Profiles of the six participating chemistry teachers

Teacher	Codes	Gender	Qualification	Teaching experience (years)	Teaching subjects
Mrs Zikalala	TB	Female	B.Sc + PGCE	6-15	Mathematics and Chemistry
Mrs Dlamini	TA	Female	B.Sc + PGCE	≥ 16	Chemistry and Science
Mr Mavuso	TE	Male	B.Ed	6-15	Mathematics and Chemistry
Mr Cele	TD	Male	B.Sc + PGCE	≥ 16	Mathematics and Chemistry
Ms Dube	TF	Female	B.Sc + PGCE	6-15	Biology and Chemistry
Mr Fakudze	TC	Male	B.Sc + PGCE	6-15	Biology, Chemistry and Science

The participants (three males and three females) all possessed a teaching qualification. Five of the six participants possessed a Bachelor of Science (B.Sc) degree, with one of their majors being chemistry and a Post Graduate Certificate in Education (PGCE). The sixth participant possessed a Bachelor of Education (B.Ed) degree, with one of his majors being in chemistry. This study aimed to explore the PCK of experienced teachers; hence, all the participants had more than six years of teaching experience, with two having taught for over 16 years. According to Chan and Yung (2018), the development of a teacher's PCK greatly depends on the teacher's experience in teaching. All participants, having majored in Chemistry, are teaching Chemistry at high school level.

4.3.1 Chemistry Teachers' Views about SD and ESD Prior to PDI

The views of the chemistry teachers about SD and ESD, were found using the screening questionnaire (Appendix B) and an interview (Appendix E). The screening questionnaire was used to determine their views before the intervention and the interview was used to determine their views after the intervention. In this section, only the data from the screening questionnaire is presented as it was collected before the intervention took place. The data from the interview is presented in the next chapter as the interview took place during the intervention. Although the screening questionnaire was used to collect data from a general sample of Chemistry teachers, only the data belonging to the six participating teachers is presented in this study.

The main purpose of Section B of the screening questionnaire was to find out about the teachers' background knowledge on SD and ESD before the professional development intervention. The teachers' perceptions about SD and ESD were found using two sets of 5-point Likert scale questions. Teachers were asked whether they agreed or disagreed with twelve statements regarding SD and eight statements pertaining to ESD. As this is a case study, only frequency was used to analyse the responses, as the focus of the question was only to ascertain whether the teachers agreed with the statements or not. The questionnaire also had questions regarding the teachers' views on the relevance of sustainability to their chemistry teaching and teachers' stance on the importance of students learning about sustainability and related issues.

4.3.1.1 Understanding of SD and ESD

In this study, as mentioned earlier, content knowledge refers to the chemistry teachers' understanding of SD and how it can be integrated into education. Teachers were given a list of 12 statements about SD and asked to indicate their level of agreement with the statement. Table 4.2 shows the SD statements and the number of indications by teachers.

Table 4.2

Participants' responses to the statements on sustainable development

According to my understanding, sustainable development advocates for:		Strongly agree	Agree	Not sure	Disagree	Strongly disagree
1	Maintenance of biodiversity	5	1	-	-	-
2	Conservation of natural resources	5	1	-	-	-
3	Alleviating poverty	2	3	1	-	-
4	Recycling of waste products	3	3	-	-	-
5	Balance between use and regeneration of renewable resources	4	2	-	-	-
6	Transparency and accountability in government decision making	3	2	1	-	-
7	A higher quality of life for all people	3	2	1	-	-

According to my understanding, sustainable development advocates for:		Strongly agree	Agree	Not sure	Disagree	Strongly disagree
8	Resilience to climate change and its impacts	2	2	2	-	-
9	Full participation of women	0	4	2	-	-
10	Responsible consumption and production patterns	2	3	1	-	-
11	Preservation and restoration of the environment	5	1	-	-	-
12	Protecting and promoting human health	4	2	-	-	-
	TOTAL (Possible total of 72)	38	26	8	0	0

All the participating chemistry teachers unanimously agreed that SD advocates for the maintenance of biodiversity, conservation of natural resources, recycling of waste products, the balance between use and regeneration of renewable resources, preservation and restoration of the environment and protecting and promoting human health. For the other statements, although most agreed with the statements, one or two of the teachers were not certain.

Some participants were uncertain about SD advocating for poverty alleviation, transparency and accountability in government decision-making, a higher quality of life for all people, resilience to climate change and its impacts, the full participation of women and responsible consumption and production patterns. When analysing the statements that brought doubt to the teachers, it is evident that five of these six statements are based on the social aspect of SD. This evidence could show that the teachers are not familiar with the social aspect of sustainable development. Overall there was a higher level of agreement amongst the participants than uncertainty and disagreement. This evidence shows that Chemistry teachers are generally knowledgeable about the aspects for which SD advocates.

The teachers who formed the focus sample were also given statements to assess their understanding of ESD. According to Burmeister et al. (2012), ESD focuses on preparing young people to become responsible citizens to ensure sustainability for both present and future generations. The teachers' opinions of ESD were found using statements about which participants were asked whether they agreed or not. Again these statements were taken from the UNESCO Sourcebook on ESD (2012), specifically from the "Characteristics of ESD" section. Table 4.3 shows the responses of the teachers to the statements on ESD.

Table 4.3

Participants' responses to the statements on education for sustainable development

	According to my understanding, education for sustainable development:	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
1	Includes all three spheres of sustainability–economy, environment and society	2	4	-	-	-
2	Incorporates principles, perspectives and values related to sustainability	2	3	1	-	-
3	Engages formal, non-formal and informal education	-	4	1	1	-
4	Integrates critical issues into the curriculum	2	3	-	1	-
5	Is locally relevant and culturally appropriate	2	1	1	2	-
6	Is interdisciplinary	2	2	2	-	-
7	Is student-centred	1	2	3	-	-
8	Uses pedagogies that promote participatory learning and higher order thinking skills	3	1	2	-	-
	TOTAL (Possible total of 48)	14	20	10	4	0

It can be seen from Table 4.3 that all teachers agreed that ESD includes all three spheres of sustainability, i.e. economy, environment and society. This was the only statement that brought unanimous agreement amongst the chemistry teachers. The statements that had only one teacher either being unsure or disagreeing were that ESD incorporates principles, perspectives and values related to sustainability and integrate critical issues into the curriculum. Only four teachers believed ESD engages formal, non-formal and informal education, is interdisciplinary, and uses pedagogies that promote participatory learning and higher order thinking skills. Generally, the teachers did not understand that ESD is student-centred, locally relevant and culturally appropriate.

The responses from the table show that there were a higher number of incidents where teachers were either unsure or disagreed with the statements pertaining to ESD. When comparing the number of teachers agreeing on the statements about SD and ESD, the teachers' responses show that they generally have a better understanding of the aspects that sustainable development advocates for, compared to the characteristics of education for sustainable development. This comparison was made because the researcher believed that the participants, being teachers and part of the education sector, might have been more aware of ESD than SD.

4.3.1.2 Relevance of Sustainability to Chemistry Teaching

The researcher used data from the screening questionnaire (Appendix A) to ascertain whether teachers considered sustainability relevant to their subject and their teaching. The questions asked were as follows:

- Do you think sustainability issues are relevant to the subject you teach?
- Which sustainability issues do you consider to be relevant to chemistry teaching?
- Which of the sustainability issues mentioned above have you included in your teaching in the past?
- Which of these Physical Science topics have you used to address sustainability issues?

The researcher summarised the teachers' responses to these four questions in a table for this section. Although the questions in the questionnaire were open-ended, the responses mostly required the participants to give a list, and some of the mentioned points appeared more than once. The summarised responses in Table 4.4 give a picture of the participants' views regarding the relevance of sustainability to chemistry teaching, the sustainability issues they have included in their teaching and the chemistry topics from the EGCSE physical science syllabus previously used to address sustainability issues. For ease of identifying the correct respondents, the researcher placed codes in brackets. For example, Mrs Dlamini was Teacher A; therefore, her code was TA (See Table 4.1).

From the responses, it can be seen that all teachers believe that sustainability is relevant to chemistry. The sustainability issues that the teachers considered most relevant to chemistry were conservation of natural resources, global warming, pollution, the use of renewable resources, and preservation and restoration of the environment. All of the sustainability issues mentioned by the teachers had been taught by at least one of the teachers during one of their chemistry lessons.

Table 4.4

Participants' responses to the questions on integrating sustainability into their teaching

Question	Teachers' responses
Do you think sustainability issues are relevant to the subject you teach?	All the teachers agreed on the relevance of sustainability to chemistry
Which sustainability issues do you consider to be relevant to Chemistry teaching?	- preservation and restoration of the environment [TF][TC] - the use and regeneration of renewable resources [TF][TC] -Energy(fuels and alternative sources) [TE] - land, water and air pollution [TD][TE] - Extraction of metals [TD] - Preservation of the ozone layer [TA] - Global warming [TA][TE] - Climate change [TC] - Conservation of natural resources[TA][TB][TC][TE] - Recycling of materials [TC]
Which of the sustainability issues mentioned above have you included in your teaching in the past?	- Ozone layer [TA] - Conservation of resources [TB] - Preservation and restoration of the environment, the use and regeneration of renewable resources,climate change, conservation of natural resources, recycling of materials [TC] Land, water and air pollution; extraction of metals [TD] -Pollution; fuels; conservation [TE] - No response [TF]
Which of these Physical Science topics have you used to address sustainability issues?	- Chemical reactions [TC, TA,TE] - Acids, bases and salts [TB, TE] - Metals [TC, TB, TD, TE] - Non-metals [TA, TE] - Organic chemistry [TD,TE] - No response [TF]

The physical science EGCSE topics that the teachers chose as most suitable for integrating sustainability issues were chemical reactions, acids, bases and salts, metals, non-metals and organic chemistry. The choices made by the teachers show that they are knowledgeable about the content of the syllabus as these topics, especially the latter three, have greater opportunities for integration of sustainability issues. The issues mentioned by the teachers are mostly taught under one of three topics: metals, non-metals and organic chemistry.

4.3.1.3 Importance of Learning about Sustainability and Related Issues

The issue of importance is not equivalent to relevance. An issue can be relevant to the students but not seen as important in the eye of the participant. According to Lachica et al. (2008), importance is not determined by the students' needs as they perceive them but rather by a larger group of people who are more knowledgeable about what those students may need. The question of whether the teachers thought it was important for students to learn about sustainability and its related issues was also asked in the questionnaire. All the teachers agreed that it is important for students to be taught about sustainability issues. Of the six teachers, one (TA) did not explain why she thought it was important. These are the reasons given by the five other teachers;

> "Students are the future policymakers and persons of influence in society" (TE)
>
> "To help make use of our natural resources without exhausting them" (TF)
>
> "We are currently faced with the problem of global warming which has resulted in change in weather patterns and natural disasters. If students and everyone is aware, it would make a big difference" (TB)
>
> "So that they can be part of the practices and implementation of sustainable development strategies" (TC)
>
> "They are [the] current generation to take forward the message to the next generation" (TD)

All of these reasons given by the teachers emphasise their understanding of the important role that students must play in caring for the environment, passing the message of sustainability forward and conserving resources so that future generations can also benefit from them.

4.4 Data Collected From the Pre-PDI Questionnaire

Before the professional development intervention, the six participating teachers were asked to respond to the pre-PDI questionnaire (Appendix C). The questions focused on obtaining information from the teachers about what they would consider when teaching lessons on the *extraction of metals* with a particular focus on its impact on the environment and conservation of resources. This questionnaire's responses helped the researcher establish the teacher's initial pPCK about environmental sustainability.

4.4.1 Layout of Data from the Questionnaire

The CoRe-prompts (Loughran et al., 2004) were modified to come up with the questions used in a questionnaire format. These questions each fall under a category that is a component of PCK (Chan et al., 2019). Table 4.5 shows the alignment of the questions in the questionnaire, the questions from the CoRe and the components of PCK. This alignment played a significant role in how the researcher presented the data from the questionnaires. When presenting the data, each participant's responses to the questions were discussed under subheadings that are the components of PCK.

Table 4.5

Alignment of questions in the pre-PDI questionnaire to PCK components and CoRe questions

Component of PCK in Grand rubric (Chan et al., 2019)	**CoRe (Loughran et al., 2004)**	**Question(s)**
Curricular saliency	What do you intend the students to learn about this idea?	* What are you going to teach learners about 'Extraction of metals'? * What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?
	Why it is important for students to know this.	* In the EGCSE curriculum, environmental issues are included (See outcome 6 and 7 above). Do you agree with this inclusion and why? * Why is it important for students to know about conserving resources and the impact that mining has on the environment?
Student understanding of science	Difficulties/ limitations connected with teaching this idea.	* What do you consider difficult about teaching *conserving resources*? Why? * What do you consider difficult about teaching *the environmental impact of mining*? Why?
	Knowledge about students' thinking which influences your teaching of this idea.	* What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?
	Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	* What types of questions would you use to access student thinking and understanding about *conserving resources* and *the impact that mining has on the environment*?

Component of PCK in Grand rubric (Chan et al., 2019)	**CoRe (Loughran et al., 2004)**	**Question(s)**
Conceptual teaching strategies	Teaching procedures (and particular reasons for using these to engage with this idea).	* What teaching strategies would you use to teach *conserving resources*? Why? * What teaching strategies would you use to teach *the environmental impact of mining*? Why? * What questions, related to environmental sustainability, would you consider important to ask your learners during your teaching? * What representations (analogies, examples, diagrams, etc.) would you use during your teaching *conserving resources*? Why? * What representations would you use during your teaching *the environmental impact of mining*? Why? * In what ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?

4.4.2 Analysis of Data from the Pre-PDI Questionnaire - The PCK Rubric

The data from the questionnaire was analysed using a PCK rubric (Appendix H). The rubric was based on the grand rubric proposed by Chan et al. (2019). This grand rubric proposes five knowledge components of PCK; knowledge and skills related to Curricular Saliency, knowledge and skills related to Conceptual Teaching Strategies, knowledge and skills related to Student Understanding of science, and integration between PCK components and pedagogical reasoning. As the researcher only focused on the teachers' pPCK and ePCK during the planning phase of teaching, the component that deals with the integration between PCK components was not included. The reasoning behind this was that the best way for a teacher to reveal this component is through teaching a concept, which the participants in this study have not done. Also, the complex nature of this component would require a rubric of its own (Chan et al., 2019). Although the researchers who proposed the grand rubric believed that pedagogical reasoning takes place during the manifestations of all other components, they positioned the PCK component of pedagogical reasoning as a standalone component. During the construction of the PCK rubric used in this study, the researcher opted to incorporate pedagogical reasoning into its respective components. This meant that the rubric level indicators catered for pedagogical reasoning within each of the other three components that were part of the rubric.

The researcher adapted the grand PCK rubric template (Chan et al., 2019) and used it to score teachers' responses to the questionnaire. Each question was aligned to the PCK component prompts and then rated using a four-point scale with scores of 1 for limited, 2 for basic, 3 for developing and 4 for exemplary (Park et al., 2011). Before the scoring commenced, the rubric was discussed by three people, and this discussion led to changes being made to the rubric. The scoring process began with the researcher giving scores for one participant. These scores, together with the rubric and questionnaire, were then sent to two people who went through the researcher's scores and scored the participants' responses. Discussions on the three sets of scores led the researcher to work on how the rubric could be streamlined to ensure that the categories were distinct. Once further changes were made, the scoring process started again, and more discussions followed. Throughout the scoring process for all participants, the rubric was constantly changed, and scores were reconsidered. A detailed description of the validation of the rubric and the scoring was given and can be found in Section 3.9 in Chapter 3.

Once the component responses were scored, the average for each PCK component was found. The researcher chose to use score averages that were to one decimal place so that during the comparison of the pre- and post-PCK scores, even the slightest change to the teachers' PCK could be observed. Although most PCK studies have used whole numbers to represent pre- and post- PCK (Makhechane & Mavhunga, 2021; Mavhunga, 2019a), there have been some that have used decimals (Mazibe et al., 2020). Since the focus of this study was on the possible development of a teacher's pPCK after a PDI, any development, whether minimal or major, is of importance to the researcher. The use of whole numbers could conceal the fact that there was some development, and therefore averages that were to one decimal place were used. Figure 4.2 below shows a section of the rubric which considers a teacher's knowledge of student thinking in relation to the sustainability topics. The full rubric can be viewed in Appendix H.

Figure 4.2

Section of the PCK rubric showing teacher's knowledge and skills related to student thinking

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Knowledge and Skills related to Student thinking (S)	**S1 -** What do you consider difficult about teaching *conserving resources and the environmental impact of mining*? Why?	-No difficulties identified - Identifies broad topics/statements -No reason given	- Identifies general learner/teaching difficulties with no relation to key ideas - refers to contextual constraints - Provides generic reasons	- An appropriate difficulty related to one of the key ideas is identified and clearly formulated. - Reasons for difficulty show an awareness of student thinking and aspects of curricular saliency	- Appropriate difficulties for both key ideas are identified and clearly formulated. - Reasons given show an awareness of student thinking/ learning and aspects of curricular saliency
	S2 - What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?	- No indication of knowledge about misconceptions - The response is poorly formulated	- Identifies common learner errors /misunderstandings rather than misconceptions - Misconception identified is not clearly formulated	- Identifies two misconceptions - An indication of knowledge about misconceptions is evident - Response not well formulated	- Identifies two or more misconceptions - Response is well articulated - An indication of knowledge about misconceptions is evident
	S3 – What questions would you use to access student thinking and understanding about *conserving resources* and *the impact that mining has on the environment*?	-No questions are given -Question(s) given are vague or irrelevant -Questions are not clearly formulated	-A list of 2 or 3 questions given -Questions not all clearly formulated - Questions not linked to student thinking and conceptual teaching strategies	- A list of 2 or 3 questions appropriate for eliciting student thinking - Questions are clearly formulated - Questions linked to student thinking/ conceptual teaching strategies	- An extensive list of questions is given - Evidence of questions appropriate for eliciting student thinking - Questions linked to knowledge of student thinking and choice of conceptual teaching strategies

To further assist the researcher with the scoring process, the researcher used model answers and a master CoRe (Appendix I) that had been created by the researcher with a collection of chemistry educatorss and validated by one of the supervisors who is a chemistry education expert. These answers are an extensive yet not exhaustive representation of the collective PCK (cPCK) about environmental sustainability in the extraction of metals.

4.4.3 Teachers' PCK, as Revealed in the Pre-PDI Questionnaire

As the design of this study was a holistic multiple case study, the questionnaire data from each participant was treated as an individual case so that the researcher could compare the cases and draw a general conclusion. As mentioned above, the responses from each participant were discussed using the components of PCK as themes. Once the data from the questionnaire had been presented, the analysis of the observations made on the teacher's initial PCK using the rubric were summarised in a table.

4.4.3.1 PCK Revealed in Mrs Zikalala's Pre-questionnaire

4.4.3.1.1 Curricular Saliency

The four concepts that Mrs Zikalala listed as being most important in her teaching were *"occurrence of metals on the Earth's crust; methods of extraction of metals; the reactivity series in relation to method of extraction; and, resource management and impacts of the extraction"*. The concepts given by Mrs Zikalala were appropriate, and both of the big ideas were mentioned. There was also sufficient evidence of sequencing of her concepts, showing that Mrs Zikalala's knowledge in this area is sufficient, and as such, she was scored a four. Figure 4.3 shows an extract of the rubric and the indicators for the level.

Figure 4.3

Rubric extract showing Mrs Zikalala's score for the area of new concepts

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Knowledge and Skills related to Curricular Saliency (C)	**CS1 -** Name the four most important concepts you would address when teaching "extraction of metals"	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - reference to one of the big ideas - evidence of sequencing is present	- Appropriate ideas are identified but an important idea is missing - reference to the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident

When asked which concepts needed to be taught to learners before teaching the extraction of metals, Mrs Zikalala mentioned *"the reactivity series of metals"* and *"chemical reactions [redox reactions]"*. Although the concepts mentioned were appropriate, the list is not extensive. Since the topic "redox reactions" appears before "the reactivity series" in the EGCSE Physical science syllabus, we can conclude that there is no evidence of sequencing. For this reason, her knowledge of student pre-concepts was seen as basic, and she was scored a two.

In response to whether environmental issues should be included in the EGCSE curriculum, Mrs Zikalala had the following to say,

> *It is of paramount importance that learners understand the impacts of metal extraction [social, economic and environmental]. This is because mining contributes to erosion, deforestation, loss of biodiversity, high water usage, and water pollution,*

contamination of soil, ground and surface water. All these in the long run can cause health problems which could affect everyone in society. (Mrs Zikalala)

This response showed that Mrs Zikalala was aware of the environmental issues that stem from mining and the need for students to be made aware of these. Although the reason she gave was well articulated, her knowledge in this area was seen to be developing as the reason she gave was in line with only one of the aims of the EGCSE Physical science syllabus. As a result, she was scored a three. Figure 4.4 shows the aims of the syllabus including the one that Mrs Zikalala mentioned.

Figure 4.4

Model answer showing the aims of the EGCSE syllabus including the one Mrs Zikalala highlighted

In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	1. To develop skills and abilities that are useful in addressing environmental issues 2. To stimulate learner interest in, and care for, the environment 3. To promote awareness that the applications of science may be both beneficial and detrimental to the individual, the community and the environment

When giving reasons why she thought it was important for students to know about Big ideas A and B, she said, *"this can help integrate science and technology into finding solutions... which can help the society"* and *"finding solutions with regard to mineral supply... and finding ways of minimising the environmental impacts of mining"*. The reasons given by Mrs Zikalala were appropriate and show that she has an in-depth understanding of the link between environmental and social issues. Mrs Zikalala emphasised the importance of finding solutions to environmental and societal problems and as such, she was scored a four.

4.4.3.1.2 Conceptual Teaching Strategies

Mrs Zikalala gave a detailed account of the teaching strategies that she would employ when teaching the big ideas. The teaching methods she gave were discussion, presentation, inquiry, question and answer, and case studies. For Big idea A, she suggests starting with a discussion on resources. In this discussion, the students would be expected to come up with the effects of resource depletion and *"recommendations of resource conservation and alternatives"*. She continues, stating that the outcomes of the discussions will be shared with the rest of the class through presentations. An inquiry-based approach was chosen for Big idea B, as students would *"reflect on the different mining methods and...how waste is created and disposed of during the process of mining"*. She also describes that students would use case studies to find the impacts of mining on the environment. The teaching strategies she chose were student-centred, and her thorough description of how the strategies would be used gave a clear picture of learner involvement. In her reasoning, she did not emphasise the need for solutions to the problems that the students were finding and, as such, she was given a score of 3.

Mrs Zikalala gave an extensive list of questions she considered important to ask during her teaching. The questions she mentioned were, "*What resources are largely used and why?", "What resources are in danger of running out, and how could that impact us?", "How can we minimise the impacts mining has had on the environment?", "What alternatives can we use and how?",* and *"What recommendations do you have on resources usage in relation to the impacts they have on the environment".* All the questions focused on the big ideas, and sequencing is evident. Figure 4.5 shows evidence of questions that encourage higher-order thinking and problem-solving skills; therefore, her questioning skills were scored a four.

Figure 4.5

Questions requiring problem-solving that Mrs Zikalala considers important to ask her learners

1. What resources are largely used and why?
2. What resources are in danger of running out and how could that impact us?
3. How can we minimise the impacts mining has had on the environment?
4. What alternatives can we use and how?
5. What recommendations do you have on resources usage in relation to the impacts they have on the environment.

Mrs Zikalala identifies images as her choice of representation for Big Idea A. The images would show "the over usage of resources" and "alternative energy sources". For Big Idea B, she listed two examples, a case study and a video. Her reason for using images for both ideas was to help learners *"visualise these concepts and...aid its retention"*. She mentioned that she hoped that the case studies would allow learners to work independently, and the video would promote critical thinking amongst the learners. This was an adequate selection of representations, and her description of how they would be used showed sufficient evidence of reasoning and how they would be used to develop concepts. The term "adequate" is used in this descriptor to mean three or four, and "extensive" has been used throughout the rubric to mean four or more. She was scored a 3 as her response to this question showed that she had a developing knowledge of representations and how they can be used to support conceptual understanding. Figure 4.6 shows the rubric indicators for this score.

Figure 4.6

Rubric extract showing Mrs Zikalala's score for the area of representations under Conceptual Teaching Strategies

CTS3 - What representations would you use during your teaching conserving resources and *the environmental impact of mining*? Why? How?	- One or two representations mentioned - No reasoning identified - No explanation of how they will be used to support conceptual understanding	-One or two representations mentioned -Reasoning is insufficient/ redundant - inadequate description of how they will be used to support conceptual development	- An adequate selection of representations - Sufficient evidence of reasoning - Evidence of use of representations to support conceptual development	- An extensive selection of representations - Reasoning includes development of specific concepts with logical sequencing of events - Explanatory notes to make links to concepts being developed

When Mrs Zikalala was asked about the assessment methods that she would use during her teaching, she instead described the teaching resources that she would use. Although she went into detail about the "images of alternative resources" and the "case studies of areas and people affected by mining", there was no evidence of how these would be used to assess the students. Figure 4.7 below shows that her incomplete response to this question led to a score of 1.

Figure 4.7

Mrs Zikalala's knowledge of assessment methods, as seen in the rubric

CTS4 - What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?	- No assessment strategies provided - No evidence of appropriate assessment strategies	- Lists one or two general assessment strategies -No indications of how they are linked to concepts	- Lists appropriate assessment strategies - There are indications of how they are linked to concepts	- Lists assessment strategies with indications of how they are linked to concepts -Strategies encourage problem solving skills and critical reasoning

4.4.3.1.3 Student Understanding

When asked about the difficulties she faces when teaching, she says that the students have *"minimal knowledge of resources used in the world"*. She explains that this lack of knowledge makes it difficult for her to teach Big Idea A, as it is unfamiliar to the students. When giving reasons why students could be unfamiliar with the content, she refers to students' lack of exposure to resources. Mrs Zikalala said she faced no difficulties pertaining to Big Idea B, especially if the concept was well explained and *"learners thoroughly understand"*. Even though she referred to an appropriate difficulty level when responding to this question, her reason for the difficulty was general and she showed little awareness of knowledge of student thinking. She was thus scored a two.

When identifying typical misconceptions that students have about Big Ideas A and B, Mrs Zikalala was able to identify three misconceptions. The first one was that students believe that *"mining always leaves the environment in a bad state"*. The second misconception was since students know that mining has *"detrimental effects on the environment, closed mines cannot be rehabilitated"*. The third misconception based on Big Idea A, was that students believe that *"alternative resources are expensive and therefore should not be considered"*. From this response, it is evident that Mrs Zikalala's exemplary knowledge of student misconceptions, and she was scored a four.

Mrs Zikalala lists the questions she would use to access student thinking as *"progressive inquiry-based questions"*. She continues to give an extensive list of examples of questions she would use (Figure 4.8).

Figure 4.8

The questions Mrs Zikalala would use to assess students' thinking

> Progressive inquiry based questions for example, What resources are widely used today and why? Are these resources in danger of running out? What could happen if they could run out? What can we use instead of these resources which their extraction and use is detrimental to the environment? How has mining impacted water resources? What wildlife and how has wildlife been impacted by mining? What are the indicators that mining impacts the environment? Is it only negative impacts or do we have positive impacts on the environment?

The sequencing of the questions aims for gradual conceptual development of each big idea. Some of the questions discourage simplistic answers and encourage complex responses. Mrs Zikalala's knowledge of questioning in this area is exemplary, and she was scored a four.

4.4.3.1.4 Summary of Mrs Zikalala's Initial PCK

Table 4.6 shows a summary of Mrs Zikalala's initial PCK. This is the PCK that she revealed before undergoing the professional development intervention.

Table 4.6

A summary of the observations made on Mrs Zikalala's initial PCK using the rubric

Component of PCK	Score	Overall score for PCK component
Curricular saliency		
Concepts addressed when teaching	4	
Pre-concepts required by students	2	
Inclusion of environmental issues	3	
Importance of knowing about the big ideas	4	
		3.3
Conceptual teaching strategies		
Teaching strategies/method	3	
Questions to be asked	4	
Representations	3	
Assessment strategies	1	
		2.8
Student Understanding		
Difficulties	2	
Students' misconceptions	4	
Questions to access thinking	4	
		3.3
	Overall initial PCK	**3.1**

Mrs Zikalala's overall initial PCK was considered to be developing. The PCK components in which she achieved the highest scores were knowledge and skills related to the curricular saliency and the component of knowledge and skills related to student understanding. Her lowest score was in the component of knowledge and skills related to conceptual teaching strategies.

4.4.3.2 PCK Revealed in Mrs Dlamini's Pre-questionnaire

4.4.3.2.1 Curricular Saliency

Mrs Dlamini was able to list the concepts to be addressed when teaching. The four most important concepts listed by Mrs Dlamini were *"most metals exist as compounds, where are they found, how are metals obtained and effects of extraction on the environment"*. Figure 4.9 shows the model answers for this question and the concepts viewed as important when addressing the topic of extraction of metals. Although Mrs Dlamini's sequencing was found to be appropriate, more than one of the concepts that were viewed as important in the model answers and master CoRe were missing, and therefore she was scored a two.

Figure 4.9

Model answers showing the most important concepts that need to be taught when teaching the extraction of metals

Name the four most important concepts you would address when teaching "Extraction of metals".	- Sources of metals/ where and how the metals are found - Ease of obtaining metals from their ores can be found by relating the elements to the reactivity series - Iron can be extracted from iron ore in the blast furnace - Conservation of resources is important - Mining and extraction of metals has an environmental impact - Adverse environmental effects of mining can be minimised when mined lands are returned to a natural or economically usable state (Reclamation)

When asked which concepts needed to be taught to learners before the topicof the extraction of metals, she listed *"the reactivity series, stoichiometry, chemical reactions, redox reactions and pollution"*. This list is comprised of chemistry topics from the EGCSE syllabus. Nevertheless, the researcher concluded that even though the topics were appropriate, the sequencing of the ideas was not evident. For this reason, her knowledge of learners' pre-concepts was seen as basic, and she was scored a two. Figure 4.10 shows how Mrs Dlamini was scored in this area.

Figure 4.10

Rubric extract showing how Mrs Dlamini was scored a 2 in the area of pre-conceptions of students

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Knowledge and Skills related to Curricular Saliency (C)	**CS1 -** Name the four most important concepts you would address when teaching "extraction of metals"	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - evidence of sequencing is present	- Appropriate ideas are identified - reference to one of the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident
	CS2 – What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?	- Ideas mentioned are not appropriate -sequencing is not evident	- Ideas mentioned are appropriate - sequencing of ideas is not evident	- Identified pre-concepts are required to understand the topic -List is not extensive - Provides logical sequencing of concepts	- Identifies pre-concepts that are needed to understand the topic -list is extensive (4+) - Provides logical sequencing of concepts

Mrs Dlamini agreed that environmental issues should be included in the curriculum because *"resources take time to be formed, so need to be conserved"* and *"there are adverse effects on the environment"*. Although her reasons were not well articulated in terms of teaching outcomes, her second point could be linked to the third aim of the EGCSE Physical Science syllabus, which is related to environmental sustainability. Mrs Dlamini was, therefore, scored a two. Figure 4.11 shows the aims of the syllabus that needed to be linked to these reasons.

Figure 4.11

Model answer showing the aims of the EGCSE syllabus that can be related to environmental sustainability.

In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	1. To develop skills and abilities that are useful in addressing environmental issues 2. To stimulate learner interest in, and care for, the environment 3. To promote awareness that the applications of science may be both beneficial and detrimental to the individual, the community and the environment

When giving her reasons why she thought it was important for students to know about Big Ideas A and B, Mrs Dlamini said, *"to prevent depletion of resources and keep resources for future generations"*. Although this reason was well formulated, there was no link to the role students should play. There was also no evidence of a link between the big ideas and the environment, the society or the economy that would directly affect the students. Also, Big Idea B was also not considered in her response, and thus Mrs Dlamini was scored a two.

4.4.3.2.2 Conceptual Teaching Strategies

When selecting teaching strategies that would be employed when teaching Big Idea A, Mrs Dlamini provides discussion and use of diagrams. She listed field trips and discussions for teaching Big Idea B (See Figure 4.12). The chosen strategies were considered general, and there was no evidence that her teaching strategies would encourage critical thinking and problem-solving. Her reasoning behind her choice of teaching strategies seemed incomplete and showed no consideration of the other topic-specific PCK components. As such, her knowledge of appropriate teaching methods was considered to be basic and she was scored a two.

Figure 4.12

Mrs Dlamini's responses to the question on teaching strategies

3(a)	What teaching strategies would you use to teach*conserving resources*? Why? -diagrams of resources at present and in the past- to make them to see that the resources are reduced and take time to build up. -discussion of alternative ways to use than depleting the resources–to make them aware of renewable resources.
(b)	What teaching strategies would you use to teach *the environmental impact of mining*? Why? -use of field-trip to visit site of mining area to see the impact of mining –to see the effects -discussion on conserving resources among students- to get many points on discussion of conservation -use of diagram from internet that show mining sites and impact of mining- to see the impacts and be able to relate to real problems associated with mining.

Mrs Dlamini listed three questions that she thought would be important when teaching the big ideas. All three questions focused on Big Idea A. Her questions were, *"Why is it important to conserve resources?", "If the resources are depleted, what could be the effect?"* and *"What other aspects of SD are affected when these resources are depleted?"*. These questions were sequenced appropriately and although there was evidence that her questions may elicit some higher order thinking from the students, there was no evidence of questions that would require problem-solving. Also, her questions addressed only one of the big ideas, and as such, the teacher was given a score of two. Figure 4.13 shows the rubric blocks and the indicators for the level.

Figure 4.13

Rubric extract showing Mrs Dlamini's scores for the area of questioning under Conceptual Teaching Strategies

CTS2 - What questions, related to environmental sustainability (ES), would you consider important to ask your learners during your teaching?	- Questions listed are not specific to the key ideas - Questions are general - Sequencing is not evident	- Questions asked are related to one of the key ideas - No evidence of questions that require higher order thinking and problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require higher order thinking but not problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require critical thinking and problem solving - Sequencing of questions is evident

Mrs Dlamini identifies diagrams as her choice of representation for both Big Ideas A and B. She also describes what the diagrams will be showing. For Big idea A, she says the diagram *"compares the areas of mining before and after mining"*, and for Big Idea B, the diagram shows *"sinkholes, soil erosion, loss of vegetation, deforestation"*. Although these representations were considered appropriate, she does not specify how she will use them or why she believes these diagrams will support students' understanding of the big ideas. She, therefore, was scored a two on her knowledge of representations that would support her teaching.

When asked about the methods she would use to assess student understanding of the big ideas, Mrs Dlamini showed no evidence of knowing appropriate methods. She instead listed representations and teaching methods by saying, *"handout on mining for reading, diagrams, videos, fieldtrips, class discussions"*. She did not explain how these would be used to assess students' understanding. From these responses, there is a lack of evidence of her knowledge of ways to assess learners' conceptual understanding of the big ideas; therefore, as seen in Figure 4.14, she was scored a one.

Figure 4.14

Rubric block showing how Mrs Dlamini was scored a one on her knowledge of assessment methods

CTS4 - What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?	- No assessment strategies provided - No evidence of appropriate assessment strategies	- Lists one or two general assessment strategies -No indications of how they are linked to concepts	- Lists appropriate assessment strategies - There are indications of how they are linked to concepts	- Lists assessment strategies with indications of how they are linked to concepts -Strategies encourage problem solving skills and critical reasoning

4.4.3.2.3 Student Understanding

Mrs Dlamini states that what she finds difficult to teach students about Big Idea A is that *"mining of resources should be reduced or stopped"*. The reason given for the difficulty was that *"this industry (mining) creates a lot of money for the country and gives jobs to people who support their families"*. She also finds it difficult to teach the *"loss of diversity"* about Big idea B. Her reason for the difficulty experienced when teaching about the loss of biodiversity was *"the learners take it as if, since it (mining) is done in the mountains it has less effect on them, yet it is important for the balance of the ecosystem i.e. food webs and food chains"*. Although the difficulty mentioned for Big Idea A was neither conceptual nor contextual, Mrs Dlamini's challenge was apparently more of a moral issue. She supposedly finds it difficult to explain to a student the negative issues associated with mining when the livelihood of the student's family depends on mining. Despite giving an appropriate difficulty for Big Idea B, it was not clearly formulated, and the reasons were generic; thus, she was scored a two.

When asked about typical misconceptions that students have with regard to Big Ideas A and B, Mrs Dlamini referred to students believing that the damages caused by mining were *"permanent"*. Figure 4.15 shows suggestions of misconceptions in the master CoRe. The misconception identified by Mrs Dlamini is in line with the misconception underlined in Figure 4.15.

Figure 4.15

Some students' misconceptions about conserving resources and the impact that mining has on the environment

S2 - What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?	- There is an infinite supply of Earth's natural resources - Some ecosystems have limitless resources and provide an opportunity for limitless growth of a population (Brody and Koch 1990) - Natural gas is a renewable resource (Tortop, 2012) -Humans can fabricate rocks and minerals.	- Environmental damage is irreversible -All mines leave the environment devastated. - Air pollution (and not greenhouse gases) cause climate change -Carbon dioxide (CO_2) is the only gas that increases the greenhouse effect - CO_2 depletes the ozone layer (Arslan , Cigdemoglu & Moseley,2012) - During reclamation fauna will return unaided after the establishment of vegetation (Thompson & Thompson, 2004)

Although she could identify a misconception, it was not well formulated. This shows that she has basic knowledge about her students' misconceptions and was therefore given a 2.

Mrs Dlamini listed the questions that she would use to assess students' thinking. The questions *"how does mining affect the people, animals, plants, environment?"* and *"what changes are brought by mining to that area?"* will possibly elicit similar responses from the students, so they will be regarded as one question. The other question mentioned by Mrs Dlamini was *"what measures can be done to reduce the damages caused by mining on the environment?"* This question will encourage students to solve the problems caused by mining. Although the questions used interrogative pronouns appropriate for eliciting student understanding and were in line with the teaching strategies she planned to use, the list of questions was not extensive. Therefore, she was scored a 3 for knowledge of questioning to assess student thinking.

4.4.3.2.4 Summary of Mrs Dlamini's Initial PCK

Table 4.7 shows a summary of Mrs Dlamini's initial PCK she revealed before undergoing the professional development intervention. The table shows the scores allocated to the responses given by Mrs Dlamini.

Table 4.7

A summary of the observations made on Mrs Dlamini's initial PCK using the rubric

Component of PCK	Score	Overall score for PCK component
Curricular saliency		
Concepts addressed when teaching	2	
Pre-concepts required by students	2	
Inclusion of environmental issues	2	
Importance of knowing about the big ideas	2	
		2.0
Conceptual teaching strategies		
Teaching strategies/method	2	
Questions to be asked	2	
Representations	2	
Assessment strategies	1	
		1.8
Student Understanding		
Difficulties	2	
Student misconceptions	2	
Questions to access thinking	3	
		2.3
Overall initial PCK		**1.9**

Mrs Dlamini's overall initial PCK was considered to be basic. The PCK component in which she had the highest score was knowledge and skills related to the curricular saliency of the topic. Her lowest score was in the component of knowledge and skills related to conceptual teaching strategies.

4.4.3.3 PCK revealed in Mr Mavuso's Pre-questionnaire

4.4.3.3.1 Curricular Saliency

Mr Mavuso named the most important concepts he would address when teaching as *"the reactivity series of metals (their reaction with moisture and oxygen); the ease of extracting metals from their ores, in relation to their position in the reactivity series; and the preferred methods of extraction, in relation to the position of the metal in the reactivity series"*. The first concept is normally taught before the topic of extraction of metals and is considered to be a concept that is required by students to understand the topic of instruction. The second and third concepts will be considered as one because they both referred to the extraction of metals *"in relation to their position in the reactivity series"*. For his fourth most important concept, Mr Mavuso referred to both big ideas by stating *"the impact of mining on the ecosystem and ways to conserve the ecosystem"*. Although the ideas identified were appropriate and sequencing was evident, an important idea was missing. Figure 4.16 is an extract of the model answers showing any of the three concepts Mr Mavuso could have mentioned; where and how metals are found, extraction of iron using the blast furnace and minimising the effects of mining. His knowledge in the area of knowledge of concepts was seen to be developing, and he was scored a three.

Figure 4.16

An extract of the model answers showing concepts that Mr Mavuso was missing in his response

Name the four most important concepts you would address when teaching "Extraction of metals".	- Sources of metals/ where and how the metals are found - Ease of obtaining metals from their ores can be found by relating the elements to the reactivity series - Iron can be extracted from iron ore in the blast furnace - Conservation of resources is important - Mining and extraction of metals has an environmental impact - Adverse environmental effects of mining can be minimised when mined lands are returned to a natural or economically usable state (Reclamation)

When asked what pre-concepts he would require from his students, he responded by identifying two concepts, *"reduction and oxidation in terms of oxygen loss/gain and electron transfer"* and *"electrolysis of molten compounds"*. The concepts mentioned by Mr Mavuso, and their sequencing, were appropriate. His list of concepts was not extensive, and these made his knowledge in the area of student pre-concepts seem to be developing and he was scored a 3. Figure 4.17 shows how Mr Mavuso was scored in this area.

Figure 4.17

Rubric showing how Mr Mavuso was scored a 3 in the area of students' knowledge of pre-conceptions

CS2 – What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?	- Ideas mentioned are not appropriate -sequencing is not evident	- Ideas mentioned are appropriate - sequencing of ideas is not evident	- Identified pre-concepts are required to understand the topic -List is not extensive - Provides logical sequencing of concepts	- Identifies pre-concepts that are needed to understand the topic -list is extensive (4+) - Provides logical sequencing of concepts

Mr Mavuso agreed with the inclusion of environmental issues into the curriculum. His reasoning for the inclusion referred to the fact that environmental issues are included in the subject of Geography and so students, *"are able to understand the concept much better"*. This reason was unclear and not linked to any of the EGCSE syllabus' aims, therefore, his knowledge in this area was seen as limited, and he was scored a one. Figure 4.18 below shows the aims of the EGCSE syllabus that needed to be linked to the reasons.

Figure 4.18

Model answer shows the EGCSE syllabus's aims that can be related to environmental sustainability

In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	1. To develop skills and abilities that are useful in addressing environmental issues 2. To stimulate learner interest in, and care for, the environment 3. To promote awareness that the applications of science may be both beneficial and detrimental to the individual, the community and the environment

When asked why it is important for students to know about Big Ideas A and B, Mr Mavuso responded, *"The world is experiencing food shortages and extinction of species due to global warming/climate change, so learners need to understand the importance of conservation"*. From this response, it is evident that Mr Mavuso is aware of the link between social and environmental issues. He also describes the student's role by adding that they should "*partake in the campaign to curb the effects of climate change*". His response showed that his knowledge in this area was developing, as his role for students did not relate to any of the big ideas. He was, therefore, scored a three.

4.4.3.3.2 Conceptual Teaching Strategies

When selecting the teaching strategies that he would use to teach on the big ideas, Mr Mavuso's response mentions one strategy for each of the big ideas. For Big idea A, he mentioned student-led discussions, and his justification for using these was that *"exchanging roles helps learners to understand the information better"*. He did not elaborate on the roles or the information to which he referred. The teaching strategy he chose for Big idea B was visualisation. He described that the learners would *"observe sample pictures of an environment before and after a mining operation"*, and that using visualisation as a teaching strategy would *"help learners retain the information for a longer time"*. The strategies were appropriate but considered to be general, as there was insufficient evidence from his response to decide whether they would be used in a student-centred manner. The reasons for choosing these strategies were generic as they were not aligned to ESD. He was, therefore, scored a 2, as his knowledge in the area of conceptual teaching strategies was seen as basic.

The questions that Mr Mavuso thought would be important to ask his learners during his teaching of the big ideas were, *"How do trees help in controlling global warming? Explain their role"*, and *"Explain the importance of recycling non-biodegradable matter such as plastics and bottles"*. Although there was evidence that these questions would require higher order thinking, neither explicitly referred to Big Ideas A and B; however, they did refer to sustainability issues captured in other topics in the EGCSE physical science syllabus. Mr Mavuso's knowledge in the area of questioning was found to be basic, so he scored a two. The extract from the PCK rubric in Figure 4.19 shows the indicators that led to this score.

Figure 4.19

Rubric block showing how Mr Mavuso was scored a 2 on his knowledge of questioning

CTS2 - What questions, related to environmental sustainability (ES), would you consider important to ask your learners during your teaching?	- Questions listed are not specific to the key ideas - Questions are general - Sequencing is not evident	- Questions asked are related to one of the key ideas - No evidence of questions that require higher order thinking and problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require higher order thinking but not problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require critical thinking and problem solving - Sequencing of questions is evident

The representations that Mr Mavuso chose to use for both his big ideas were examples and pictures. For big idea A, he selected the example of the nature and game reserves in Eswatini that are used to conserve endangered species of plants and animals. He continued to say that pictures showing conserved and extinct species would give learners more clarity. For Big Idea B, Mr Mavuso said he would use examples of coal and quarry mines in Eswatini and ask learners to *"describe the condition of the air, land and water near the mines"*. He again mentioned the use of pictures that would show an ecosystem polluted by a mining operation. His reason for using examples for both Big Ideas A and B was, *"these examples are relevant, and places learners are familiar with"*. Descriptions of his representations and how they would be used were insufficient because his reasoning for his choice of representations was inadequate, and there was no evidence of how he would use these representations to support conceptual understanding. His knowledge in the area of representations was seen as basic, and he was scored a two.

When asked about the methods he would use to assess learner understanding of the big ideas, Mr Mavuso listed two methods, *"assignments"* and *"classwork and homework"*. These assessment methods are general, and his descriptions of how these assessments would be used were inadequate and did not indicate how they are linked to the big ideas (See Figure 4.20). His knowledge of assessment was, therefore, scored a two, as it was seen as basic.

Figure 4.20

Mr Mavuso's methods of assessment

What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?

- Assignments: learners would be grouped then given topics of, to research and write short essays.
- Classwork and homework: learners would answer questions that require them to recall information that was learnt.

4.4.3.3.3 Student Understanding

Mr Mavuso states that what he finds difficult to teach about Big Idea A is *"the difference between renewable and non-renewable resources"*. His reason for the difficulty was that learners tend to confuse the two, and therefore *"more emphasis with examples is needed"*. For Big Idea B, Mr Mavuso says he finds it difficult *"explaining the difference between* *effects and impacts of mining"*. His reason for this difficulty was the same as for Big Idea A as he said that *"more emphasis is needed in explaining"*. Figure 4.21 shows model answers with regards to difficulties related to learners. The difficulties mentioned by Mr Mavuso were appropriate, as this difficulty is related to students' misunderstanding of terms, as well as the teacher's difficulty in explaining the terms.

Figure 4.21

Model answers showing difficulties that can be related to students

Knowledge and Skills related to Student thinking (S)	S1 - What do you consider difficult about teaching this idea? *Why?*	**Difficulties** (*related to students*)	**Difficulties** (*related to students*)
		- student misunderstanding of terms (renewable vs. non-renewable) - lack of prior knowledge on conservation issues/natural resources - students cannot relate to conservation. - promoting outdoor experiences and encourage students to become engaged in environmental activities	-Learners find it hard to express complex environmental issues in ways that are understandable (Biodiversity, deforestation, land degradation, acid-mine drainage, greenhouse effect, global warming etc)

Despite giving appropriate difficulties, there was no evidence in his response of understanding why the students were finding it difficult to differentiate between the terms. As such, his knowledge of teaching difficulties was seen as basic and he scored a two.

When identifying the misconceptions he may encounter during his teaching, Mr Mavuso describes *"confusing effects with impacts"*. As mentioned above, a misunderstanding of terminology can be viewed as a teaching or learning difficulty rather than a misconception. For this reason, his knowledge of misconceptions was viewed as basic, and he was scored a two.

When asked about the questions he would use to elicit student thinking, Mr Mavuso lists *"problem-solving"* and *"inference"* questions. Although the type of questions he gave would encourage complex thinking, he did not give examples of the actual questions he would ask and therefore scored a one.

4.4.3.3.4 Summary of Mr Mavuso's Initial PCK

Table 4.8 shows a summary of Mr Mavuso's initial PCK that he revealed before undergoing the professional development intervention.

Table 4.8

A summary of the observations made on Mr Mavuso's initial PCK using the rubric

Component of PCK	Score	Average score for PCK component
Curricular saliency		
Concepts addressed when teaching	3	
Pre-concepts required by students	3	
Inclusion of environmental issues	1	
Importance of knowing about the big ideas	3	
		2.5
Conceptual teaching strategies		
Teaching strategies/ method	2	
Questions to be asked	2	
Representations	2	
Assessment strategies	2	
		2.0
Student Understanding		
Difficulties	2	
Students misconceptions	2	
Questions to access thinking	1	
		1.7
Overall initial PCK		**2.1**

Mr Mavuso's overall initial PCK was considered to be basic. The PCK component in which he had the highest score was knowledge and skills related to the curricular saliency of the topic. His lowest score was in the component of knowledge and skills related to students' understanding.

4.4.3.4 PCK revealed in Mr Cele's Pre-questionnaire

4.4.3.4.1 Curricular Saliency

Mr Cele listed the concepts that he viewed as being important to the teaching of extraction of metals. His chosen concepts were *"the reactivity series of metals, extraction processes from the different ores of metals, the importance of conservation of resources, and the positive and negative environmental impact of mining"*. All the ideas identified by Mr Cele were appropriate, and a sequencing of the ideas was evident. He believed that those ideas directly linked to sustainability were important to his teaching, and as such, he mentioned both big ideas. Mr Cele’s knowledge in this area was seen as exemplary. The rubric extract in Figure 4.22 shows the indicators that led Mr Cele to score a four.

Figure 4.22

Rubric indicators showing Mr Cele's exemplary knowledge of concepts to address when teaching

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Knowledge and Skills related to Curricular Saliency (C)	**CS1 -** Name the four most important concepts you would address when teaching “extraction of metals”	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - reference to one of the big ideas - evidence of sequencing is present	- Appropriate ideas are identified but an important idea is missing - reference to the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident

When asked which concepts needed to be taught to learners before the topic of the extraction of metals, he responded by listing *“the reactivity series of metals”* and *“reactions of metals”*. Although the list is not extensive, the concepts he mentioned are appropriate as they are a prerequisite to teaching this topic. The sequencing of the ideas is not evident as knowledge of reactions of metals is a required pre-concept to place the metals in order of their reactivity. Mr Cele's knowledge in the area of student pre-concepts was seen as basic, and he was scored a two.

Mr Cele agreed that it is important for environmental issues to be included in the curriculum and that it should be a topic on its own. His reason for the inclusion was, *“there are a lot of pollutants and some are emerging because of advances in technology”*, and it can *“sensitise the issue of the impacts of mining”*. He added that it could *“help contextualise the subject, chemistry, in learners”*. His reasons were well articulated, and his first two reasons were in line with one of the aims of the EGCSE syllabus. Mr Cele was scored a 3 for his knowledge in this area as it was seen as developing (See Figure 4.23).

Figure 4.23

Mr Cele's score for his reasons for the inclusion of sustainability issues into the curriculum

CS3- In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	-No reasons provided - Reasons are unclear and not linked to the outcomes of the syllabus	- Reasons provided are well articulated - Reasons are not linked to the aims of the EGCSE syllabus	- Reasons given well articulated - Reasons given linked to one or two of the aims of the EGCSE syllabus	-Two or more reasons given - Reasons provided are linked to three of the aims of the EGCSE syllabus

When asked why it is important for students to know about Big Ideas A and B, Mr Cele gave the following response,

> *The negative impact of unsustainable utility of natural resources is very close to students' lives. The occurrence of natural disasters, outbreaks/pandemics and climate changes due to greenhouse gas emissions, water, land and soil pollution, all impact their daily lives.* (Mr Cele).

Although his response does not link to the students' intended role in sustainable development, it shows that Mr Cele is aware of several sustainability issues and the relationship between environmental and social issues. His knowledge and reasoning in this area were seen as developing, and he was scored a three.

4.4.3.4.2 Conceptual Teaching Strategies

The teaching strategies Mr Cele chose to employ when teaching Big Idea were classroom discussions and site visits. While teaching Big Idea B, he would use group presentations (PowerPoint), storytelling and demonstrations. In his response, Mr Cele admits to having used the lecture method in the past but claims the learners could not relate to the concepts and *"couldn't make connections with their everyday life experiences"*, thus, he decided to change his strategy. His reasons for choosing these strategies were *"for relevance"*, to encourage learners to research, share information and *"help in correcting misconceptions"*. Although his reasons were not aligned with ESD, group presentations are considered student-centred and inquiry-based as they require the students to conduct research to find information and visual representations. Mr Cele could give brief explanations of the roles the students would play, and he was scored a 3 as his knowledge of teaching strategies was seen as developing. Figure 4.24 shows a rubric extract with the quality indicators for his score.

Figure 4.24

Mr Cele's rubric score pertaining to his knowledge of teaching strategies and questioning

Knowledge and Skills related to Conceptual Teaching Strategies (CTS)	**CTS1-** What teaching strategies would you use to teach *conserving resources* and the *environmental impact of mining*? Why?	- Lists one or two general strategies - No justification provided - Justification incomplete	- Lists general strategies - Reasons provided are generic and not necessarily aligned to ESD	- One or two strategies that are student centred - Evidence of learner involvement - Reasons not aligned to ESD specific strategies	- Presents relevant ESD teaching strategies to teach the required concept - Clear reasons, consistent with ESD specific strategies

When asked about the questions he considered important to ask during his teaching, he gave four questions. In his first question, he focuses on helping students develop ideas to promote sustainability by talking about the availability of apples for future generations (See Figure 4.25). The second question he considered was, *"differentiate between renewable and non-renewable resources"*. Another question prompted students to give examples of natural resources and describe *"what practices are being put in place to ensure that the mentioned resources are sustainably utilised"*. In his final question, Mr Cele describes how plastics manufacturing has shifted from using non-renewable to renewable resources. He then prompts students to "*give another example of environmental sustainability and explain why you think its manufacture or use is sustainable"*. Figure 4.25 below shows Mr Cele's complete response.

Figure 4.25

Mr Cele's response showing the questions he considered important to ask during his teaching

What questions, related to environmental sustainability, would you consider important to ask your learners during your teaching? Think of questions aimed at conceptual development and reasoning.

- IF ONE IS EATING AN APPLE TODAY, HOW CAN HE OR SHE ENSURE THAT EVEN THE FUTURE GENERATION ENJOYS THE APPLE FRUIT IN TURN?
- DIFFERENTIATE BETWEEN RENEWABLE AND NON-RENEWABLE SOURCES OF ENERGY
- GIVE FIVE EXAMPLES OF NATURAL RESOURCES THAT WE USE IN OUR DAILY LIVES THAT HAVE THE POSSIBILITY TO BE SUSTAINED FOR GENERATIONS AND GENERATIONS. WHAT PRACTICES ARE BEING PUT IN PLACE TO ENSURE THAT THE MENTIONED RESOURCES ARE SUSTAINABLY UTILIZED
- ONE COMMON WAY OF SUSTAINABILITY IS THE RECYCLING OF PLASTICS. PLASTICS ARE MADE FROM POLYETHENE, WHICH IS A POLYMER OF ETHENE. ETHENE IS EXTRACTED FROM PETROLEUM, WHICH IS NON RENEWABLE RESOURCE. CURRENTLY, PLASTICS ARE MADE FROM PLANTS LIGNIN (SUGARCANE) AND THE WHOLE WORLD ENCOURAGES THE USE OF RENEWABLES TO MANUFACTURE OUR DAILY PRODUCTS. GIVE ANOTHER EXAMPLE OF ENVIRONMENTAL SUSTAINABILITY AND EXPLAIN WHY YOU THINK ITS MANUFACTURE OR USE IS SUSTAINABLE

Mr Cele's questions were only related to Big Idea A, and although some of the questions required critical thinking, there was no evidence of them requiring the students to solve problems. Mr Cele's knowledge in the area of questioning was seen as basic, and he was scored a two.

When listing the representations he would use when teaching the big ideas, Mr Cele did not give an extensive list. For Big Idea A, he suggested three representations, of which only the *"picture of wild animals in a zoo or game reserve"* and a *"diagram* [picture] *of people using firewood"* were actual representations. His third suggestion was a story which culminated in a question. Mr Cele stated that for Big Idea B, *"an animation can be perfect"*. This animation would cover *"how a mine is established, developed and run* [managed]*"*. Although the representations were appropriate for the big ideas, the selection and description of how these representations would be used were inadequate. His justification for his choice of representations was insufficient, and in an attempt to justify his use of a diagram, he reveals his own misconception. Figure 4.26 shows part of Mr Cele's response in which he states that firewood is a non-renewable resource.

Figure 4.26

Mr Cele's response showing his justification for using diagrams as a representation

> DIAGRAMS OF PEOPLE USING FIREWOOD AS AN ENERGY SOURCE TO ILLUSTRATE NON-RENEWABLE ENERGY SOURCES, THIS WOULD HELP TO EXPLAIN WHY THEY ARE SAID TO BE NOT USABLE OR CANNOT BE RE-USED

Mr Cele's knowledge in the area of representations was seen as basic, and as such, he was scored a two.

When asked about the assessment strategy he would use, Mr Cele mentioned he would narrate different scenarios and *"ask learners to identify resources that need to be conserved and explain how".* Although this assessment strategy is linked to one of the big ideas, he mentioned only one assessment, and as such, he was scored a two.

4.4.3.4.3 Student Understanding

Mr Cele identified three difficulties in teaching Big Idea A. The first was based on the challenges he faces when explaining the concept of conservation of resources. He states that *"the obvious example is the conservation of biological species in game reserves",* and he finds it difficult to explain *"the concept in relation to metal extraction"*. He also found that, when referring to conservation sites/areas, students had difficulty because they "*couldn't think that wild animals and wetlands are being protected by law to avoid their extinction, instead they think that it is done to attract tourists and make money".* The third difficulty Mr Cele mentioned was that *"there are limited resources in the country so learners may not understand about resources"*. In response to difficulties pertaining to Big Idea B, he identified two difficulties. He said it was "*difficult for learners to associate mining with environment effects"*. His reason for this difficulty was that *"we have few mines in the country, and most learners have not visited these places"*. The other difficulty he mentioned was that *"learners do not have background information on mining"*. Mr Cele identified difficulties that were related to the key ideas. Although the reasons for the difficulties were contextual and did not show awareness of difficulties associated with the learning of concepts (curricular saliency), they did show an awareness of students' thinking. Mr Cele's knowledge in the area of difficulties was seen as developing, and he was scored a three. Figure 4.27 shows the rubric indicators which led to this score.

Figure 4.27

Rubric indicators showing how Mr Cele scored a two on student difficulties

Knowledge and Skills related to Student thinking (S)	**S1 -** What do you consider difficult about teaching *conserving resources and the environmental impact of mining*? Why?	-No difficulties identified - Identifies broad topics/statements -No reason given	- Identifies general learner/teaching difficulties with no relation to key ideas - refers to contextual constraints - Provides generic reasons	- An appropriate difficulty related to one of the key ideas is identified and clearly formulated. - Reasons for difficulty show an awareness of student thinking and aspects of curricular saliency	- Appropriate difficulties for both key ideas are identified and clearly formulated. - Reasons given show an awareness of student thinking/ learning and aspects of curricular saliency

Mr Cele was unable to put forward the misconceptions he encountered when teaching about Big Ideas A and B. However, he identifies students' difficulty to *"make the link between recycling and conservation"*. His response showed no indication of knowledge about misconceptions; therefore, he was scored a one.

When Mr Cele was asked about the questions he would use to assess student thinking, he gave two examples: *"how could you ensure conservation of [a] named natural resource?", "What do you think are the environmental impacts of deforestation?"*. Although these questions were appropriate for eliciting student thinking, there was no evidence of how these questions were linked to student understanding or the conceptual teaching strategies he would have used. Mr Cele's knowledge in assessing student thinking was seen as basic and as such, he was scored a two.

4.4.3.4.4 Summary of Mr Cele's Initial PCK

Table 4.9 summarises the scores allocated to the responses given by Mr Cele. It shows Mr Cele's initial PCK per component and the overall initial PCK he revealed before undergoing the professional development intervention.

Table 4.9

A summary of the observations made on Mr Cele's initial PCK using the rubric

Component of PCK	Score	Overall score for PCK component
Curricular saliency		
Concepts addressed when teaching	4	
Pre-concepts required by students	2	
Inclusion of environmental issues	3	
Importance of knowing about the big ideas	3	
		3.0
Conceptual teaching strategies		
Teaching strategies/method	3	
Questions to be asked	2	
Representations	2	
Assessment strategies	2	
		2.3
Student Understanding		
Difficulties	3	
Student misconceptions	1	
Questions to access thinking	2	
		2.0
Overall initial PCK		**2.4**

Although Mr Cele's overall initial PCK was considered to be basic, his initial PCK in the component of knowledge and skills related to the curricular saliency of the topic was found to be developing. His lowest score was in the component of knowledge and skills related to student understanding.

4.4.3.5 PCK revealed in Ms Dube's Pre-questionnaire

4.4.3.5.1 Curricular Saliency

Ms Dube named the most important concepts she would address when teaching extraction of metals as *"Oxidation/reduction, Electrolysis, Methods of extracting metals"*, and *"Conservation of environment"*. The first and second concepts are normally taught before the topic on the extraction of metals as students need them to understand the topic of instruction. As such, they are not considered pre-concepts but rather new knowledge to be taught. The third concept is considered as an appropriate idea, and the fourth idea refers to one of the big ideas. Based on only the third and fourth ideas identified being appropriate, sequencing was evident. There was more than one important idea missing, and as such, her knowledge of concepts to be taught was seen to be basic, and she was scored a two. Figure 4.28 below shows how Ms Dube was scored in this area.

Figure 4.28

Rubric showing how Ms Dube was scored a two in the area of knowledge of important concepts

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
CS1 - Name the four most important concepts you would address when teaching "extraction of metals"	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - reference to one of the big ideas - evidence of sequencing is present	- Appropriate ideas are identified but an important idea is missing - reference to the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident

When asked what concepts needed to be taught to learners before teaching them about metals extraction, she identified three concepts. The concepts were *"physical and chemical properties of metals, oxidation/reduction"*, and *"the reactivity series of metals"*. All the concepts mentioned by Ms Dube are required to understand the topic and sequencing is logical. Her list of concepts was not extensive, giving her a score of 3 as her knowledge in this area was seen as developing.

Ms Dube agreed with the inclusion of environmental issues into the curriculum. Her reasoning for the inclusion was that learners *"need to be aware that some aspects of chemistry have an impact on the environment"*. She continued to say that *"they need the knowledge on these impacts and possible ways that can be undertaken to minimise the effects on the environment"*. She concluded her response by saying that *"they should ensure that the environment is protected at all costs"*. Figure 4.29 below shows her full response. All of the reasons she provided were linked to three of the aims of the EGCSE syllabus. Ms Dube's knowledge of the inclusion of environmental issues into the curriculum was exemplary and she scored a four.

Figure 4.29

Ms Dube's response on the inclusion of environmental issues into the curriculum

> In the EGCSE curriculum, environmental issues are included (See outcome 6 and 7 above). Do you agree with this inclusion and why?
>
> Yes, I agree. The environments is man's greatest resource. Learners need to be aware of the fact that chemistry applies to everyday life not just chemicals and the lab. They need to be aware that some aspects of chemistry have an impact on the environment hence they need the knowledge on these impacts and possible ways that can be undertaken to minimise the effects on the environment. Learners need to be aware that as chemists carry out their studies they should ensure that the environment is protected at all costs.

When asked why it is important for students to know about Big Ideas A and B, Ms Dube responded by saying, *"the students know that the resources, if not conserved, can run out since they are not man-made, hence appreciate the importance of conserving them"*. She added that *"leaners will recognise that mining sites should be chosen carefully such that [they are] not situated in areas where humans, animals as well as the environment itself will be negatively affected"*. Ms Dube then decided to list five points. The first three were "*For environmental sustainability, For maintaining biodiversity"*, and *"Conserving resources means that the impact of mining on the environment can be reduced"*. All of her reasons are generic, and there is no evidence of knowledge of the need for skills that the students should develop to achieve these. The last two points were:

> *To avoid activities that destroy the environment as the rehabilitation of the resources causes [the] state a lot of money; conserving resources may also bring more revenue to the country since most of the species, sites and places of attraction will attract more visitors hence increased revenue and economic growth for the country*. (Ms Dube)

Although, from these last two reasons, it is evident that Ms Dube is aware of the link between economic and environmental issues as it benefits the country. However, she does not clarify how these reasons are directly linked to the students. Her knowledge in this area was seen as basic, and she was scored a two.

4.4.3.5.2 Conceptual Teaching Strategies

When selecting the strategies she would use to teach the big ideas, Ms Dube opted to use the same strategy for both of the big ideas. For Big Idea A, the learners would be given *"examples of resources available in the country"*, after which they would choose one *"of the listed resources and make a full presentation about it"*. For Big Idea B, the learners would *"choose one mining site in Swaziland and research about how mining has affected the surrounding environment in relation to vegetation, human beings and animals"*. This would also be followed by a presentation. For both ideas, the students would be given guiding questions. Also, for Big Idea B, the presentations would be followed by a worksheet with *"diagrams and questions which will prompt learners to identify how mining has changed the environment and how the environment can be restored"*. Although the strategy was appropriate, and there was evidence from her response that showed learner involvement, she only gave justification for her choice of strategy for Big Idea B. She was, therefore, scored a 2, as her knowledge in the area of conceptual teaching strategies was seen as basic.

The questions that Ms Dube thought would be important to ask her learners during her teaching of the big ideas were, *"What [do] learners understand environmental sustainability means? What does environmental sustainability mean for the state, economy and environment? What human activities affect environmental sustainability?"* and *"How can learners improve/ensure environmental sustainability and possible challenges they can face?"*

Although there was evidence that these questions would require higher-order thinking, neither of the questions explicitly referred to Big Ideas A or B. The questions are general and as such Ms Dube's knowledge in the area of questioning was found to be limited and she was scored a one. The extract from the PCK rubric, in Figure 4.30 shows the indicators that led to this score.

Figure 4.30

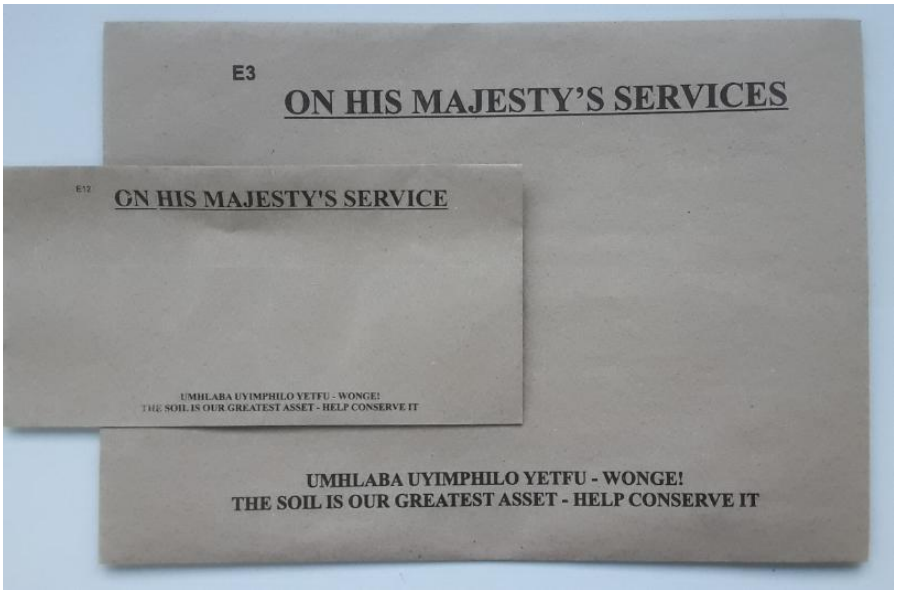
Rubric block showing how Ms Dube was scored a one on her knowledge of questioning

CTS2 - What questions, related to environmental sustainability (ES), would you consider important to ask your learners during your teaching?	- Questions listed are not specific to the key ideas - Questions are general - Sequencing is not evident	- Questions asked are related to one of the key ideas - No evidence of questions that require higher order thinking and problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require higher order thinking but not problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require critical thinking and problem solving - Sequencing of questions is evident

Ms Dube chose to use diagrams, a table, pictures and a video as representations for both her big ideas. For Big Idea A, she would start the lesson by showing *"learners diagrams of renewable and non-renewable resources all mixed up"*. The learners would then have to *"draw up a table and classify each one correctly"*. The learners would then be presented with an empty brown envelope written *"The Earth is our greatest resource – help conserve it"*. In Eswatini, there are government envelopes that have a statement on conservation. Figure 4.31 shows an envelope similar to the one Ms Dube used.

Figure 4.31

An Eswatini government envelope with a statement on conservation



Once learners were shown the envelope, they would be prompted to *"unpack the meaning of that statement"* and *"describe ways to conserve resources and what would happen if not* *conserved".* The lesson would end with learners observing pictures of *"drought-ridden areas, littered out area, deforestation"* and *"old mines"*. Ms Dube would use these pictures to *"show learners the importance of conserving resources and what happens if not done"*. For Big Idea B, she said she would use a video of *"heavy equipment and machinery clearing around mining areas, and transporting whatever ore to processing facilities using public roads, [and] water bodies contaminated by chemicals emitted from mining process e.g. acid mine draining".* She again mentioned the use of pictures, this time they would show before and after images of "*destructed habitats of animals*" and *"people around a mining area who are sick"*. When justifying her choice of visual representations, she said that they are *"not easily forgotten by the learners and easily understood"*. Ms Dube's reasoning for her choice and descriptions of how the representations would be used were sufficient. Her selection of representations was not extensive, as there were less than four, and she was scored a 3, as her knowledge in the area of representations was seen as developing.

When asked for the methods that she would use to assess students' understanding of the big ideas, Ms Dube chose to use *"formative assessment in the form of a topic test"*. She continued to say that the *"questions also include other learning outcomes for the topic"*. This assessment method is general and there are no indications in her response of how it is linked to the big ideas. Therefore, her assessment knowledge scored a 2, as it was seen as basic.

4.4.3.5.3 Student Understanding

Ms Dube stated that what she found difficult to teach about Big Idea A is that students are "*not exposed to conservation practices in their environment"* and *"they do not practice conserving resources in their everyday lives*". She also added that *"they do not understand the difference between renewable and non-renewable resources"*. For Big Idea B, she says, *"learners cannot relate to the impact mining has on the environment"*. Her reason for this difficulty was that *"they are not close to a mining site"* and *"have never seen areas affected by mining"*. The difficulties mentioned by Ms Dube were appropriate and related to the key ideas. There was no evidence in her response of reasons for these difficulties related to Big Idea A. Her reasoning for the difficulties related to Big Idea B did not refer to the actual concepts that could have been causing difficulties. Although she referred to contextual constraints, learners having never seen a mine may influence their thinking of the effects of mining. As such, her knowledge in the area of teaching difficulties was seen as basic, and she was scored a two.

When asked to identify the misconceptions she encountered during her teaching about the big ideas, she described that students think that *"natural resources never run out"* and *"mining does not affect the environment"*. Although only the first idea is stated as a misconception in the model answers and master CoRe, this list is not exhaustive. Therefore the second idea will not be disregarded as Ms Dube's response shows an indication of knowledge about misconceptions. Her knowledge in the area of misconceptions was viewed as developing, and she was scored a three. The rubric extract in Figure 4.32 shows how she was scored in this area.

Figure 4.32

Rubric extract showing how Ms Dube was scored a 3 in the area of knowledge of misconceptions

S2 - What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?	- No indication of knowledge about misconceptions - The response is poorly formulated	- Identifies common learner errors /misunderstandings rather than misconceptions - Misconception identified is not clearly formulated	- Identifies two misconceptions - An indication of knowledge about misconceptions is evident - Response not well formulated	- Identifies two or more misconceptions - Response is well articulated - An indication of knowledge about misconceptions is evident

When asked about the questions she would use to elicit student thinking, Ms Dube responds by saying she would ask *"questions that probe learners to think about the concepts discussed in the topic"*. She continues to give examples and lists, *"What is meant by conserving resources? Is it really necessary? What would happen if not done"?* Although she doesn't give examples related to Big Idea B, she mentions, *Also, on the impact of mining, I would ask those questions"*. Although the questions she gave would elicit student thinking, they are not all clearly formulated and do not show a link to the conceptual teaching strategies she mentioned earlier. Her knowledge in this area of student understanding was seen as basic and she was scored a two.

4.4.3.5.4 Summary of Ms Dube's Initial PCK

Table 4.10 summarises Ms Dube's initial PCK that she revealed before undergoing the professional development intervention.

Table 4.10

A summary of the observations made on Ms Dube's initial PCK using the rubric

Component of PCK	Score	Average score for PCK component
Curricular saliency		
Concepts addressed when teaching	2	
Pre-concepts required by students	3	
Inclusion of environmental issues	4	
Importance of knowing about the big ideas	2	
		2.8
Conceptual teaching strategies		
Teaching strategies/method	2	
Questions to be asked	1	
Representations	3	
Assessment strategies	2	
		2.0
Student Understanding		
Difficulties	2	
Student misconceptions	3	
Questions to assess students' thinking	2	
		2.3
Overall initial PCK		**2.4**

Ms Dubes's overall initial PCK was considered to be basic. The PCK component in which she had the highest score was knowledge and skills related to the curricular saliency of the topic. Her PCK in this component was seen to be developing. Her lowest score was in the component of knowledge and skills related to the conceptual teaching strategies.

4.4.3.6 PCK Revealed in Mr Fakudze's Pre-questionnaire

4.4.3.6.1 Curricular Saliency

Mr Fakudze was prompted to list the most important concepts he would address during his teaching of "*extraction of metals*". Mr Fakudze listed: *"Describe native metals first, metal ores and identify native metals. Introduce the reactivity series that metals are arranged in order of their reactivity and that metals at the top are highly reactive. Relate the reactivity series with the extraction of each metal",* and *"Explain that metals at the bottom of the* *reactivity series are obtained in their pure state because they are native"*. Although his response was not well formulated, it was understandable. Although sequencing was evident and some appropriate ideas were mentioned, more than one important idea was missing. Figure 4.33 shows that Mr Fakudze's knowledge in this area was basic, and as such, he was scored a two.

Figure 4.33

Rubric extract showing Mr Fakudze's limited knowledge in the area of important concepts

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
CS1 - Name the four most important concepts you would address when teaching "extraction of metals"	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - reference to one of the big ideas - evidence of sequencing is present	- Appropriate ideas are identified but an important idea is missing - reference to the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident

When asked which concepts needed to be taught to learners before the topic of "extraction of metals", Mr Fakudze mentioned, "*Unreactive metals such as gold and silver occur in their ores as elements. Ores of other metals appear as compounds. Explain that compounds of more reactive metals in the reactivity series need costly methods like electrolysis",* and *"Explain that compounds of less reactive metals are stable, so they need a reducing"*. The ideas mentioned are inappropriate as they do not constitute the pre-concepts required by students to understand the topic. They make up part of the new knowledge that students will gain while teaching the topic. Mr Fakudze's responses indicate that his knowledge in this area is limited, and he was scored a one.

Mr Fakudze agreed with the inclusion of environmental issues into the EGCSE curriculum. He said that *"learners need to know ... that environmental issues are common in nowadays and an issue of global importance, as human behaviour towards the environment causes harm to the environment"*. His response is well articulated, and his reason for the inclusion is in line with one of the aims of the EGCSE syllabus. His knowledge in this area of curricular saliency is seen as developing, and as such he was scored a three.

When asked why it is important for students to know about the big ideas, Mr Fakudze responded by saying that learners needed to know that *"mining has long-term effects on the* *environment and it takes years for the environment to replenish"*. The response given by Mr Fakudze does not show evidence of his understanding of how these effects on the environment are linked to societal issues. It also does not indicate the knowledge and skills needed by students and the role they play in minimising these environmental effects. For this reason he was scored a 2, as his knowledge in this area was seen as basic.

4.4.3.6.2 Conceptual Teaching Strategies

When selecting teaching strategies that would be employed during his teaching of the big ideas, Mr Fakudze opted to use a *"site visit to Ngwenya iron ore mine"* followed by report writing and a class discussion for both Big Ideas A and B. His response does not indicate what he expects learners to write. He did mention that during the discussion, the students would discuss "*What could have been done to solve the issues at Ngwenya iron ore mine"*. This strategy is considered general as there is insufficient evidence of learner involvement. He did not justify his choice, and as such, he was scored a one, as his knowledge of teaching strategies was found to be limited.

When asked about the questions that he considers important when teaching the Big Ideas, he grouped his questions based on two ideas, *"water as our precious resource"* and the *"cutting down of trees for firewood"*. Figure 4.34 shows the questions he would ask.

Figure 4.34

Questions that Mr Fakudze considers important to ask during his teaching

What questions, related to environmental sustainability, would you consider important to ask your learners during your teaching? Think of questions aimed at conceptual development and reasoning.

I always make an example of water as our precious resources.

1. How would you cope if water would be finished in the area and had nowhere to run to?
2. What are you doing now to conserve water and make sure so that I last for years?

I also relate to cutting down of trees for firewood as it is a common problem in the area.

1. What would happen if you continue cutting down trees for firewood?
2. What solutions are you employing to solve the issue of firewood in the area so that we can have trees for future generations?

Although he did not explicitly mention Big Idea A, the questions referring to water as a precious resource and the cutting of trees could be related to Big Idea A, since water and trees are considered natural resources. There were no questions pertaining to Big Idea B in his response. Despite this, there was evidence of questions requiring problem-solving skills, and if the two resources, water and trees, are looked at independently, sequencing of the questions is evident. Mr Fakudze's knowledge in the area of questioning was seen as developing, and as such, he was scored a three. Figure 4.35 shows the rubric blocks and the indicators for the level.

Figure 4.35

Rubric extract showing Mr Fakudze's scores for the area of questioning under Conceptual Teaching Strategies

CTS2 - What questions, related to environmental sustainability (ES), would you consider important to ask your learners during your teaching?	- Questions listed are not specific to the key ideas - Questions are general - Sequencing is not evident	- Questions asked are related to one of the key ideas - No evidence of questions that require higher order thinking and problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require higher order thinking but not problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require critical thinking and problem solving - Sequencing of questions is evident

Mr. Fakudze stated that he would use a sticker and pictures as representations to enhance students' understanding of the big ideas. For Big Idea A, a sticker with a statement written, *"throwing plastics using a window is a crime, it can result ina fine of E50 so help protect the environment"* would be used as an example of how the Eswatini Environmental Authority tries to protect the environment and conserve resources. He describes that after showing the students the sticker, he would ask them to name *"natural resources they know and how they can be conserved"*. For Big Idea B, he would use pictures of local mines and would make students aware that *"due to mining very large pits were left behind which is a threat to people and animals living in the area"* and *" that there was vegetation growing in the mining areas but it was destroyed for the resources"*. In his response, Mr Fakudze mentions only two representations. Although he described how these representations would be used, there was insufficient evidence of how they would support conceptual development. Mr Fakudze did not justify the choice of these representations; as such, his knowledge in this area was seen as basic and he was scored a two.

When indicating the assessment method he would use, Mr Fakudze responded by providing a question he would ask the learners. He stated, *"explain the effects of mining on the environment being vegetation, land and water"*. Although the question was linked to the topic, the response did not include any evidence of how the question would be given to learners or even what they would be expected to do. His assessment method was seen to be general; therefore, he was scored a 2, as his knowledge was found to be basic.

4.4.3.6.3 Student Understanding

When asked about the difficulties he encounters when teaching about Big Idea A, Mr Fakudze stated that students *"confuse it with environmental conservation"*. For Big Idea B, he mentioned that his school does not always permit for students to visit local mines, thus making it difficult to teach about this idea. Although the response was not clearly formulated, his difficulty for Big Idea A was appropriate as it refers to students' actual misunderstanding. The difficulty he mentioned for Big Idea B was a contextual constraint and did not reveal knowledge of students' thinking. Mr Fakudze could also not give reasons for these difficulties, and as such, his knowledge of the difficulties was found to be basic, and he was scored a two.

In response to the question on the typical misconceptions he faced when teaching about Big Ideas A and B, he said students "*have the concept that it's only mining [that] has effects on the depletion of natural resources"*. Although a potential misconception was identified, the response was not clearly formulated. As such, his knowledge of common student misconceptions was scored a two, as it was found to be basic.

When asked about the questions he would use to access student thinking, Mr Fakudze responded with the question, *"explain how mining can have a long-term effect on the environment and natural resources"*. Although the question he gave was clearly formulated, he did not reveal any intention of asking other questions, and as such, he was scored a one.

4.4.3.6.4 Summary of Mr Fakudze's Initial PCK

Table 4.11 shows a summary of Mr Fakudze's initial PCK he revealed before undergoing the professional development intervention. The table shows the scores allocated to the responses given by Mr Fakudze.

Table 4.11

A summary of the observations made on Mr Fakudze's initial PCK using the rubric

Component of PCK	Score	Overall score for PCK component
Curricular saliency		
Concepts addressed when teaching	2	
Pre-concepts required by students	1	
Inclusion of environmental issues	3	
Importance of knowing about the big ideas	2	
		2.0
Conceptual teaching strategies		
Teaching strategies/method	1	
Questions to be asked	3	
Representations	2	
Assessment strategies	2	
		2.0
Student Understanding		
Difficulties	2	
Student misconceptions	2	
Questions to access thinking	1	
		1.7
Overall initial PCK		**1.9**

Mr Fakudze's overall initial PCK was considered to be basic. The PCK component in which he had the highest score was knowledge and skills related to the curricular saliency of the topic. His lowest score was in the component of knowledge and skills related to student understanding.

4.5 A Summary of the Analysis of Quality of the Teachers' Initial Topic-specific PCK

In the tables (Tables 4.6, 4.7, 4.8, 4.9, 4.10, and 4.11), each sub-component's outcome (component prompt) was scored using the rubric for each participant. The averages for each component were then calculated to get scores for each PCK component. In this summary, only the PCK component scores for each participant are shown. This was done to compare the scores for each PCK component for the six teachers. A summary of the analysis of the teachers' responses using the PCK rubric is given in Table 4.12.

Table 4.12

A summary of the analysis of the teachers' responses using the PCK rubric

Component of PCK	Score					
	Mrs Zikalala	Mrs Dlamini	Mr Mavuso	Mr Cele	Ms Dube	Mr Fakudze
Curricular saliency	3.3	2.0	2.5	3.0	2.8	2.0
Conceptual teaching strategies	2.8	1.8	2.0	2.3	2.0	2.0
Student Understanding	3.3	2.3	1.7	2.0	2.3	1.7
Overall initial PCK	3.1	2.0	2.1	2.4	2.4	1.9

The teachers' responses to these questions gave much insight into the initial PCK of the teachers. The same questionnaire was administered to the teachers after the intervention and the responses were used together with a lesson plan to determine the teachers' final PCK. The responses from the pre-intervention questionnaire were later compared to the responses of the post-intervention questionnaire and used to determine whether the intervention did or did not develop the teachers' PCK about environmental sustainability.

4.6 Chapter Summary

This chapter presented the findings from the data collected before the commencement of the professional development intervention. This data was collected using two questionnaires. The first questionnaire was a screening questionnaire which gave insight into the background information of the teachers and their views on sustainability and ESD. Regarding what SD advocates for, there was unanimous agreement on six of the twelve statements. These statements were maintenance of biodiversity, conservation of natural resources, recycling waste products, the balance between use and regeneration of renewable resources, preservation and restoration of the environment and protecting and promoting human health. Conservation of resources and preservation and restoration of the environment could be linked to what later became the big ideas. Much doubt has arisen from statements that referred to the social aspects of SD. When prompted on their understanding of ESD, there was evidence of only one of the eight statements where there was unanimous agreement. This was that ESD includes all three spheres of sustainability, i.e. economy, environment and society. Three of the six participants were unsure whether ESD was student centred and two of the six were unsure whether ESD promotes participatory learning and higher order thinking skills. Three teachers were either unsure or disagreed that ESD is locally relevant and culturally appropriate. From these findings, it was evident that the teachers had more uncertainties about ESD than SD. According to Burmeister and Eilks (2013), the effective integration of sustainability into a lesson relies on the teachers' knowledge of ESD. This suggested to the researcher that the PDI needed a session whereby the teachers would be exposed to ESD.

In the teachers' responses to the questions on sustainability, conservation of resources, which was Big Idea A, was an issue that four of the six teachers considered relevant to chemistry. Of those four, three mentioned that they had included it in their teaching in the past. Only one teacher mentioned the extraction of metals, yet four teachers chose the topic of "metals" as the most suitable for addressing sustainability issues. These responses showed that the teachers were familiar with the big ideas; conserving resources and the environmental impact of mining. This finding assured the researcher that an appropriate topic, extraction of metals, was chosen for the study.

The second questionnaire was the pre-intervention questionnaire which gave an understanding of the participants' initial pPCK. The findings from each participant were presented separately and compared in a summary table later. It was found that all teachers had a basic initial PCK, except for Mrs Zikakala, who was found to have a developing PCK. When analysing their PCK per component, it was revealed that all the teachers had the highest scores in the knowledge and skills component related to curricular saliency. Mrs Zikalala, Mrs Dlamini and Ms Dube had their lowest scores in the component of conceptual teaching strategies, and Mr Mavuso, Mr Cele and Mr Fakudze had their lowest scores in the component of student understanding. The varying scores of the teachers in the different components of PCK informed the PDI by consolidating the idea that it should cover all components of PCK.

The following chapter discusses the online professional development intervention which was the focal point for the data collection that took place during the course of the study. It also presents the findings from the data that was collected from the interviews that took place during the intervention.

5 CHAPTER 5
THE INTERVENTION

5.1 Overview

This chapter focuses on the Professional Development Intervention (PDI) conducted with the six teachers participating in the study. The chapter starts with a description of the design, structure and content of the online presentation of the intervention. The chapter then presents the data from the interviews conducted during the intervention. The data from the first interview provides evidence of the teachers' knowledge of the curricular saliency of the topic through the teachers' responses to the questions enquiring into the teachers' views about sustainability and education for sustainability. The data from the second and third interviews provide evidence related to the teachers' knowledge about curricular saliency, conceptual teaching strategies and student understanding of the topic of environmental sustainability. The data collected through the interviews supplemented the teachers' responses to the questionnaire and assisted in answering the following research questions:

1. What are chemistry teachers' views about sustainability and education for sustainability?
2. What is the nature of personal topic-specific PCK about extraction of metals with big ideas related to environmental sustainability, revealed in the teachers' planning prior to the PDI?
3. What is the nature of personal topic-specific PCK about extraction of metals with big ideas related to environmental sustainability, revealed in the teachers' planning after the PDI?
4. How does a professional development intervention influence the development of an experienced chemistry teacher's topic-specific PCK on the extraction of metals?

The chapter will end with a summary.

5.2 The Intervention

Over the years, the requirements for learning have been changing. Learning is becoming deeper, more complicated and sophisticated. This means the demand on the teacher competencies that teachers need to develop to teach in the 21st century has intensified. Teacher educators are obligated to look into ways of helping teachers develop these 21st century competencies (Darling-Hammond et al., 2017). Those teachers in service constantly need ways to learn new ways of teaching and develop their PCK as a whole. PCK is a key component of successful teaching (Kleickmann, 2013). Grossman (1990) states that a teacher's PCK can develop from various sources. Although Friedrichsen (2009) stated professional development programmes as a source of subject matter knowledge for teachers, the same can be expected of PCK. Education for sustainable development is a concept that sees a change from traditional forms of teaching to more contemporary, student-centred teaching. This study aimed to find how chemistry teachers reveal their personal PCK about environmental sustainability through planning a lesson on the extraction of metals and how this PCK can be developed. The researcher generated a professional development intervention which could help experienced chemistry teachers develop their PCK about the simultaneous teaching of chemistry and environmental sustainability.

5.2.1 The Design

The design the researcher chose for this intervention was based on the objectives the researcher hoped to achieve. As seen in the research questions above, the study mainly investigated how exposure to an intervention could affect the teachers' transfer of PCK from cPCK to pPCK, and from pPCK to the ePCK. The intervention focused on developing teachers' personal PCK about environmental sustainability. The intervention exposed the teachers to relevant sustainability issues, the concept of education for sustainable development, and how the components of PCK could help them plan an effective lesson by exploring some attributes of a good teacher. According to Lin (2006), a teacher's professional development opportunities could be in the form of seminars, workshops, professional dialogues, curriculum development meetings, peer classroom observation and peer coaching. Although the intervention was initially supposed to be face-to-face, it was later adapted to an online format because of COVID-19 regulations.

5.2.2 The Structure

The professional development intervention comprised four 15-20 minute online training sessions. The sessions were in the form of narrated PowerPoint presentations which were sent to the participants via email. This format was chosen instead of real-time online Google or Zoom meetings because schools were closed during the intervention, and most participants did not have access to a stable internet connection.

The first and second sessions focused on developing the teacher's knowledge about the curricular saliency of the topic of environmental sustainability by focusing on a lesson on the extraction of metals. The first session covered sustainability issues considered relevant to students and those directly or indirectly linked to the extraction of metals. The second session exposed teachers to ESD and explored how a teacher could use their current syllabus to incorporate sustainability issues. The third session focused on developing teachers' understanding of student thinking and learning. The fourth and final session explored conceptual teaching strategies, which could be used when planning a lesson with environmental sustainability and pedagogical reasoning in mind. This training happened after the researcher had established the teachers' baseline knowledge about SD and ESD, and their baseline PCK about the teaching of the extraction of metals, with an infused element of environmental sustainability.

5.2.3 The Content

As mentioned earlier, the baseline knowledge of the teachers was established before the intervention. This baseline knowledge was found using questionnaires, which focused on the participant's knowledge of curricular saliency, conceptual teaching strategies and student understanding about the topic. The intervention content was therefore aligned to these PCK components to enhance the teachers' knowledge in these areas. Data was also collected after the intervention to compare teachers' initial PCK (before the PDI) and final PCK (after the PDI).

5.2.3.1 Session 1

The researcher started this session by reviewing the attributes of a good teacher. These attributes relate to the components of PCK in everyday terminology, as the researcher did not want to overwhelm participants with big words and definitions. Table 5.1 shows how the attributes of a good teacher were aligned to the components of PCK.

Table 5.1

Alignment of components of PCK and attributes of a good teacher

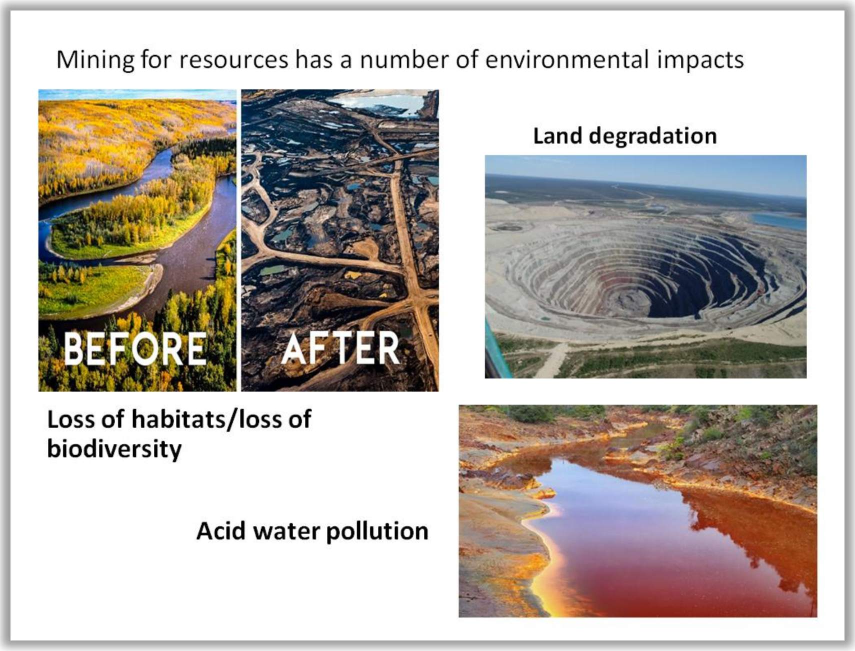
Component of PCK	Attributes of a good teacher
Curricular Saliency	• Know the curriculum • Know what students have been taught previously • Know about issues that are relevant to the students
Conceptual Teaching Strategies	• Know how to select teaching methods that will promote meaningful learning • Know how to select teaching aids and resources that will help the students understand
Student Understanding of Science	• Know what interests the students have • Know what ideas the students have about scientific concepts • Know how to connect concepts to help students understand

Component of PCK	Attributes of a good teacher
Integration between PCK Components	• Know how to adjust instruction based on student learning • Be able to interconnect and use all this knowledge to make teaching most effective
Pedagogical Reasoning	• Be able to justify their instructional moves

One of the attributes mentioned was that a good teacher must know the issues that are relevant to students and is related to knowledge about the curricular saliency of the topic. This attribute allowed the researcher to introduce the teachers to global issues, which under sustainable development can be grouped into economic, societal or environmental issues. The researcher therefore started by briefly listing economic issues, followed by societal issues. The environmental issues, which are the focus of this study, were discussed last with a greater focus on the environmental issues caused by mining resources. Figure 5.1 depicts one of the slides in this session showing the environmental impacts of mining.

Figure 5.1

Environmental impacts of mining from the Session 1 presentation



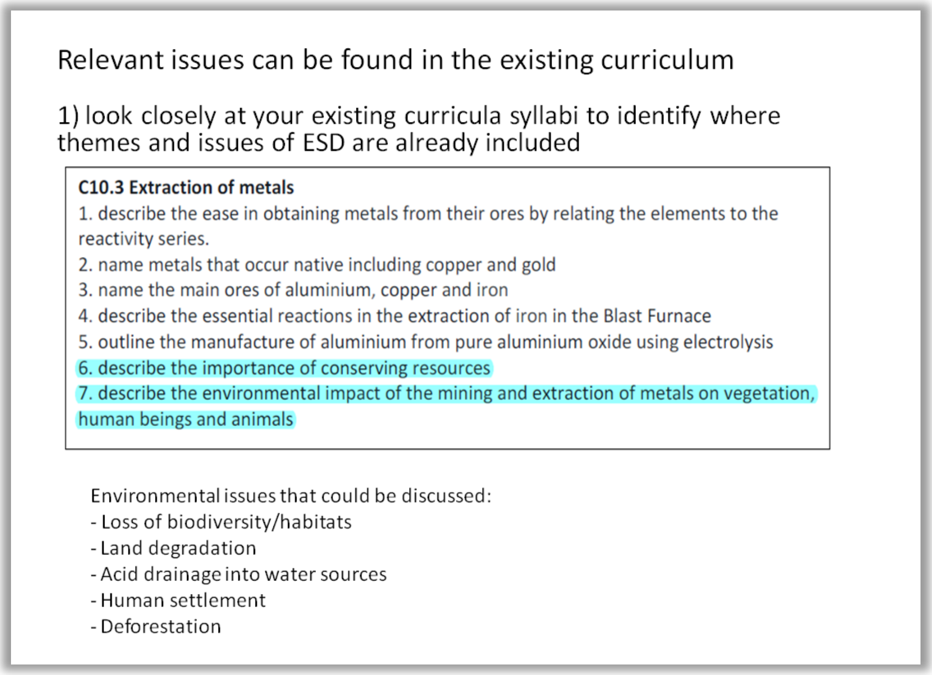
On this particular slide, the researcher was discussing the environmental impacts of mining. The focus on the environmental impacts of mining was because the study aimed to determine the teachers' PCK about environmental sustainability as seen through the planning of a lesson about the syllabus topic "Extraction of metals". The researcher chose to use this topic throughout the intervention, focusing on the outcomes (big ideas) dealing with the "environmental impact of mining" and "conservation of resources" as these gave the researcher greater opportunities to integrate environmental sustainability issues. A discussion of these issues gave the researcher a chance to introduce the concept of Education for Sustainable Development (ESD) to the participating teachers. This was the first step to exposing the teachers to aspects that have the potential to enhance their knowledge about the curricular saliency of the topic.

5.2.3.2 Session 2

The second session started with a brief account of the link between Sustainable Development (SD) and ESD, using Sustainable Development Goal (SDG) Number 4, emphasising quality education. The session quickly moved on to the characteristics of ESD, some of which were later used in Session 4 to guide teachers in selecting appropriate teaching strategies. The teachers were then shown how to identify sustainability issues in atopic in the existing Physical Science curriculum and asked to do the same in another topic. This was done by analysing the learning outcomes stated in the syllabus and identifying themes and issues of SD. This exercise was linked to the attributes of a good teacher aligned to the teacher's knowledge of curricular saliency, which states that a good teacher should be able to identify issues relevant to the students. Figure 5.2 depicts a screenshot of the slide that paid attention to the learning outcomes under the topic of the extraction of metals.

Figure 5.2

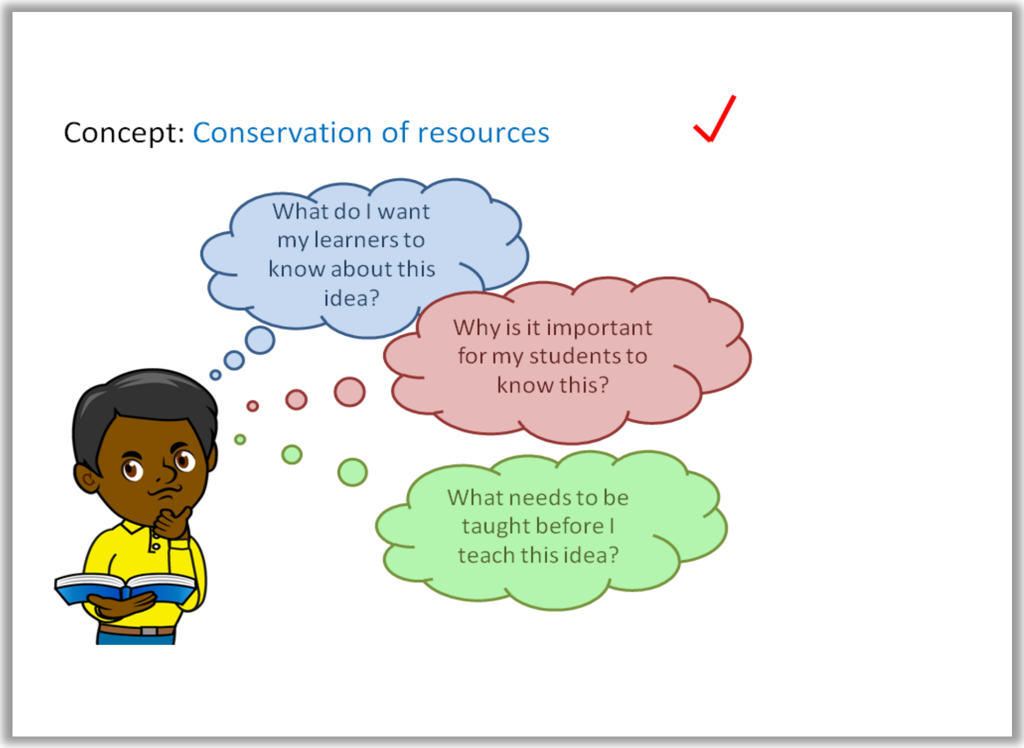
How to identify themes and issues of sustainability in the existing syllabus



Once the "big ideas" were identified, the researcher focused on teachers' awareness that there are questions that a teacher should ask themselves before teaching the content (relating to curricular saliency). The screenshot from the presentation shows the questions that a teacher should ask (Figure 5.3).

Figure 5.3

A screenshot from Session 2 with questions used to assess a teacher's curricular saliency



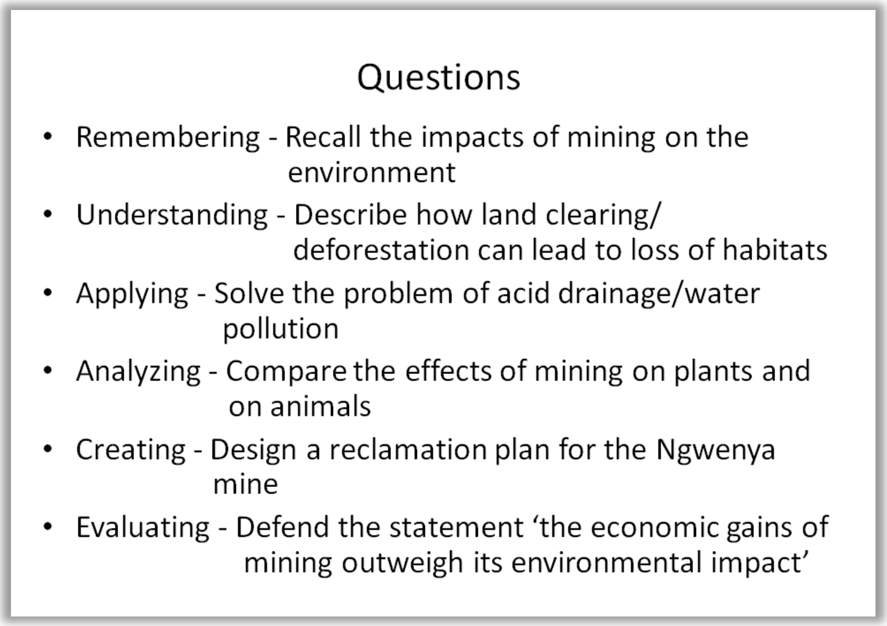
These questions from the Loughran et al. (2012) CoRe are used to help researchers assess a teacher's knowledge and skills related to curricular saliency. Since this is a PDI focused on enhancing a teacher's PCK about environmental sustainability, the researcher purposefully based the PDI content on the components of PCK. However, as explained earlier, the phrase "pedagogical content knowledge" and the PCK terminology was initially not used to avoid confusing teachers with unfamiliar terminology. The session continued to guide teachers on how to answer these questions using the example of the "big idea" of the conservation of resources.

5.2.3.3 Session 3

This session was based on PCK components three and four; knowledge and skills related to students' understanding of science and integration between PCK components (adjusting instructional moves based on student learning of concepts). The components discussed in this session focused mainly on student learning and thinking and how a teacher responds to these. Therefore, as with the data presented in Chapter 4, the researcher will continue to present and discuss these components together as "Student understanding". This session emphasised the importance of a teacher's skills and knowledge of identifying and acknowledging variations in student learning and eliciting and assessing student difficulties and misconceptions. The session looked at questioning as a method of eliciting student thinking. Examples of questions in line with the extraction of metals, which could be asked before, during and after the lesson, were discussed. The researcher used a slide (Figure 5.5) to show the teachers how to use Bloom's taxonomy to plan the questions they would ask during the lesson. This was important for the intervention as ESD promotes higher order thinking skills which can mostly be accessed through higher order questioning.

Figure 5.4

How teachers could use Bloom's taxonomy when planning their questions



The third session also looked at some misconceptions and common learner errors surrounding the topic and some reasons why students would find these concepts difficult to understand.

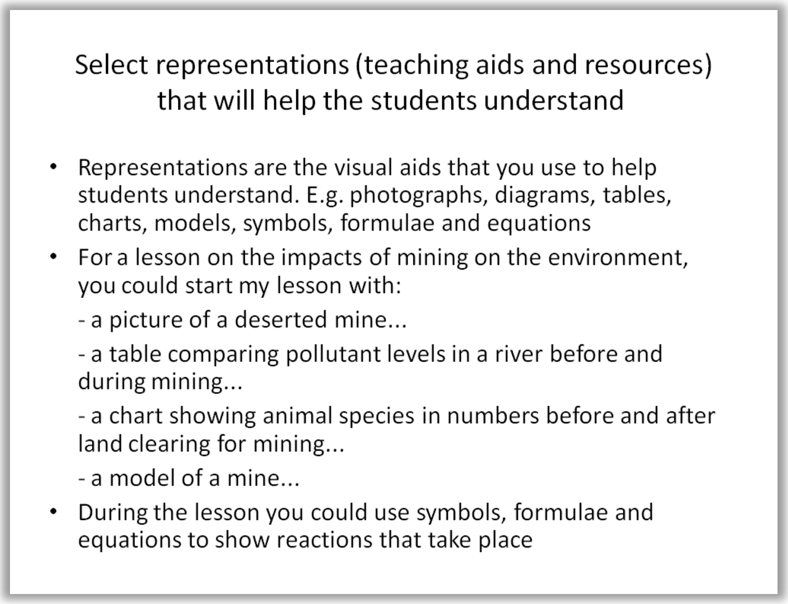
The session ended with examples of how a teacher can adjust instruction during the lesson if some students struggle to understand the concept. These suggestions included teachers slowing down their pace, providing more visual aids, and providing written and oral directions.

5.2.3.4 Session 4

This session, which was also the final session, was based on the PCK components focusing on knowledge and skills related to conceptual teaching strategies and pedagogical reasoning. It started by highlighting the importance of choosing teaching strategies and representations to enhance student understanding and promote meaningful learning. The teachers were reminded of the characteristics of ESD they were exposed to in the second session. These characteristics included: allowing a learner to be creative, thinking critically, asking questions, analysing local contexts and making decisions, being student-centred, and promoting higher order thinking and problem-solving skills. A recommendation was given for teachers to consider these characteristics when selecting their teaching strategies. They were also given the example of infusing problem-based learning into class discussions, issue analysis, inquiry and simulations. Teachers were also provided with examples of representations they could use when teaching aboutthe impact of mining. Figure 5.5 shows the slide on representations.

Figure 5.5

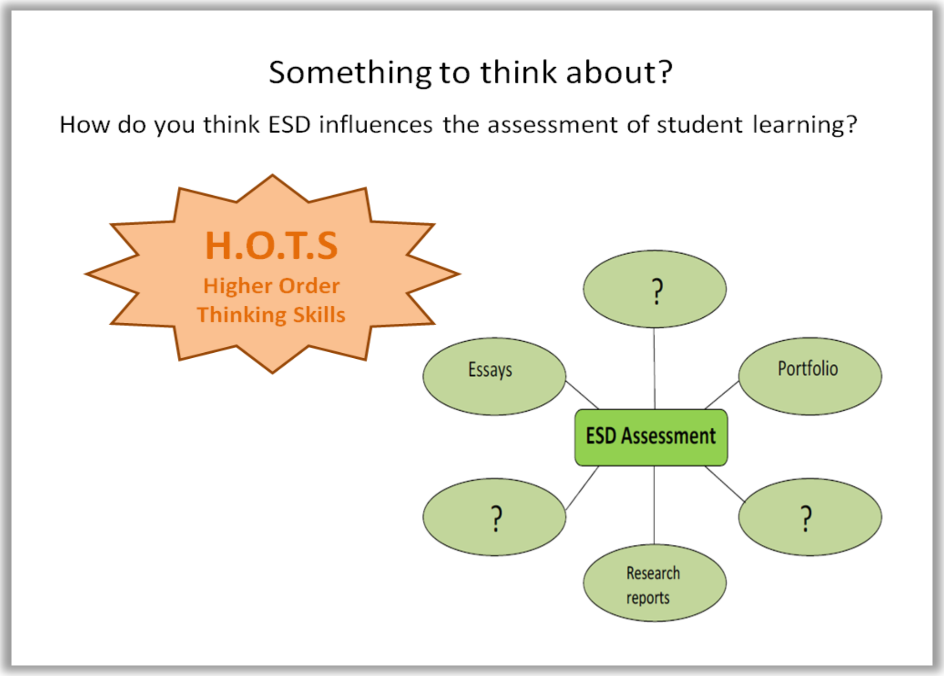
Examples of representations that could be used when teaching



Like in the other sessions, teachers were asked to reflect on or think about the content they had been given. Figure 5.6 shows a slide in this session where teachers were asked to think about how ESD could affect the assessment methods, especially because ESD encourages higher-order thinking.

Figure 5.6

A reflection on assessment methods that require deeper thinking



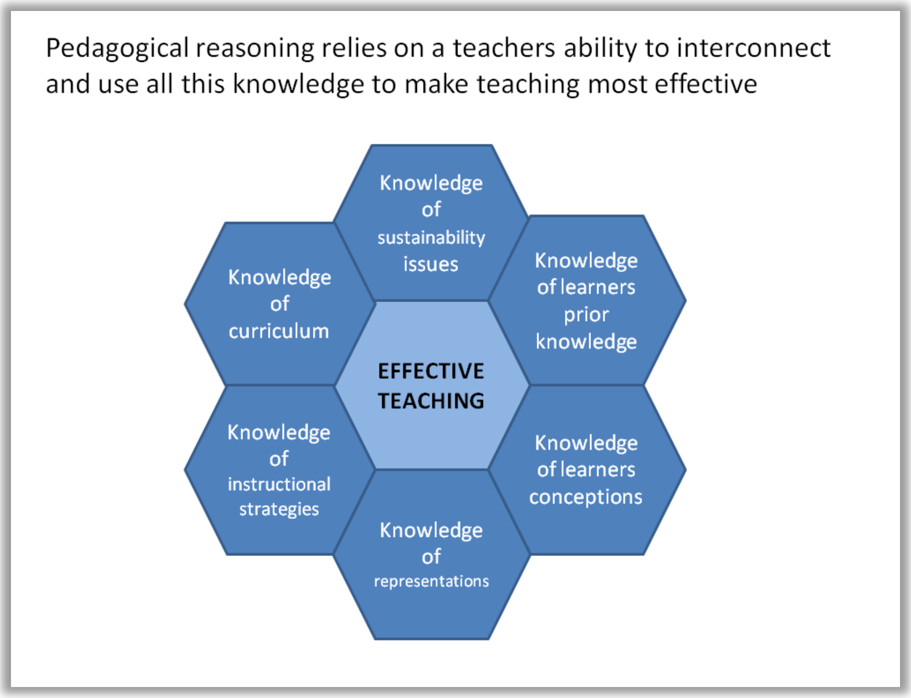
Teachers were encouraged to also use assessments that require critical reasoning and original work by the pupil, such as essays, projects, speeches, portfolios, research reports and multi-media presentations.

The session continued to introduce teachers to the concept of pedagogical reasoning. A teacher's mind is constantly working, figuring out what to teach, when, why and finally, how to teach it. Pedagogical reasoning takes place during all phases of the teaching process, before, during and after the lesson. Therefore, pedagogical reasoning exists in all the different components of PCK, and a teacher must also be able to justify their choices.

Figure 5.8 shows the slide that the researcher designed to show the teachers the knowledge bases that are necessary for effective teaching.

Figure 5.7

Knowledge required for effective teaching on sustainability issues



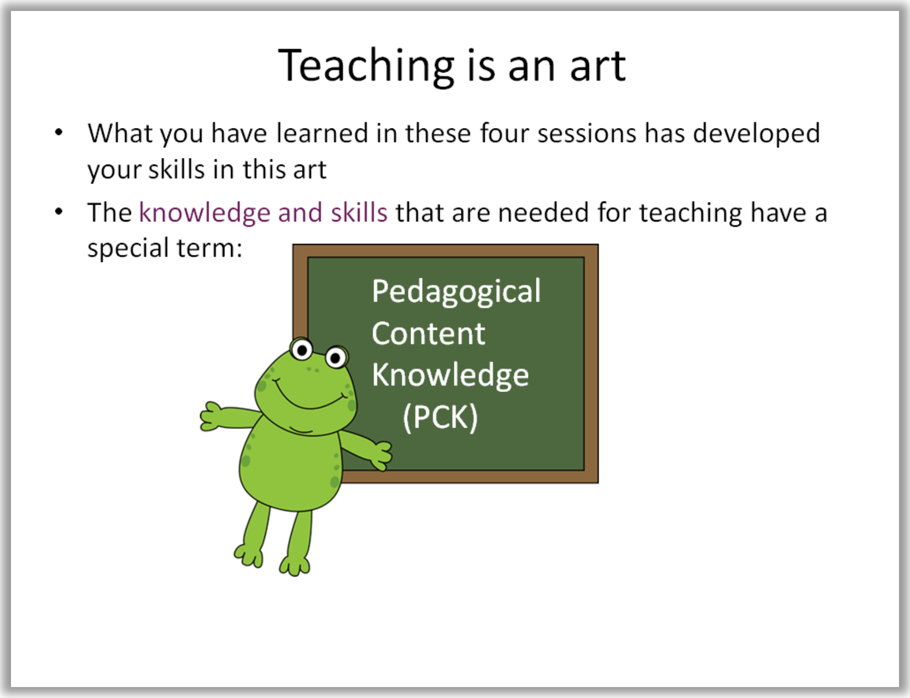
The fourth session ended withan introduction of the construct PCK (Figure 5.8). To bring the intervention to a close, the researcher explained that teachers' PCK is determined by their ability to:

- select scientific concepts that are relevant to the students and connect them to make them pedagogically appropriate;
- select instructional strategies and representations that promote meaningful learning;
- recognise and engage students’ prior knowledge, misconceptions and interests;
- adjust instruction based on student learning, and
- interconnect the components of PCK and justify the choice of teaching moves.

These competencies are aligned with the components of PCK.

Figure 5.8

The revelation of the consruct of PCK



5.2.4 The Online Presentation of the PDI

Before the commencement of the intervention, the researcher phoned the participants to explain how and why the study had changed. The study had changed because of the COVID-19 pandemic, which resulted in the closure of schools and restrictions surrounding the ease and safety of face-to-face interactions. The participants were also asked if they were still willing to participate in the study, which now involved a professional development intervention in digital format. Once consent to continue with the study was given by participants, the researcher asked the participants for their active email addresses. These addresses were integral as the intervention comprised narrated PowerPoint presentations sent to the participants via email.

Table 5.1 shows the contents of the emails sent to the participants and what was expected of the participants after each email. This table is very similar to the timeline that was sent to the teachers in the first PDI email. The first email also contained a resource pack. This resource pack, as mentioned before, contained materials that the participant could read during the intervention period. Throughout the intervention period, the participants and the researcher communicated via WhatsApp.

Table 5.1

A detailed account of the delivery of the intervention

Date	Content of the email	What is expected of the participant?
Week 1	**Email 1** - Resource pack - PDI timeline	1. look through the timeline 2. browse through the contents of the resource pack
Week 2	**Email 2** - Session 1	3. watch PDI Session 1 4. contact the researcher once the session has been completed to set up the telephone interview (1)
Week 3	**Email 3** - Session 2 - Session 3 *The researcher used WhatsApp to contact the participants to check on their progress.	5. watch PDI Session 2 6. watch PDI Session 3 7. contact the researcher for the telephone interview (2)
Week 4	**Email 4** - Session 4	8. watch PDI Session 4 9. alert the researcher that all sessions have been completed
Week5	**Email 5** - Pre-questionnaire that participant had responded to before the PDI - Lesson planning template	10. modify answers on the questionnaire in light of new knowledge and send the questionnaire back to the researcher 11. plan a lesson on "the impact of mining" and send the lesson plan to the researcher
Week 6	Once the questionnaire and lesson plan on "the impact of mining" have been received, the researcher set up a telephone interview with participants	12. Be available for a telephone interview

Each email contained a list of attachments included in the email and detailed instructions on what would be expected of the participant. All contact details belonging to the researcher were sent with each email.

In the following section, the researcher will present the interview data that was collected during the intervention. Three interviews were conducted: the first one was after the first session, the second interview was after the second and third sessions, and the third one was conducted after the intervention was over. These interviews served to support the answering of the research questions. Only the responses from the first interview will be discussed in this chapter, as the information given to the participants in the first session of the PDI was linked to the first research question. The responses from the first interview will be presented under the sub-heading: Chemistry teachers' views about sustainability and education for sustainability. These responses will give information on the teachers' knowledge about the curricular saliency of the topic.

5.3 Chemistry Teachers' Views about Sustainability and Education for Sustainability after the PDI

Teachers' views about sustainability and education for sustainability were elicited again once the intervention had started, in the responses to the questions in the first PDI interview. This interview was scheduled after the first session of the intervention, which introduced the teachers to the concepts of Sustainable Development and Education for Sustainable Development. The responses are therefore referred to as the post-PDI Session 1 intervention views of teachers concerning sustainability and education for sustainability. The researcher thought this was the most appropriate interview time as the following three sessions focused mainly on developing the teachers' PCK about environmental sustainability. The responses from this interview reveal the teachers' knowledge about the curricular saliency of the topic as the questions sought teachers' views on the importance of students learning about sustainability and the relevance of sustainability issues to chemistry, and the issues that could potentially be discussed while teaching content from the current EGCSE physical science syllabus. The responses also revealed the teachers' pedagogical reasoning about the knowledge needed to teach a chemistry topic infused with elements of sustainability. The question that focused on reasoning asked teachers whether they thought it was important to undergo professional development to help them understand how to educate for sustainability and what they thought the content of the training should be. The participants' responses will be discussed separately, starting with their knowledge of curricular saliency about environmental sustainability and then their pedagogical reasoning about what knowledge a teacher requires to teach this topic.

5.3.1 Mrs Zikalala's Responses

Mrs Zikalala thought it was important for students to learn about sustainability. Her reason was that, *"it allows them to be responsible for their actions and to actually contribute their vision to the sustainable future that we are paving the way for"*.

The topics in chemistry that she chose as being suitable for addressing sustainability issues were the production of energy, redox reactions, criteria for purity, the energetics of a reaction, mining and its impact, acids, bases and salts, electricity and chemistry, non-metals and organic chemistry. Mrs Zikalala explained that her list looks extensive because all new topics require *"prerequisite knowledge for them to understand new knowledge or the new subject content"* so she highlighted those too.

The sustainability issues that she thought would be suitable for the chemistry topics she mentioned above were land and water pollution, acid rain, global warming, climate change, industrialisation and fuels and food security.

Mrs Zikalala believes that it is very important for teachers to undergo professional development. Her recommendations for the training were based on enhancing teachers' knowledge of curricular saliency and conceptual teaching strategies about the topic of environmental sustainability. She proposed that the training starts with an *"introduction to the sustainable development concept"* and be followed by the sustainability *"challenges"* that we face and the sustainable development goals. She emphasised the need for teachers to be made aware of *"where it (sustainable development) is coming from, what is the reason behind it why should it be integrated into the education system"*. She continued to describe the need for teachers to be *"taught methods of integrating this (sustainable development) into the curriculum"* and emphasised *"teaching methods that will enable them to incorporate the concept into all the different subject areas"*. She ended her response with the idea that the teachers might already know some of the methods.

5.3.2 Mrs Dlamini's Responses

Mrs Dlamini believed that students must learn about sustainability and sustainability issues. She found it important because the students had to be taught how to keep the environment in its present state for future generations. Although she did not elaborate much on the environmental aspect of sustainability, she did mention some social issues in her reason.

"so they can live in peace without inequality and maybe also when we look at gender-based violence, teach them not to discriminate and maybe health-wise because chemistry talks about producing chemicals."

When asked about the topics in the physical science EGCSE syllabus that she thought could allow the incorporation of sustainability issues, she replied:

"renewable and non-renewable resources, environmental impacts of mining, non-metals when we talk about land, water and air pollution... we can also add...uhm... manufacture of products but that is not so much in the syllabus".

When prompted in the interview about which sustainability issues she would incorporate into these issues, she hesitated and said, *"the issue of society... it doesn't go in well, so maybe issues of health and diseases are in other subjects".*

This answer shows that Mrs Dlamini is aware of the social aspect of sustainability but does not see how it can be related to the subject of chemistry. The researcher ended this interview with a reminder that ESD is interdisciplinary.

She agreed when asked whether teachers needed professional development to implement ESD. When prompted on the content and structure of such training, she identified that knowing *"how to teach it"* would help when teaching sustainability and other topics. She also mentioned the need to create awareness about sustainability issues and said:

what is affecting us like pollution, those issues that we can see every day or if we are given the chance to visit the area like the mines and see the chemical products, pH levels in soils, wastes, and ask will they affect our water quality. (Mrs Dlamini)

Her response revealed her reasoning concerning the need for knowledge about conceptual teaching strategies and some aspects of curricular saliency.

5.3.3 Mr Mavuso's Responses

In response to the question on whether he thought it was important for students to learn about sustainability and sustainability issues, Mr Mavuso agreed, saying:

"Personally, I think it is important, they are relevant to challenges that we face inside the classroom, and that means the learners will be equipped on ways to tackle those problems."

The topics that Mr Mavuso thought would be suitable for addressing sustainability were *"experimental techniques, chemical reactions, metals and organic chemistry"*.

When prompted about the sustainability issues that he found relevant for incorporation into the topics that he mentioned, he responded:

> *I would include economic development because mostly when you are conducting a chemistry lesson, there are ways in which you can install an economic issue to the students, so economy can be a relevant issue. Also, another issue is global warming and climate change. (Mr Mavuso)*

Mr Mavuso agreed that it was important for teachers to be trained to incorporate sustainability into their teaching. When asked what he had in mind concerning the structure and content of training for teachers, he pointed out that he was interested in**:**

> *"how to incorporate sustainability in each and every lesson, especially into topics where it is difficult to place it."*

Although his response revealed some reasoning, it was not elaborate enough to identify which knowledge of the components of PCK he would have liked to enhance.

5.3.4 Mr Cele's Responses

When asked whether he thought it was important for students to learn about sustainability and sustainability issues, he started by linking sustainability, environmental protection and development. He then said he believed that sustainability-related issues impacted students' lives, before making another more detailed connection between the three. This was his response:

> *They are the ones who are affected by the development that is happening in the country, so because whatever happens to the environment can either have a good or bad impact... so for sustainability, they need to be aware of the positive and negative. (Mr Cele)*

The sustainability issues that Mr Cele describes as being relevant to chemistry are environmental toxicology, biodiversity, disposal of waste and recycling. When asked which topics in the EGCSE physical science syllabus he could use to incorporate these issues, he was hesitant and failed to give a clear response. He eventually named the topic of organic chemistry.

According to Mr Cele, teachers need professional development. His suggestion for professional development training for in-service teachers was to use *"what we have been using all along in the education system–workshops–with their items now considering sustainability."* His response did not reveal a need for teachers to enhance their knowledge in any of the PCK components.

5.3.5 Ms Dube's Responses

Ms Dube states that it is important for students to learn about sustainability and related issues. Her view is that the only way development can be sustainable is if the students understand the sustainability issues and *"apply it to real life"*. She also believed that learning about sustainability could enhance their skills and make them more responsible. This is what she said:

> *"this would help them to develop some problem-solving skills that will make them aware that their actions and decisions affect the environment or ... all in all I think it will help them become responsible adults and contribute to a sustainably developed community or country."*

When asked what she thought of teachers as key agents in implementing education for sustainability, she said, *"teachers can be key agents but they would have to work hand in hand with the students' families."* According to Ms Dube, the teachers' main role is to impart knowledge about sustainability and its relevant issues to the students. She believes that *"the application of the knowledge would have to take place in their everyday lives, outside the school"* and *"the parents come in when they (students) have to implement this knowledge that they have gained."* She continues to explain why teachers are better suited to teach about sustainability. She states that teachers are equipped with an understanding of *"the different types of learners"* and which teaching methods and teaching aids will help them best understand sustainable development.

Ms Dube holds that sustainability issues are indeed relevant to the subject of chemistry. The topics that she thought gave a good opportunity to discuss these issues were: the extraction of metals (which is a subtopic under metals), air (which is a subtopic under non-metals), fuels, alcohols and macromolecules (which fall under the subtopic organic chemistry). When listing these topics, she referred to some issues that she would discuss, such as *"resource conservation"* and "*air pollution"*. When prompted further for other issues, she continues to say, *"The global issues that I think we can discuss are land pollution, deforestation, global warming and climate change, air pollution... mining and its impact".*

She agreed when asked whether teachers need to undergo professional development on education for sustainable development. When suggesting what the teachers' training would look like, she described the content of the "course" as follows:

> *They have to first explain what education for sustainable development is, its characteristics. Then once they have done that, they should discuss ways in which the teacher can connect the concept of sustainable development to chemistry to help learners understand how the teachers can link syllabus topics to sustainable development and sustainability issues. (Ms Dube)*

This response reveals pedagogical reasoning as it details the knowledge about the aspects of curricular saliency she hopes to gain.

She adds that *"teachers can be helped with teaching methods that will promote meaningful learning on sustainability issues."* She also mentions the need for teachers to be provided with "*teaching aids and resources that will help the students understand sustainability issues*". She also gives an example of such resources when she says:

> *[They must provide] a worksheet that can guide us with examples on how we can incorporate the social, economic and environmental issues into the syllabus, a worksheet with questions where students will answer up until they reach an understanding of whatever concept is being discussed under the sustainability issues.(Ms Dube)*

Ms Dube's pedagogical reasoning is again revealed as she links teachers' knowledge of conceptual teaching strategies to student thinking.

5.3.6 Mr Fakudze's Responses

Mr Fakudze believes that it is essential for students to learn about sustainability and sustainability issues. His reason was that *"sustainability is an issue of great concern these days"*. He also states that students should be introduced to sustainability as early as primary school, as *"it can result in a greater change and it can create a lot of awareness to our students so that they can know about sustainability as early as possible".*

When listing the topics he found suitable for integrating into sustainability issues, Mr Fakudze mentioned the topics and the issues he could incorporate. He said:

> *[We can incorporate] organic chemistry, where we talk about fuels such as petroleum, all the fuels that cause global warming. Also, we have non-metals which are addressing the pollutants in the air such as sulfur dioxide and nitrogen oxide and also we have another topic which includes macromolecules, such as polythene which are our plastics that are polluting our land. (Mr Fakudze)*

He agrees with the notion of teachers undergoing professional training in educating for sustainability. The training, according to Mr Fakudze should focus on *"global warming and climate change"*. His reason is that these two issues, which are sustainability issues are explicitly mentioned in the chemistry section of the physical science syllabus and he has difficulty when teaching them. Although Mr Fakudze's response did not detail the exact content of the professional development, it shows his own reasoning with regards to knowledge about the curricular saliency of the topic.

5.4 Chapter Summary

In this chapter, I started with a detailed description of the professional development intervention that was given to the six participating teachers. I went on to present the teachers' responses to the first interview conducted during the intervention. My reason was to find the teachers' views about sustainability and education for sustainability after they had been through a session about these concepts.

Analysis of the teachers' responses revealed that all participants believed that it was important for students to learn about sustainability. These views could have been influenced by the research topic, as the participants may have believed that was the expected answer. The topics that were mentioned by more than one participant as being suitable for incorporating sustainability were organic chemistry, non-metals and metals. The sustainability issues that they would discuss under these topics were air, land and water pollution, global warming, climate change, biodiversity, recycling, deforestation and resource conservation. They also all agreed on the key role teachers need to play in the implementation of ESD and the need for professional development. Their suggestions for the content of the professional development focused mainly on aspects of knowledge about the topic's curricular saliency and conceptual teaching strategies. This was captured in the teachers' responses which mentioned the need for information about the concept of Sustainable

Development and Education for Sustainable Development, teaching methods and resources that can be used during teaching and examples of lessons that incorporate sustainability into their teaching.

The following chapter will discuss the insights that emanated from the interactions that took place after the intervention. The chapter will start with a description of how the data is presented and analysed. This will be followed by the presentation and analysis of the participants' responses to the second and final interview, the post-intervention questionnaire and the lesson plans. The chapter will end with comparing the teachers' pre- and post-intervention pPCK about environmental sustainability.

6 CHAPTER 6
POST-INTERVENTION DATA

6.1 Overview

This chapter focuses on the post-intervention PCK of the participants, during and after they had undergone the online professional development intervention (PDI). The same questionnaire administered before the intervention was administered to the teachers after the intervention. The responses to this questionnaire, the interview questions, and a lesson plan were used to determine the teachers' post-PCK. The analysis of their responses was also used to determine whether the intervention contributed to the improvement of teachers' PCK about environmental sustainability.

The researcher is aware that not all changes seen in the teacher responses can be attributed to the intervention. Teachers may have had some knowledge before the intervention which they could not relate to but could make connections through the content of the intervention. There may have been other experiences that could have contributed to the development of the teachers' PCK. These experiences could have been interactions with students or teachers. Since the intervention occurred during COVID-lockdown, when schools were closed, it is reasonable to assume that most of the PCK development could be attributed to the intervention as these teacher-teacher and student-teacher interactions were not possible at this time. One limitation of this study was that, because of the COVID lockdown, the researcher could not observe the teacher's lessons and see how their pPCK translates to ePCK in real classroom settings.

6.2 Data Sources

As mentioned briefly above, the post-PCK and, subsequently, teachers' PCK development were investigated by analysing the teachers' responses to the interviews, post-PDI questionnaire and the lesson plans they created after the intervention. These responses assisted in answering the third research question, which was:

> What is the nature of personal topic-specific PCK about the teaching of extraction of metals with an infused element on environmental sustainability, revealed in the teachers' planning after the PDI?

These data sources and how they were analysed are described below.

6.2.1 Teachers' PCK, as Revealed in Responses to Interview Questions

During and after the intervention, the participants were interviewed. The data obtained from the second and third interviews were presented under the subsection: "Teachers' new knowledge", and will support the data collected using the post-PDI questionnaire and lesson plan. The responses from the second and third interviews reveal how the teachers' knowledge about the curricular saliency, conceptual teaching strategies and student understanding have changed during and after the PDI.

The researcher believes that some of the questions asked during these interviews elicited information on the teachers' post-PCK. During the intervention, the teachers were given information about the attributes of a good teacher. These attributes were later aligned to the components of PCK. The interview questions, and the PCK component to which it could potentially contribute, are shown below. The responses to these questions are discussed in the order in which they were presented to the participant.

A question from Interview 2 was:

- Now that you are aware of ESD and some attributes of a good teacher, will your lesson planning experience be different? How?

The response to this question may give information about different PCK components, such as curricular saliency, conceptual teaching strategies and student understanding, and can therefore be analysed under these components.

A question from Interview 3 was:

- What did you learn during this intervention that you did not know before?
  - (i) About the topic of sustainability and educating for sustainability (ESD)?
  - (ii) About being a good teacher?

The response to the first part of this question gave information about the teacher's knowledge about the curricular saliency of the topic. The response to the second part elicited information about any of the different components, depending on the part of the intervention that impacted the teacher the most. An interview was also conducted once the researcher had received the responses to the post PDI questionnaire and the lesson plan. The interview mainly aimed to clarify some of the participants' responses. The results of this interview are discussed together with the responses.

6.2.2 Teachers' pPCK, as Revealed in the Post-questionnaire

The PDI consisted of four 15-20 minute narrated presentations delivered electronically to the participants. This PDI was collective PCK (cPCK) as it was an amalgam of contributions regarding students' knowledge, curricular knowledge, pedagogical knowledge, assessment knowledge and content knowledge. Details of the PDI were discussed in Chapter 5.

After the intervention was completed, the researcher gave the participants a copy of the questionnaire, with their own responses, completed before the intervention. The participants were asked to look through the questionnaire and either delete, modify or add to their responses, in light of the new knowledge they gained through the intervention. These responses would reveal the elements of the cPCK that were transferred to the teachers' own pPCK. Only the changes noted by the researcher are discussed in this section. The researcher analysed the responses using the PCK rubric (Appendix H), and scores were given. These scores were later used to see if there was a shift in the teachers' scores for the pre-intervention questionnaire.

6.2.3 Teachers' ePCK, as Revealed in a Lesson Plan

Before the intervention, the teachers were given a resource pack which they were to go through as a source of additional information during the intervention. The resource pack included, amongst other things, a lesson plan template (See Appendix L) and an example lesson plan on "the environmental impact of mining". The teachers were made aware that on completion of the intervention, they would be asked to create their own lesson plan using the example lesson plan given to them in the resource pack as a starting point for their own lesson plan.

When creating their own lesson plan, the teachers we asked to add the knowledge that they had gained during the intervention, and that was revealed during the interviews and post-questionnaire that the researcher now considered as part of their pPCK. The lesson plan would allow the teachers to enact this pPCK. The teachers were asked to focus their lesson on Outcome Number 6 under the topic "extraction of metals" found in the EGCSE Physical science syllabus. The outcome states that learners should be able to "describe the environmental impact of the mining and extraction of metals on vegetation, human beings and animals".

The teachers were asked to use the lesson plan template they were given in the resource pack to assist in the lesson design process. The template required the participants to specify information such as the lesson's purpose, teaching methods and resources. It also allowed the participant to describe both student and teaching activities that would occur throughout the lesson, as well as methods of assessment.

Presentation of the data revealed in the lesson plan occurs under the same components of PCK used to present and discuss the responses from the post-questionnaire: curricular saliency, conceptual teaching strategies and student understanding. Table 6.1 shows the subheading from the lesson plan and the PCK component under which it was discussed.

For analysis, the subheadings were linked to questions in the PCK rubric, according to the information they elicited. For example, under curricular saliency, the “purpose” in the lesson plan was linked to the question, “Why is it important for students to know about conservation of resources and the impact of mining on the environment?” Table 6.1 summarises the rubric questions used to score the components in the lesson plan.

When scoring the teachers’ responses, the researcher assumed that the teachers’ knowledge could be revealed in any one of the instruments. The researcher viewed the highest score from either of the instruments as evidence of the teacher's knowledge.

Table 6.1

The sub-headings from the lesson plan and the related command prompt from rubric

PCK component	Sub-heading in the lesson plan	Prompt in CoRe
Curricular saliency	Purpose	*Why is it important for students to know about conserving resources and the impact that mining has on the environment?
	Prior knowledge	*What concept(s) need to be taught to learners before teaching them about “extraction of metals”?
	Learning outcome(s)	*Name the four most important concepts you would address when teaching “extraction of metals”

PCK component	Sub-heading in the lesson plan	Prompt in CoRe
Conceptual teaching strategies	Instructional strategies	*What teaching strategies would you use to teach *conserving resources* and *the environmental impact of mining*? Why?
	Resources	*What representations would you use during your teaching conserving resources and *the environmental impact of mining*? Why? How?
	Essential questions	*What questions, related to environmental sustainability (ES), would you consider important to ask your learners during your teaching?
	Teacher/student activities	*What representations would you use during your teaching conserving resources and *the environmental impact of mining*? Why? How?
	Assessment	*What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?
Student understanding	Check for understanding	*What questions would you use to access student thinking and understanding about *conserving resources* and *the impact that mining has on the environment*?

Since the PCK rubric was initially designed to assess the responses to the CoRe prompts, the rubric was adjusted for the assessment of ePCK revealed in the lesson plan. The prompts for the CoRe, used to design the rubric, focus on both big ideas; however, the teachers were asked to plan a lesson only on *the impact of mining*. For this reason, some adjustments were made to the rubric while scoring. Firstly, any mention of conservation of resources or sustainability in the rubric was ignored (highlighted in red) when assessing the lesson plan. Secondly, where the question mentions "extraction of metals" (highlighted in blue), only the big idea "impact of mining" was considered. Lastly, the response to the question on "how" and "why" the resources were used can be found under student/teacher activities (highlighted in pink). See Table 6.1.

Also, those indicators in the rubric that focus on mentioning both the big ideas were not a determining factor in the scoring as they were seen to mean the same thing, “reference to the big idea”. Figure 6.1 shows the PCK rubric and indicators referring to the big ideas that were not considered when assessing the lesson plan.

Figure 6.1

An extract of the PCK rubric showing indicators that refer to the big ideas

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Knowledge and Skills related to Curricular Saliency (C)	**CS1** - Name the four most important concepts you would address when teaching “extraction of metals”	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - reference to one of the big ideas - evidence of sequencing is present	- Appropriate ideas are identified but an important idea is missing - reference to the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident

The analysis focused on the extent to which the teacher individualised the lesson plan initially based on the example given before the intervention. The researcher looked for things the teacher changed in the example lesson plan. These modifications were analysed to determine whether these changes were evidence of a PCK that had developed or improved. If the lesson plan was changed completely, it indicated that the teacher decided to enact their own pPCK fully.

6.3 Presentation of Teachers’ Post-PCK Revealed in Their Responses to the Interviews, Post-PDI Questionnaire and Lesson Plan

In this chapter, the researcher has continued with the theme of presenting and analysing data from each participant separately. First, the responses to the interviews are discussed. This discussion is followed by the presentation and analysis of modifications made by the teacher in the post-PDI questionnaire. The PCK rubric was used to score these responses. The new scores, if any, are given as a summary of the pPCK of the teacher after the PDI. The researcher then continues to present the teacher’s lesson plan, again using the PCK rubric to score the teachers’ responses. A more detailed description of how the PCK rubric was used to score the lesson plan is given in Section 6.1.3 above. These scores from the responses in the lesson plan demonstrate whether the teachers could enact their full pPCK, therefore revealing the teachers’ ePCK. The final post PCK score was found by selecting the higher of the scores received from the questionnaire (pPCK) and the lesson plan (ePCK). The post-PCK of the teacher can be identified by this value because ePCK is a subset of pPCK (Carlson & Daehler, 2019). In the end, the researcher summarises the post PCK of the teacher.

6.3.1 Mrs Zikalala's Post-PCK

6.3.1.1 Post-PCK, as Inferred from Mrs Zikalala's Interview Responses

Mrs Zikalala was asked if she thought her lesson planning experience would be different, now that she was aware of ESD and the attributes of a good teacher. She responded, *"I think this will influence the way I tackle things now"*. The researcher asked her to elaborate and she explained as follows:

> *In the past, we did focus more on the content. But now we will relate content not only to what they know but to the social and environmental issues that we're facing and actually let them know what the world's expectations is.* (Mrs Zikalala; Interview 2)

This response proves that she understands that the content taught must be locally and globally relevant to the students. This is one of the main characteristics of ESD. She adds, *"there will be inquiry-related content that will allow them to think and engage them in problems."* This response reveals that Mrs Zikalala understands the connection between curricular saliency and conceptual teaching strategies. She states that this *"relevant"* content must be taught using inquiry and problem-based learning, which are part of ESD pedagogy.

When asked about what she had learnt, during the intervention about sustainability and education for sustainability, she acknowledged that this was a new thing for her. She continued to state:

> *"I learnt that sustainability is development that is more concerned with our tomorrow. It's just a paradigm for thinking about the future in which environmental, social and economic considerations are balanced."*

She continued to say:

> *"It's about teaching about sustainability issues so that we become responsible. That it is my duty, it is my role to create awareness about these issues that affect them, the kids that we teach."*

She concluded by saying that she also learnt about some issues and how they can be incorporated into the curriculum. Mrs Zikalala's response demonstrates how her knowledge of the curricular saliency of the topic has changed. It also shows that she is now more aware of her role as a teacher in ESD.

In response to what she learnt about being a good teacher, she said:

> *"I feel science can become so abstract and becomes out of touch... know the issues that are relevant to them [the students] and know how they think, what they think so that I can recognise and engage that knowledge by creating opportunities for them to reveal their thinking."* (Mrs Zikalala)

This response shows that Mrs Zikalala understands the importance of assessing student thinking to make the learning process more meaningful.

She continued to say that she learnt the importance of *"engaging learners with the teaching aids, knowing how exactly to do this to achieve a type of learning that is more inquiry-based and more student-centred"*. Her response revealed aspects of knowledge on conceptual teaching strategies.

In her responses, there was evidence that Mrs Zikalala had gained knowledge of all three components of PCK.

6.3.1.2 Post-PCK, as Inferred from Mrs Zikalala's Post-questionnaire Responses

In this section, I discuss the modifications made by Mrs Zikalala to the responses in her pre-questionnaire. These modifications took place after she had completed the online intervention. For uniformity, the modifications were grouped according to the PCK component under which they fall. Each modification was discussed to reveal whether the modification resulted in any changes to the scoring of the teacher's responses using the PCK rubric.

Curricular Saliency

Mrs Zikalala made two lengthy additions under this component. Her first addition was in response to whether she agreed with the inclusion of sustainability issues into the curriculum and why. For this question, her score for the initial PCK was a three. In addition, she gave two more reasons in line with two of the aims of the EGCSE syllabus. She stated, "*to give* *them the skills necessary to handle social and environmental changes and actually lead lives at which they can care for and respect our planets resources too"*. Figure 6.2 shows the part of the addition in which the two aims were mentioned.

Figure 6.2.

Mrs Zikalala's addition to the question on the inclusion of environmental issues into the curriculum

In the EGCSE curriculum, environmental issues are included (See outcome 6 and 7 above). Do you agree with this inclusion and why?

It is of paramount importance that learners understand the impacts of metal extraction [social, economic and environmental]. This is because mining contributes to erosion, deforestation, loss of biodiversity, high water usage, and water pollution, contamination of soil, ground and surface water. All these in the long run can cause health problems which could affect everyone in society. This objective is an integration of the aims of the syllabus [AIM 4.] as well as relating science to the society.This inclusion is of importance not only in the country but to the expectations the world has on us. Learners are the future, the key agents for future change so it is quite important that we expose learners as an opportunity to give them the skills necessary to handle social and environmental changes and actually lead lives at which they can care for and respect our planets resources too.

Her final response to this question included reasons linked to all three of the aims of the syllabus. This showed exemplary knowledge in this area, and she was scored a 4 (See Figure 6.3).

Figure 6.3.

Rubric extract showing indicators for Mrs Zikalala's knowledge on inclusion of environmental issues into the curriculum

CS3- In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	-No reasons provided - Reasons are unclear and not linked to the outcomes of the syllabus	- Reasons provided are well articulated - Reasons are not linked to the aims of the EGCSE syllabus	- Reasons given well articulated - Reasons given linked to one or two of the aims of the EGCSE syllabus	-Two or more reasons given - Reasons provided are linked to three of the aims of the EGCSE syllabus

When asked why it was important for students to know about conserving resources, her pre-intervention response gave her a score of 4. After the intervention, she decided to add to her initial response by mentioning that students need "*to take responsibility for their actions and contribute their vision for a sustainable future*" and *"This is an opportunity to give the younger generation the ideas necessary to handle the social and environmental changes that occur in the near future"*. (See Figure 6.4)

Figure 6.4.

Mrs Zikalala's modification on the importance of students knowing about the big ideas

Why is it important for students to know about conserving resources and the impact that mining has on the environment?

Learners need to be in touch with environmental struggles as societal problems that the world is facing. Being in touch with these can help integrate science and technology into finding solutions in the long run which can help the society and the country at large. Learners will understand how we can work in finding solutions with regards to mineral supply like general approaches to maximize exploration of new minerals and finding ways of minimising the environmental impacts of mining that the already existing resources have.

Conserving resources is part of sustainability, a motion at which now the world is in line with. Them exercising such will allow them to take responsibility for their actions and contribute their vision for a sustainable future. This is an opportunity to give the younger generation the ideas necessary to handle the social and environmental changes that occur in the near future. The future is in them and understanding the necessity for change as well as understand that they will be living in a world different from ours.

Her reasons were appropriate and she continued to show an in-depth understanding of the need for students to be taught about the existing problems and also how to solve these problems and take responsibility. Mrs Zikalala's knowledge is exemplary, and she was scored a four.

Conceptual Teaching Strategies

She also modified her response on the teaching strategies she would use to teach big idea A. She added, *"student-led discussions"* (See Figure 6.5). The teaching strategy added by Mrs Zikalala did not affect her initial score of 3. The score was unchanged because she did not present a reason why she would employ the discussion and did not explain how the discussions would be used to support conceptual understanding.

Figure 6.5.

Mrs Zikalala's modification to choice of teaching strategy for Big Idea A

> What teaching strategies would you use to teach*conserving resources*? Why?
>
> A student-centred approach including discussion, presentation as well as question and answer strategies. This is because the topic Conserving resources entails concepts they are familiar with to their everyday life, including resources they use on the daily, like which resources could affect us would they run out but among others at which learners can discuss these in groups and share with the entire classroom at which then they could also provide recommendations of resources conservation and alternatives.
>
> Student-led discussions

When listing the questions she considered important to ask her learners; she scored a 4 on the pre-questionnaire. After the intervention, she added one more question, *"What solutions can we provide in a quest to curb the impact extraction of resources has on the environment?"* This question also required students to use their problem-solving skills, and as such, her knowledge in this area remained worth a four.

She also modified her response on the representations she would use to teach Big Idea B. She added a *"blueberry muffin activity"* and "*field trips to local mines in the country"*. For each of these representations she described why she chose these representations and how they would be used to support conceptual development. The representations added by Mrs Zikalala did not affect her initial score of 3. This was because there was no logical sequencing of the use of these representations.

In her response to the pre-questionnaire, Mrs Zikalala showed no evidence of knowing appropriate assessment methods and, as such, was scored a one. After the intervention, she added:

> *"The use of higher order thinking strategies where learners are not only answering questions related to problems identified but actually identifying solutions" and "designing methods/ models that can be useful in curbing the environmental issues we are facing imposed by mining*." (Mrs Zikalala)

The assessment strategy that she added shows a link to the concept of mining. Her emphasis on the need to encourage problem-solving and critical thinking shows an exemplary knowledge of assessment methods, and she was scored a 4 (See Figure 6.6 below).

Figure 6.6

Rubric extract showing scoring indicators for Mrs Zikalala's assessment methods

CTS4 - What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?	- No assessment strategies provided - No evidence of appropriate assessment strategies	- Lists one or two general assessment strategies -No indications of how they are linked to concepts	- Lists appropriate assessment strategies - There are indications of how they are linked to concepts	- Lists assessment strategies with indications of how they are linked to concepts -Strategies encourage problem solving skills and critical reasoning

Student Understanding

Mrs Zikalala made only one modification under this component. She modified the type of questions she would use to assess students' thinking. In the pre-questionnaire, she revealed exemplary knowledge in this area. The questions she added were, "*Is the mining problem a problem for everyone? Do these impacts call for concern? How can we conserve resources?"* These questions added to the already extensive list of questions, and her score remained a four.

6.3.1.3 Post-PCK, as Inferred from Mrs Zikalala's Lesson Plan

Curricular Saliency

Mrs Zikalala stated the lesson's purpose to be, *"To identify the impact mining has had on the vegetation, human beings as well as animals".* Although her reason was clear, and she mentioned the environmental and social effects of mining, she did not mention the knowledge and skills students would gain to help them tackle these environmental issues. Her score based on the lesson plan would have been a 2, but as she scored a 4 in the post-questionnaire, her score remained a four.

According to her, the knowledge students should have to understand the new concepts are *"the different mining methods, the importance of mining and how minerals mined are used in our everyday life"*. These ideas are appropriate as these are the pre-knowledge needed by the students. However, her list is not extensive as she is missing an important concept relating to the sources of metals. This reveals a developing knowledge in this area, so her score is changed from a two to a three.

Mrs Zikalala gave four learning outcomes for her lesson. She wrote,

> *Describe the environmental impacts of mining on vegetation, describe the environmental impacts of mining on human beings, describe the environmental impacts of mining on animals and provide solutions on the negative impacts mining has had on the environment.* (Mrs Zikalala)

She gave appropriate outcomes, and sequencing was evident. All the important ideas were mentioned, so her knowledge in this area remained exemplary, and she was scored a four.

Conceptual Teaching Strategies

Mrs Zikalala chose to use question and answer, teacher-led discussions and presentations as her instructional strategies for the lesson. Since these are general strategies, the researcher sought evidence, under the activities section, of how these strategies were used and if they showed learner involvement. She started the lesson by using questioning to assess students' prior knowledge and then used an activity where students were to extract blueberries from a muffin and answer her questions in a teacher-led discussion. For the main activity, students would be given handouts to assist them in preparing for a presentation on the impacts of mining and solutions to those impacts. Although the teaching strategies seem general at first, her description of how these would be used, showed evidence of participatory learning, collaboration and problem-solving, which are key characteristics of ESD. Her score in the post questionnaire was a three. However, because of her description in the lesson plan of how these strategies would be used, she was given an overall score of four.

The questions that she thought were essential to her teaching were: *"How has mining affected the environment (human beings, vegetation and animals)?"*, *"What alternative resources can be used instead of mining these resources?"* and *"How can we minimise the impacts of mining?"* The questions are related to the key idea and there is evidence of questions that require higher-order thinking and problem-solving. Her knowledge in this area is exemplary, and her score remained a four.

She decided that she would use blueberry muffins and hand-outs on mining and its impacts as her resources for the lesson. She described student and teacher activities and under the questions she would ask during the activity, how the muffins and handouts would be used. Her description showed evidence of how these resources would support conceptual development. Although her selection of representations was not extensive, she was the only teacher amongst the participants who included the actual handouts she would use. The handouts provided information on *"how mining has affected certain spheres of the world"* and were excerpts focusing on the impacts of mining in South Africa, Kenya and the United States of America. These gave the researcher a clearer picture of her lesson, and as such she was scored a four.

Mrs Zikalala chose to assess her students with *"reading and writing on what has been done so far to try to rehabilitate areas affected by mining"* and *"Writing on what global views do other countries have on mining impacts and what is being done.* According to her lesson plan, the students would have already made presentations on different solutions as each group was given a different handout. This could have been an extension activity. This assessment strategy is appropriate as it promotes research skills as well as independent learning with the aim of finding solutions to the environmental challenges caused by mining. Her score on the assessment remained a four.

Student Understanding

She gave an extensive list of questions she would use to determine student understanding. The questions she planned to ask during her introduction using the blueberry muffin activity were, *"Why is mining important? Is it possible to extract the blueberries from the muffins and leaving the muffin intact? Can the muffin return to its original state?"* and *"What is the aftermath of mineral extraction?"* For her main activity, the questions she planned to ask were, *"What are the environmental impacts of the extraction of metals on vegetation, human beings and animals?"* and *"What solutions can be provided?"* During the conclusion of her lesson, she would ask, *"Is it possible to make a mine return to its original state?"* and *"Why is mining something everyone should be concerned about?"* There was evidence of questions that elicited student thinking, and the questions were aligned to the teaching strategies and resources she planned to use. For this reason, her score was a four.

6.3.1.4 A Summary of Mrs Zikalala's Post-PCK

Table 6.2 summarises Mrs Zikalala's post-PCK. As mentioned earlier, the final score for each category was found by selecting the higher scores received from the post-PDI questionnaire (pPCK) and the lesson plan (ePCK). This value is considered the final post PCK score because ePCK is a subset of pPCK.

Table 6.2

Summary of the observations made on Mrs Zikalala's post PCK using the rubric

Component of PCK	Score from questionnaire*(pPCK)*/ Score from lesson plan*(ePCK)*	Final score (PCK)	Overall score for PCK component
Curricular saliency			
Concepts addressed when teaching	4/4	4	
Pre-concepts required by students	2/3	3	
Inclusion of environmental issues	4/4	4	
Importance of knowing about the big ideas	4/4	4	
			3.8
Conceptual teaching strategies			
Teaching strategies/ method	3/4	4	
Questions to be asked	4/4	4	
Representations	3/4	4	
Assessment strategies	4/4	4	
			4.0
Student Understanding			
Difficulties	2/2	2	
Student misconceptions	4/4	4	
Questions to access thinking	4/4	4	
			3.3
		Overall post- PCK	**3.7**

An analysis of Mrs Zikalala's pPCK score from the post-PDI questionnaire and her ePCK score from the lesson plan shows that either her pPCK score and ePCK were the same or her ePCK score was higher than her pPCK score. This suggests that Mrs Zikalala was able to draw on her pPCK to demonstrate her ePCK.

6.3.1.5 An Interpretation of Findings from Mrs Zikalala

Mrs Zikalala's overall post-PCK was considered to be exemplary. This suggests that she could draw on the cPCK in the intervention and demonstrate her pPCK. According to Carlson and Daehler (2019), there are amplifiers and filters that determine what is transferred from a cPCK to a teachers own pPCK. It is evident from Table 6.2 that Mrs Zikalala's highest post-PCK score was in the component of conceptual teaching strategies. When looking back at Mrs Zikalala's interview responses, she said, "*science can become so abstract and becomes* *out of touch”*. From this statement, we could infer that her belief about the nature of science content could have acted as an amplifier and allowed her to sufficiently draw on the cPCK about knowledge and skills about CTS and demonstrate an exemplary pPCK. As mentioned above, when comparing Mrs Zikalala’s post-pPCK and post-ePCK, her ePCK is always the same as her pPCK or higher. This suggested that she could sufficiently transfer PCK from the cPCK to her pPCK and later demonstrate it in her ePCK. Another possible amplifier could be Mrs Zikalala’s knowledge and belief about her purpose for teaching. This belief was evident in an interview response when she said,*“it is my duty, it is my role to create an awareness about these* [sustainability] *issues”*. Although she had an overall exemplary post PCK, we cannot overlook the possibility of filters as she scored lower in the component of knowledge and skills related to students’ understanding. These filters, however, could not be identified.

6.3.2 Mrs Dlamini’s Post-PCK

6.3.2.1 Post-PCK, as Inferred from Mrs Dlamini’s Interview

When asked if she thought her lesson planning experience would be different in light of the knowledge she had gained during the intervention, she mentioned that her questioning strategy would be different. She started by describing how she did things in the past and stated how she would change.

> *Before a lesson, I would usually pop in one or two questions that are more about introducing the topic. It was never detailed, I never asked with the intention of finding out how much they really know, I just asked to take them into what I am going to be teaching about; then I would go further. But the intervention has taught me to be more detailed when asking about what they know, where they learnt about it and exactly how much they know about this topic.*(Mrs Dlamini; Interview 2)

This response proved that Mrs Dlamini understands that questioning can be used to assess students’ thinking.

When asked about what she had learnt during the intervention about sustainability and education for sustainability, she responded by saying, “*I am currently doing my master’s, so the things about sustainable development I knew even before the intervention as we did some research on it”*. However, she added that she had learnt something about ESD, particularly *“how you can look for relevant topics in the syllabus and use them to talk about sustainability in your teaching”.* This response gives us a sense of how her knowledge about curricular saliency of the topic has changed. Something else she said she learnt, was *"the reclamation process, I had never even heard that word, but surely now I will teach my students about it"*.

In response to what she learnt about being a good teacher, she stated that: "A *good teacher must be well prepared on even the questions that they will ask the students. If the questions are thought about before the lesson, then they can be used to help the students understand better"*. She added that *"a teacher must be able to choose teaching methods that will make students more involved as they are our future problem-solvers, we can't keep spoon-feeding them, they must learn to be researchers"*.

These responses are related to the component of conceptual teaching strategies as she acknowledges that a good teacher should carefully consider the questions and teaching methods they plan to use during a lesson.

In both responses, Mrs Dlamini emphasises that what she gained most from the intervention is the type of questions to ask learners, when to ask them and the importance of planning the questions to be more useful in supporting conceptual development.

6.3.2.2 Post-PCK, as Inferred from Mrs Dlamini's Post-questionnaire

In this section, I discuss the modifications and additions made by Mrs Dlamini to the responses in her pre-questionnaire. These modifications took place after Mrs Dlamini completed the online intervention. The modifications were grouped according to the PCK component under which they fall for uniformity. Each modification is discussed to reveal whether the modification caused any changes to the scoring of the teacher's responses using the PCK rubric.

Curricular Saliency

Mrs Dlamini made changes to two of her responses under this component. For the first question, her score for the initial PCK was a two. She then added the "sustainability and reclamation procedure" (See Figure 6.7 below). Although the model answers and master CoRe suggested the added concept as being important, she has not yet reached the score of three because she did not include the second big idea, so her score remained a two.

Figure 6.7

Modifications to the concepts addressed when teaching (CS1)

Name the four most important concepts you would address when teaching "extraction of metals". Name them in the sequence you would teach them.

-most metals exist as compounds

-where are they found

-how are metals obtained

-effects of extraction on the environment

Sustainability and Reclamation procedure

When asked why it was important for students to know about conserving resources, she maintained her initial response and added "to learn reclamation procedures" (See Figure 6.8)

Figure 6.8

Modifications on the importance of knowing about the big ideas (CS4)

Why is it important for students to know about conserving resources and the impact that mining has on the environment?

- to prevent depletion of resources

-to keep resources for future generations

-to learn reclamation procedures

Her reason was appropriate and showed a link to the students' roles. It can also be seen in Figure 6.9 that the reason added by Mrs Dlamini was a suggestion in the master CoRe. Her score, therefore, changed from a two to a three.

Figure 6.9

Extract of master CoRe showing suggestions on why it is important for students to know about the big ideas

PCK component	Component prompts	*'conserving resources'* (Big idea A)	*'the environmental impact of mining'* (Big idea B)
Knowledge and Skills related to Curricular Saliency (C)	**CS1- Why is it important for students to know about conserving resources and the impact that mining has on the environment?**	- learn that the earth is composed of several natural resources including plants, animals, minerals, rocks, and fossil fuels. -learn that materials important to humans are made of these natural resources. - explains how depletion of resources can affect society - explores how students can help conserve resources	-explains the effect that mining has on the environment (the bye products and pollutants) - explore the links between environmental impact and social impacts - explores the reclamation process

Conceptual Teaching Strategies

She also modified her response on the representations she would use to teach Big Idea B. She added, *"reclamation plan of mines developed to tourist areas"* (See Figure 6.10). The representation added by Mrs Dlamini did not affect her initial score of two. This was because no reasons were identified and no explanations were provided of how the reclamation plan would be used to support conceptual understanding.

Figure 6.10

Modifications to choice of representations (CTS3)

What representations would you use during your teaching *the environmental impact of mining*? Why? How?

-diagrams that show sinkholes, soil erosion, loss of vegetation, deforestation -this would elaborate that even though a lot of money is obtained from mining there are unreverssible effects that last for decades.

-reclamation plan of mines developed to tourists areas

In her response to the pre-questionnaire, Mrs Dlamini showed no evidence of knowing appropriate assessment methods and as such, was scored a one. After the intervention, she added *"classwork with questions of the extraction of metals and sustainability"*. However, this assessment strategy was considered general and had no indication of how it would be linked to the concepts. For this addition, she was scored a two (See Figure 6.11).

Figure 6.11

Rubric extract showing scoring indicators for assessment methods

CTS4 - What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?	- No assessment strategies provided - No evidence of appropriate assessment strategies	- Lists one or two general assessment strategies -No indications of how they are linked to concepts	- Lists appropriate assessment strategies - There are indications of how they are linked to concepts	- Lists assessment strategies with indications of how they are linked to concepts -Strategies encourage problem solving skills and critical reasoning

Student Understanding

When asked to review her responses, Mrs Dlamini modified the type of questions she would use to access students' thinking. The additions can be seen in Figure 6.12.

Figure 6.12

Modifications to questions used to access student thinking (S3)

What types of questions would you use to access student thinking and understanding about *conserving resources* and *the impact that mining has on the environment*?

-how does mining affect the people, animals, plants, environment.

-what changes are brought by mining to the area.

-what measures can be done to reduce the damages caused by mining on the environment.

-can the mining area go back to what it was before, if not can it be improved?

As seen in Figure 6.12, she made a seemingly small adjustment to her third question, which meant that all her questions were now clearly formulated. Clear formulation of a question was an indicator of a developing PCK in the PCK rubric. When considering the misconception Mrs Dlamini mentioned about students believing that mining damages were permanent, the added fourth question is evidence of a link to student understanding. For this reason, her knowledge of questions used to access students' understanding moved from basic to developing, and she was scored a three.

6.3.2.3 Post-PCK, as Inferred from Mrs Dlamini's Lesson Plan

Curricular Saliency

For the lesson, Mrs Dlamini stated two reasons, "*To discuss the environmental impact of the mining on the vegetation, human beings and animals. To emphasise the importance of conservation of resources"*. Although her reasons were clear, she did not mention the knowledge and skills students would gain to help them tackle these environmental issues. Her score based on the lesson plan would have been a two but she scored a three in the post-questionnaire; therefore, her score remains a three.

When asked about the knowledge that students should have to understand the new concepts, she lists, "*How does mining affect the environment –vegetation, human beings and animals? What can be done to reduce the impacts of mining?*" These ideas are not appropriate as these questions are related to the new knowledge the students would gain rather than the pre-knowledge that should already be in place. She reveals a limited knowledge in this area of the lesson plan and would have scored a one, but her score in the questionnaire was a two; therefore, the score remains a two.

For her learning outcomes, she wrote, *"To understand that mining disrupts the environment and ecosystem"* and *"To discuss things that can be done to sustain the environment".* These outcomes are appropriate and sequencing is evident, but an important idea is missing. Even though she did not mention the social effects of mining, her knowledge seems to have improved; thus, her score is now a three.

Conceptual Teaching Strategies

Mrs Dlamini used question and answer sessions, group discussions, brainstorming and presentations as her instructional strategies (See Figure 6.13). Although these are general strategies, the description of the use, under the activities section, of brainstorming before the presentations encourages students to speak, listen, write and collaborate with other students. She was scored a three because she described how these strategies would be used, which is higher than her score of two in the questionnaire. This gave her an overall score of three.

Figure 6.13

An extract from Mrs Dlamini's lesson plan showing conceptual teaching strategies

Instructional strategies	**Resources**(*clearly indicate how these resources will be used during the introduction and main activity)*	**Essential question(s)**
Question and answer Group discussions Brain storming Presentations	Hand-out on mining- given as a reading assignment. Pictures of mine before and after mining	How does mining affect the environment? What can be done to sustain the environment-reclamation procedures

Introduction *(Focus student attention)*

Time:	**Teacher activities**	**Students activities**
8 min	1. Teacher will display/project a picture showing the mine before and after mining. Teacher to ask students to identify the problems- impacts of mining that have occurred. 2. Teacher to ask students to classify the problems identified in the picture into effects that affect the vegetation, animals, and humans. 3. Teacher to ask students to outline reclamation procedures that can be done.	1. Students will study the picture and identify the impacts of mining that has occurred around the mining area. 2. Students to classify the outlined problems – impacts of mining into three groups – vegetation, animals and humans. 3. Students to outline solutions - identify reclamation procedures that can be done to prevent disruption of area as well as sustain the environment.

She used a hand-out on mining and pictures of a mine before and after mining as her lesson resources. Although she showed how the pictures would be used under student and teacher activities (See Figure 6.13), there was inadequate evidence of how these resources would support conceptual development. The score given to her was the same as the score from the questionnaire response, so her score remained a two.

The questions that she thought were essential were *"How does mining affect the environment?"* and *"What can be done to sustain the environment-reclamation procedures?"* The first question was identical, and the second question was similar to the ones used by the researcher in the example lesson plan given to the participants at the beginning of the intervention. The researcher decided not to score Mrs Dlamini for her knowledge on questions that she considered important to ask during the lesson because this was not a true reflection of her own pPCK. Her score in this area remained a two.

Mrs Dlamini chose to assess her students with a written report. She stated, "*each student to submit written report (two pages)–to be evaluated based on how their problem was addressed and the success of reclamation plan"*. In her main activity, the students would work in groups to identify the problems arising from mining. The groups focused on vegetation, animals or humans. She referred to the problems they would have identified in class in her assessment. This assessment is appropriate and links to the concepts to be discussed during the lesson. According to her lesson plan, the students would have discussed and made presentations on reclamation procedures. This assessment method gives Mrs Dlamini a score of three, which is an improvement on the score she received from her response to the questionnaire.

Student Understanding

Mrs Dlamini gave an extensive list of questions she would use to determine student understanding. Figure 6.14 shows the questions she planned to ask her students throughout the lesson. There was evidence of questions to elicit student thinking, and the questions were aligned to the teaching strategies and resources she planned to use. The questions she gave in the lesson plan improved her response in the questionnaire, giving her a score of four.

Figure 6.14

Mrs Dlamini's lesson plan showing the questions she would use to check for student understanding

Check for Understanding*(What questions will you ask and when to determine students understand?)*
Introduction –how mining impacted the environment?
-How plant and animal life affected?
-how were humans affected by mining?
-Can the mine be restored to its previous condition?

Main activity –How does mining affect the environment?
- What is land reclamation and why is it important?
-How can reclamation reduce the impact of mining?
-how can reclamation help sustain the environment?

Conclusion –Is the Sustainability of resources important to everyone?
-Is the damage and disruption of environments caused by mining reversible?

Mrs Dlamini's lesson plan had several similarities to the one the researcher gave to the participants before the intervention as part of the resource pack. When asked about the similarities in the final interview, she stated, *"I liked the idea of reclamation procedures and wanted to do a similar lesson with my own students"*.

6.3.2.4 A Summary of Mrs Dlamini's Post-PCK

She had responses in the interview and post-questionnaire that were evidence of the development of her pPCK, but when asked to design a lesson, she could not draw on her pPCK and enact it in a lesson plan. This could mean that although the cPCK had become part of her own pPCK. Mrs Dlamini was not ready to put the pPCK she had revealed into action and enact her PCK. In cases where she copied the example lesson plan, the researcher did not give any credit, but where changes were made, the changes were analysed to see if credit was due.

Table 6.3 summarises Mrs Dlamini's post-PCK. The final score for each category was found by selecting the higher of the scores received from the questionnaire and lesson plan.

Table 6.3

A summary of the observations made on Mrs Dlamini's post-PCK using the rubric

Component of PCK	Score from questionnaire (pPCK)/Score from lesson plan (ePCK)	Final score (PCK)	Overall score for PCK component
Curricular saliency			
Concepts addressed when teaching	2/3	3	
Pre-concepts required by students	2/1	2	
Inclusion of environmental issues	2/2	2	
Importance of knowing about the big ideas	3/2	3	
			2.5
Conceptual teaching strategies			
Teaching strategies/method	2/3	3	
Questions to be asked	2/2	2	
Representations	2/2	2	
Assessment strategies	2/3	3	
			2.5
Students Understanding			
Difficulties	2/2	2	
Students misconceptions	2/2	2	
Questions to access thinking	3/4	4	
			2.7
		Overall post-PCK	**2.6**

An analysis of Mrs Dlamini's pPCK score from the post-PDI questionnaire and her ePCK score from the lesson plan show that most of the time, both her pPCK score and ePCK were the same, or her ePCK score was higher than her pPCK score. However, there are two instances where her ePCK is lower than her pPCK (highlighted). In identifying pre-concepts required by students and explaining why it is important for students to know about the big ideas, Mrs Dlamini could not draw on her pPCK to demonstrate her ePCK. This means her PCK development in terms of understanding did not match her development to the extent of application as she could not apply what she had learnt. This concurs with a finding from a study by Mazibe et al. (2018), comparing teachers' reported and enacted PCK about graphs of motion. It was found that all teachers showed a lower enacted PCK than a reported PCK in at least one component of PCK.

6.3.2.5 An Interpretation of Findings from Mrs Dlamini

Mrs Dlamini's overall post-PCK was found to be developing. However, there was one instance where her post-PCK was seen to be exemplary in the area of using questions to assess students' thinking. This suggests the possibility of an amplifier in this area that allowed her to sufficiently draw on the cPCK in the intervention and demonstrate her pPCK. Her ePCK in this area was also higher than the pPCK. In her interview responses, she says, *"I never asked with the intention of finding out what they really know"*. From this response, we can infer that this is her perceived self-efficacy. Self-efficacy and enthusiasm are amplifiers and filters of teacher competence (Sorge et al., 2019). It is worth noting that after this statement, Mrs Dlamini mentioned twice that she put more effort into her questioning. There is a possibility that this realisation became an amplifier and allowed her to draw from her pPCK and demonstrate an ePCK.

As mentioned earlier, there are two instances where her ePCK is lower than her pPCK, both under the component relating to her knowledge and skills about the curricular saliency of the topic. This finding was not expected because in one of the interviews she had said, *"I am currently doing my master's, so the things about sustainable development I knew before the intervention"*. The researcher believed this would have been an amplifier in the area of CS, but this was not evident in the findings. This suggests that there could have been another factor that was acting as a filter in this area. Looking back at her interview responses, the researcher found two possible filters. In Chapter 4, Mrs Dlamini said, *"we can't keep spoon-feeding them; they must learn to be researchers"*. This response could mean that she might have focused less on the concepts because she thought it was not her responsibility. Also, this response could reflect her own learning experiences as a student herself, translating into a belief that students should go out and find their own content. Another possibility was found in the responses in the Chapter 5 interviews. The researcher found that Mrs Dlamini's focus was not on the environmental aspect of sustainability but instead on the social aspect. She repeatedly mentioned issues that are not directly related to chemistry, such as *"inequality"*, *"gender-based violence"* and *"health and disease"*. This alerted the researcher to the possibility that in her Master's studies, Mrs Dlamini's knowledge of sustainable development could have focused significantly on the social aspect of sustainability.

6.3.3 Mr Mavuso's Post-PCK

6.3.3.1 Post-PCK, as Inferred from Mr Mavuso's Interview

In light of the new knowledge that he had received about ESD and the attributes of a good teacher, Mr Mavuso stated that his lesson planning would be different. He described how his knowledge of ESD would change his teaching strategies by saying:

> *In my older lesson plan, the section where I planned about my teaching methods, I usually used teacher-led discussions and experiments. Those are the teaching methods that I mostly used. But now that I am aware and understand that ESD promotes participatory learning, I will include presentations in my methods where the learners will be able to share ideas, solve problems and then present them to the whole class.*(Mr Mavuso; Interview 2)

This response shows that Mr Mavuso is now aware of some of the characteristics of ESD, namely participatory learning and that he will try to involve all students in the learning process.

He went on to say:

> *In my traditional lesson planning, in the prerequisite information section, I would usually assume that my learners know about general issues related to the topic and I would not question them. So now that I've looked through the presentation, so now I will question my learners in order to assess their prior knowledge to the topic and, that will help me to understand what my learners are thinking*. (Mr Mavuso; Interview 2)

This response demonstrates how his knowledge about student understanding has changed. He acknowledges that he did not previously take time to assess students' prior knowledge.

When asked about what he had learnt during the intervention about sustainability and education for sustainability, he responded that he did not know *"that there are sustainable development goals and that education holds a key position in the sustainable development goals."* He also added that he has learnt *"about the characteristics of ESD and how it is implemented into teaching."*

In response to what he learnt about being a good teacher, he said that *"a good teacher must know issues that are relevant to learners"* and *"a teacher must be able to recognise them* (issues) *in our existing syllabus."* He added that he also learnt that *"a teacher must be able to select instructional strategies that promote meaningful learning"*. These responses are evidence of how Mr Mavuso's knowledge about the curricular saliency and conceptual teaching strategies of the topic has been altered.

His responses showed that Mr Mavuso had gained knowledge on different aspects of the three components of PCK.

6.3.3.2 Post-PCK, as Inferred from Mr Mavuso's Post-questionnaire

In this section, I discuss the modifications Mr Mavuso made to the responses in his pre-questionnaire. These modifications took place after he had completed the online intervention. The modifications were grouped according to the PCK component under which they fall for uniformity. Each modification was discussed to reveal whether the modification caused any changes to the scoring of the teacher's responses using the PCK rubric.

Curricular Saliency

Mr Mavuso made only one modification under this component. In response to the question on whether he agreed with the inclusion of sustainability issues into the curriculum and why, he added that *"it helps learners to think beyond technical chemistry concepts, by giving them skills to apply and solve everyday life environmental situations they face"*. For this question, his score for the initial PCK was one. His additional justification was well articulated and in line with one of the aims of the EGCSE syllabus. Figure 6.15 below shows how his knowledge in this area changed from limited to developing, and he was scored a three.

Figure 6.15

A rubric extract showing Mr Mavuso's post-PCK about the inclusion of environmental issues into the curriculum

CS3- In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	-No reasons provided - Reasons are unclear and not linked to the outcomes of the syllabus	- Reasons provided are well articulated - Reasons are not linked to the aims of the EGCSE syllabus	- Reasons given well articulated - Reasons given linked to one or two of the aims of the EGCSE syllabus	-Two or more reasons given - Reasons provided are linked to three of the aims of the EGCSE syllabus

Conceptual Teaching Strategies

Mr Mavuso also modified his response on the teaching strategies he would use to teach the big ideas by completely changing his choice of strategies. Figure 6.16 shows how Mr Mavuso changed his teaching strategies from student-led discussions and visualisation, in the pre-questionnaire, to simulations and class discussions, in the post-questionnaire. He confirmed his new insights, saying, "*simulations encourage learners to participate*" and *"class discussions help learners develop strong communication skills"*. These justifications are clear and consistent with ESD-specific strategies; therefore, his pre-PCK score was changed from a two to a four, as his knowledge of teaching strategies was now seen as exemplary. This response corresponds with Mr Mavuso's interview response where he said, *"now that I am aware and understand that ESD promotes participatory learning, I will include presentations in my methods where the learners will be able to share ideas, solve problems and then present them to the whole class"*.

Figure 6.16

Mr Mavuso's modifications to his conceptual teaching strategies

3(a)	What teaching strategies would you use to teach*conserving resources*? Why? Simulations, where learners imagine they live in an environment where they have to conserve resources. Simulations encourage learners to participate (learner-centred) and it simplifies the concept of conservation making it more understandable to learners.
(b)	What teaching strategies would you use to teach *the environmental impact of mining*? Why? Class discussions, where leaners discuss differences in pictures of an environment before and after mining took place. Class discussions help learners develop strong communication skills.

He also modified his response on the assessment strategies he would use when teaching the big ideas. He added that "*learners would be given questions, then gather information and present it to the class*" (See Figure 6.17). Although this assessment strategy was appropriate, there were no indications of how it was linked to either of the big ideas, so his score remained at two.

Figure 6.17

Mr Mavuso's modifications on the assessment strategies he would use

What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?

- Assignments: learners would be grouped then given topics of, to research and write short essays.
- Presentations: learners would be given questions, then gather information and present it to the class.

Student Understanding

When asked to review his responses to questions under this component, Mr Mavuso changed two questions. When asked what he found difficult about teaching Big Idea B, he decided to completely change his response by saying, "*explaining the issue of global warming and climate change*" and "*explaining the technical terms; greenhouse gas, global warming and climate change*". When compared with the model answers (Figure 6.18), these difficulties faced by Mr Mavuso are appropriate and related to the key concepts. Still, he did not give any reasons for the difficulties, which led to a score of two as his knowledge in this area remained basic.

Figure 6.18

Model answers showing difficulties related to teachers and the reasons

Difficulties (*related to teachers)*
-ensuring that the examples are relevant to the students

-explaining terms/environmental issues

-deciding on the best teaching approach

-lack of support from school administrators in promoting environmental conservation programmes and practices (Abd Rahman, Halim, Ahmad, & Soh, 2018)

Why?
According to Ham & Sewing (1998) difficulties faced when teaching about environmental issues are caused by:
1) conceptual constraints (teachers lack of understanding on the content)
2) logistical (such as time constraint, inadequate teaching materials, inappropriate class size, financial and transportation problems)
3) teachers' competencies (lack of pedagogical knowledge), and
4) commitment (and motivation)

Mr Mavuso also modified the misconceptions he would encounter while teaching the big ideas. In the pre-questionnaire, he responded with student difficulties instead of misconceptions. On changing his response, he stated that students are *"unable to differentiate the environmental terms; ecosystem and habitat"* and *"unable to differentiate the terms global warming and climate change.* He also added that students say, "*conservation is the maintenance and protection of animals only, not plants"* (See Figure 6.19). These responses refer to students' misunderstandings, and so his score remained a one.

Figure 6.19

Mr Mavuso's post-questionnaire response to the question on student misconceptions

What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?

- Unable to differentiate the environmental terms; ecosystem and habitat.
- Saying conservation is the maintenance and protection of animals only, not plants.
- Unable to differentiate the terms global warming and climate change.

6.3.3.3 Post-PCK, as Inferred from Mr Mavuso's Lesson Plan

Curricular Saliency

For the lesson, Mr Mavuso explained the reason was *"to create awareness on the impacts of mining metals and other minerals to the environment."* Although his reason was clear, and he mentioned the environmental impact of mining, he did not link this to the social effects of mining. He also did not point out the problem-solving knowledge and skills that students would gain to deal with these environmental issues. He would have scored two based on the lesson plan, but he scored a three in the post-questionnaire; therefore, his score remains a three.

According to him, the pre-concepts students should have to understand the new concepts are "*knowledge on what takes place during mining, how metals are extracted from their ores and how the environment around a mine looks like"*. The first and second ideas that he mentioned are appropriate. The third concept is inappropriate as it relates to the new knowledge the students would gain during the lesson. He reveals limited knowledge of prior knowledge in the lesson plan, but his score in the post-questionnaire was a three and so remains a three.

Mr Mavuso stated two learning outcomes for his lesson. He said the intended outcomes were *"to explain how mining harms the soil, water, air and vegetation"* and *"to devise a reclamation plan for a mine after mining ceases in order to restore biodiversity".* Although the outcomes he gave were appropriate and sequencing was evident, the important idea about the impact of mining on animals/humans was not considered. This revealed that his knowledge was developing and his score remained a three.

Conceptual Teaching Strategies

The instructional strategies that Mr Mavuso chose to use for the lesson were simulation, presentation and class discussion. Evidence under the activities section of the lesson plan made it clear that these strategies were student-centred and relied on learner involvement. He introduced the lesson with a simulation of the process of mining. Students were instructed to *"locate and recover the ore within a certain amount of time"*. During this time, he would lead a class discussion which would be followed by students presenting their findings on how much ore they mined and comparing "*the condition of the muffin before mining and after reclamation"*. The description of how these teaching strategies would be used shows evidence of participatory learning, collaboration and problem-solving, which are key characteristics of ESD. His score in the post questionnaire was a four, and because he described how these strategies would be used, his score remained a four.

The questions that he thought were essential to his teaching were *"How does mining change the Earth's surface?", "Describe practices at mine sites that could reduce environmental* *impacts of mining"* and *"How does reclamation reduce impacts of mining after mining ceases?"* These questions are related to the key idea, and there is evidence of questions that require higher-order thinking and problem-solving. His knowledge in this area was seen as exemplary, and his score was changed from a two to a four.

The resources that he chose to use for his lesson were *"blueberry muffins, straws, spatulas, toothpicks"* and a student worksheet. The blueberry muffin and the mining tools were to be used during the simulation. For the main activity, students would be given a worksheet *"comprising of a diagram showing activities at a mine and a table to be completed"*. The descriptions of the activities that would be carried out by the students and teachers and formed part of the questions that he would ask during teaching gave sufficient evidence of both justification and how the blueberry muffin would be used to support conceptual development. However, the description of the worksheet was inadequate and did not give a clear picture of how it would be used to support conceptual understanding or why it was chosen. Mr Mavuso was scored a two in the post questionnaire, and the knowledge he displayed in the lesson plan was also seen as basic, so his score remained a two.

According to Mr Mavuso's lesson plan, *"students will be given an assignment to go research, and write short essays arguing for or against the benefits of mining outweighing the impacts on the environment".* This assessment strategy is appropriate as there are indications of how it is linked to the main concept being taught. Although it may promote independent research, it does not promote problem-solving, which could have shown exemplary knowledge, but his knowledge is now seen as developing, and he scored a three.

Student Understanding

The list of questions he planned to ask during his simulation using the blueberry muffin activity was extensive. The questions were, "*How did mining the blueberries affect the shape of the muffin? What is the ratio of the ore to the waste rock after mining? In what way would the percentage of ore mined differ if you did not have to worry about preserving the surface of the muffin? Was the muffin able to be restored to its previous condition?"* and *"Explain some challenges in reclamation of the muffin".* For his main activity, the questions he planned to ask were, *"How does mining affect the condition of the environment? How do the actions taken at the mine reduce the impacts of mining?"* and *"How does reclamation reduce the impacts of mining?"* He planned to conclude the lesson with, "*Do you think the benefits of mining outweigh the impacts on the environment?"* Although Mr Mavuso planned to ask only one question during his conclusion, he gave an extensive list of questions that he would use to access student thinking and understanding during his introduction and main activity. There was sufficient evidence of questions to elicit student thinking, and the questions were aligned to the teaching strategies and resources he planned to use. For this reason, he was awarded a score of four.

6.3.3.4 A Summary of Mr Mavuso's Post-PCK

Table 6.4 shows a summary of Mr Mavuso's post-PCK. The final score for each category was found by selecting the higher score received from the questionnaire and lesson plan.

Table 6.4

A summary of the observations made on Mr Mavuso's post PCK using the rubric

Component of PCK	Score from questionnaire (pPCK)/ Score from lesson plan (ePCK)	Final score (PCK)	Overall score for PCK component
Curricular saliency			
Concepts addressed when teaching	3/3	3	
Pre-concepts required by students	3/3	3	
Inclusion of environmental issues	3/3	3	
Importance of knowing about the big ideas	3/3	3	
			3.0
Conceptual teaching strategies			
Teaching strategies/method	4/4	4	
Questions to be asked	2/4	4	
Representations	2/2	2	
Assessment strategies	2/3	3	
			3.3
Students' Understanding			
Difficulties	2/2	2	
Students' misconceptions	2/2	2	
Questions to assess thinking	1/4	4	
			2.7
		Overall post-PCK	**3.0**

An analysis of Mr Mavuso's pPCK score and ePCK score shows that all the time, his pPCK score and ePCK were either the same or his ePCK score was higher than his pPCK score. This means that Mr Mavuso could sufficiently draw on his pPCK to demonstrate his ePCK.

6.3.3.5 An Interpretation of Findings from Mr Mavuso

Mr Mavuso had an overall post-PCK that was developing. His highest score was in the component of knowledge and skills related to conceptual teaching strategies. This means that he could transfer knowledge from the cPCK and create his own pPCK. This transfer, as mentioned before, is informed by potential amplifiers and filters such as a teacher's attitudes, beliefs, knowledge and experiences. During his post-PDI interview Mr Mavuso revealed that in the past he used teacher-centred methods, and *"now that I am aware and understand that ESD promotes participatory learning"*, he will make an effort to include appropriate strategies into his teaching. We can infer from this response that this awareness and new knowledge could have acted as a possible amplifier in the knowledge and skills about the conceptual teaching strategies about the topic.

Table 6.4 shows no instances where his ePCK was lower than his pPCK. This implies that for all areas under the three components of PCK, Mr Mavuso was able to draw on his pPCK to demonstrate his ePCK. According to the RCM, there are always amplifiers and filters informing the transfer of knowledge between the three realms of PCK, but these factors may not have been revealed to the researcher.

6.3.4 Mr Cele's Post-PCK

6.3.4.1 Post-PCK, as Inferred from Mr Cele's Interview

Mr Cele was asked if he thought there would be a change in his lesson planning experience now that he was aware of ESD and the attributes of a good teacher. He mentioned that after this intervention, *"there is no way that my lesson could be the same"*. He pointed out that he is keen on incorporating sustainability issues into his teaching, when he said, *"it is so hard, for some topics to put in sustainability, but I've already started looking for some relevant topics in chemistry and biology."* He believes that when teachers plan a lesson, the most important question they should ask themselves is, "*how will this lesson impact the student's lives?"* He adds that, *"for a lesson to be successful it must change the students' thinking and behaviour"*. To do this, he refers to the type of questions he will construct by saying, "[they are] *questions that will involve the students and turn them into a more critical thinking and problem-solving class."*

This response shows that he understands that the content taught must be relevant to the students and promote critical thinking and problem-solving skills. These are both characteristics of ESD.

When asked what he had learnt about sustainability and education for sustainability during the intervention, he said there is little he did not know about sustainability. Concerning ESD, he said although he had heard about the concept, he had never been given a chance to think about it. He said he learnt that *"it involves raising an awareness about social, environmental and economic issues that impact our students' lives and also their future".* He continued to say that he viewed ESD *"as one vehicle to meaningful and quality education, which is the kind of education that responds to the issues that are relevant to the students".*

This response reveals how Mr Cele's knowledge of the curricular saliency of the topic has changed. He understands the importance of making content relevant to students.

In response to what he learnt about being a good teacher, he said that it is *"someone who can teach scientific content in such a way that the students understand what is in the curriculum and also apply it out of school, in real life situations".* He continued to emphasise his point and said, *"a good teacher doesn't only need to know the curriculum but also needs to know how the content of the curriculum applies to the students".* This response shows that Mr Cele understands the importance of making learning more meaningful.

In all his responses, there was evidence that Mr Cele had gained knowledge on the curricular saliency of the topic.

6.3.4.2 Post-PCK, as Inferred from Mr Cele's Post-questionnaire

In this section, I discuss the modifications made by Mr Cele to the responses in his pre-questionnaire. These modifications took place after he had completed the online intervention. The modifications were grouped according to the PCK component under which they fall for uniformity. Each modification was discussed to reveal whether it caused any changes to the scoring of the teacher's responses using the PCK rubric.

Curricular Saliency

Mr Cele made changes to three of the four questions under this component. His first modification was in response to the question about the four most important concepts he would address during his teaching of extraction of metals. Figure 6.20 shows the modifications made. For this question, his score for the initial PCK was a four. His modified response shows that his knowledge is exemplary, and his score remains a four.

Figure 6.20

Mr Cele's modified response to the question on the most important concepts he would teach

Name the four most important concepts you would address when teaching "extraction of metals". Name them in the sequence you would teach them.

I. THE REACTIVITY SERIES OF METALSAND THE EASE OF THEIR EXTRACTION

II. METHODS OF EXTRACTION OF METALS FROM THEIR DIFFERENT ORES e.g.(HAEMITATE FOR IRON, BAUXITE FOR ALUMINIUM, COPPER PYRITES COPPER)

III. EXTRACTION OF IRON IN THE BLAST FURNACE AND ALUMINIUM THROUGH ELECTROLYSIS

IV. CONSERVATION OF NATURAL RESOURCES AND THE ENVIRONMENTAL IMPACT OF MINING AND EXTRACTION OF METALS ON VEGETATION, HUMAN BEINGS AND ANIMALS

When asked which concepts needed to be taught to learners before the topic on metals extraction, he added two more concepts, namely, *"renewable and non-renewable natural resources"* and *"formation of ions from salts in aqueous medium – in order to explain electrolysis"*. Although these concepts are considered appropriate, the logical sequencing of the concepts was not evident, and as such, his knowledge of required pre-concepts was seen as basic, and his score remained a two.

His pre-intervention response gave him a score of three when asked why it was important for students to know about conserving resources. After the intervention, he added to his initial response by mentioning that it enables students "*to make good decisions and take responsibility regarding matters associated with environmental factors, respecting themselves, others and nature"*. He added that it also helps students *"appreciate the role of chemistry in bridging the gap between life and school matter, that is, allowing learners to apply scientific knowledge in everyday life-related issues"*. Mr Cele's pre-intervention score was a three, and his addition in the post-questionnaire response indicated his awareness of the need to create a sense of responsibility among the students. Figure 6.21 shows the knowledge indicators that led to his score being changed to a four.

Figure 6.21

Rubric extract showing indicators for Mr Cele's knowledge on the importance of knowing about the big ideas

CS4- Why is it important for students to know about conserving resources and the impact that mining has on the environment?	-No reasons provided - Reasons provided are generic/not clear	- Only one/two reasons stated -Reasons provided indicate no link between environment / society(student) / economy - reasons not linked to students role	- Appropriate reasons are provided - No evidence of understanding of link between environment / society / economy -reasons show link to students role	-Reasons provided show in-depth understanding of link between environment/ society (student)/ economy - Reasons show students role with regard to these big ideas(need for solutions) and a sense of responsibility

Conceptual Teaching Strategies

Mr Cele also modified his response on his teaching strategies to teach Big Idea A. His addition concerned why and how he would use his chosen strategies. Figure 6.22 shows Mr Cele's additions. Although he did give more detail on how he would use the strategies, his reasons still do not show any link to students' roles and as such his score remained a three.

Figure 6.22

Mr Cele's modification to choice of teaching strategy for Big Idea A

What teaching strategies would you use to teach*conserving resources*? Why?

- ✓ CLASSROOM DISCUSSIONS: THE STUDENTS SHOULD KNOW THE IMPORTANCE OF CONSERVING RESOURCES. LEARNERS SHOULD IDENTIFY THE RESOURCES OR SPECIES THAT NEED TO BE CONSERVED AND THEY CAN COME UP WITH THE NEGATIVE CONSEQUENCES OF SUCH EXTINCTIONS OR MISUSE. THE IMPORTANCE OF CONSERVING THESE WILL EMERGE FROM THE DISCUSSIONS.
- ✓ AGAIN, CONSERVATION OF NATURAL RESOURCES IS THE TOPIC OF THE DAY AND I DO BELIEVE THAT THERE IS A LOT OF INFORMATION LEARNERS ALREADY POSSESS ON THE SAME SUBJECT. HOWEVER, DIFFERENCES IN ACCESS TO INFORMATION CAN BE ENCOUNTERED BY THE DISCUSSIONS.
  - ➤ FIELD TRIP OR RESEARCH PROJECT: SINCE CONVERSION IMPACT THE ECONOMY AND ENHANCE TOURISM, LEARNERS CAN VISIT PLACES LIKE THE GAME RESERVES OR REACH OUT FOR DOCUMENTS THAT JUSTIFY CONSERVATION AND FIND OUT MORE ABOUT THE IMPORTANCE OF CONSERVATION.
  - ➤ LEARNERS CAN EVEN ASK MORE QUESTIONS FROM OTHER EXPERTS IN THEIR TRIPS, BASED ON THE ISSUES ASSOCIATED WITH CONSERVATION OF RESOURSES.

When listing the representations he would use to teach Big Ideas A and B, he added *"a table comparing benefits of conservation and consequences of not conserving natural resources"*, *"a picture of the land before and after mining"* and a picture or diagram of *"a comparison between the damages caused by unsustainable mining and sustainable mining"*. This response showed evidence of how each of these representations would be used to support understanding. However, this response showed no logical sequencing in using these representations, although his knowledge of representations was now seen as developing and his score was changed from a two to a three.

In his pre-questionnaire response, Mr Cele was seen to have limited knowledge of appropriate assessment strategies and so was scored as a one. After the intervention, he added, "*learners can work in groups and make presentations on their conservation models/strategies of the resources*" and *"problem-based learning, where learners discuss and come up with solutions on conservation, development and environmental protection"* and *"designing methods/models that can be useful in curbing the environmental issues we are* *facing imposed by mining".* The assessment strategies that he added show a link to both big ideas. They also encourage problem-solving and critical thinking. This modified response shows Mr Cele's exemplary knowledge of assessment strategies, and he was scored a four. Figure 6.23 shows the knowledge indicators for exemplary knowledge.

Figure 6.23

Rubric extract showing scoring indicators for Mr Cele's assessment strategies

CTS4 - What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?	- No assessment strategies provided - No evidence of appropriate assessment strategies	- Lists one or two general assessment strategies -No indications of how they are linked to concepts	- Lists appropriate assessment strategies - There are indications of how they are linked to concepts	- Lists assessment strategies with indications of how they are linked to concepts -Strategies encourage problem solving skills and critical reasoning

Student Understanding

Mr Cele made two modifications under this component. His first modification concerned the difficulties that he may face when teaching the big ideas. He added that *"improper selection of teaching aids can lead to a lot of misconceptions since learners have no life experience on mining".* According to the master CoRe, ensuring that representations are relevant is a difficulty faced by teachers, making Mr Cele's difficulty appropriate. He did not explain why a teacher may fail to select the correct examples, so his score remained a two.

He also added to the type of questions he would use to access student understanding. The question he added was, "*can you develop a mining project that will observe conservation of species and environmental protection to a greater extent?"* This question is closely related to the task that Mr Cele added as part of his assessment strategy when he said that learners would discuss and *"make presentations on their conservation models".* This response showed that the question is linked to the conceptual teaching strategy that he would use and, therefore, his score was changed from a two to a three.

6.3.4.3 Post-PCK, as Inferred from Mr Cele's Lesson Plan

Curricular Saliency

Mr Cele stated the purpose of the lesson was *"to discuss about the benefits and drawbacks of mining natural resources in relation to the environment".* Although his purpose for the lesson was clearly formulated, there was no link to society, and he did not mention the knowledge and skills students would gain to help them tackle these environmental issues. He would have scored a two based on the lesson plan, but he scored a four in the post-questionnaire; therefore, his score remains a four.

According to Mr Cele's lesson plan, the pre-concepts required for students to understand the new concepts are *"the extraction processes"* and *"the importance of minerals in their daily life"*. These ideas are appropriate as they are part of the knowledge required by students to understand the concept. Although the sequencing is logical, the list of ideas is not extensive. This reveals that his knowledge in this area is not yet exemplary but still developing, so his score is changed from a two to a three.

The two learning outcomes Mr Cele set for his lesson were, *"Describe the impacts of resource extraction on the environment"* and *"Identify the social, environmental and economic effects of mining on any given life event"*. Although he gave appropriate outcomes with visible sequencing, the idea of finding solutions on how the effects of mining can be minimised was missing. His score based on the lesson plan would have been a three, but he scored a four in the post-questionnaire; therefore, his knowledge in this area remained exemplary.

Conceptual Teaching Strategies

Mr Cele chose to use exposition, discussion and presentations as his instructional strategies for the lesson. The researcher sought additional evidence under the activities section to determine how these strategies were used and why they were chosen. Mr Cele starts his lesson with an activity where students categorise renewable and non-renewable resources. This is followed by a teacher-led discussion where students recap what they have learnt about mining in previous lessons. For the main activity, students would be grouped and given a worksheet, blueberry muffins and some "mining" tools. Their responses to the worksheet would be used to make a presentation. The second part of the main activity would have two projections of pictures. The first picture would be *"of land before and after mining"* followed by group discussions of the social, economic and environmental impacts of mining. The second projected picture would be *"pictures of two mines; one which was developed with sustainability in mind and the other which was developed unsustainably"*. This projection would be followed by a *"debate on the impacts of each on the environment and discuss them as a class."* Mr Cele chose to conclude his lesson by highlighting the lesson's main points. Although the description of how these would be used showed evidence of learner involvement, there was no evidence of enhancement of problem-solving skills which is a key characteristic of ESD. His score in the post questionnaire was a three, and because his description was not consistent with ESD-specific strategies, his knowledge was seen as developing, and his score remained a three.

The questions that he thought were essential to his teaching were *“How does mining affect the environment?”* and *“How does [the] impact of mining affect the society, environment and economy?”* The questions are related to the key idea, and there is evidence of sequencing. Although sequencing demonstrates some reasoning, there is no evidence of questions that require critical thinking and problem-solving skills, and as such, his score remained a two.

Mr Cele indicated that he would use blueberry muffins, paper towels, toothpicks, a razor, beaker, laptop and projector as his resources for the lesson. Under the sections student and teacher activities, and the questions he would ask during the activity, he described how he planned to use these items. Although his description showed evidence of how these resources would support conceptual development, his knowledge in the area of representations was seen as developing as his list was not extensive, and his score remained a three.

For his assessment, he chose an assignment where the students would be asked to “*write half of a page about five things good about mining and five things that are bad about mining. The student should explain how their choice affects social, economic or environmental life”*. According to his lesson plan, the students would have already discussed and debated the impacts of mining. This assessment strategy is appropriate as it promotes independent learning and critical thinking; however, it does not encourage problem-solving. His score for knowledge of assessment in the lesson plan would have scored him a three, but his score from the post-questionnaire was a four, and so his knowledge is seen as exemplary.

Student Understanding

He gave a list of questions that he would use to determine students’ understanding. The questions he planned to ask during his lesson introduction were: “*Does mining of minerals impact the environment?”* and *“What are the likely impacts of mining to; plants, animals, soil, water and humans?”* For his main activity, he planned to ask, *“can you successfully mine the blueberries without destroying the muffin; can we mine natural resources without destroying the environment; how does mining impact the social life, the environment and the economy of the country; and how can we reduce the negative impacts of mining, while* *ensuring sustainable development"*. He planned to conclude his lesson with the question, *"Does mining support sustainable development in terms of ensuring the wellness of future generations?"* From this list, there was evidence of questions to elicit student thinking, and the questions were aligned to the teaching strategies and resources he planned to use. The list is not extensive, which reveals that his knowledge in this area is not yet exemplary but is still developing, and so his score remains a three.

6.3.4.4 A Summary of Mr Cele's Post-PCK

Table 6.5 below shows a summary of Mr Cele's post-PCK. The final score for each of the categories was found by selecting the higher of the scores received from the questionnaire and lesson plan.

Table 6.5

A summary of the observations made on Mr Cele's post PCK using the rubric

Component of PCK	**Score from questionnaire*(pPCK)*/ Score from lesson plan*(ePCK)***	**Final score (PCK)**	**Overall score for PCK component**
Curricular saliency			
Concepts addressed when teaching	4/3	4	
Pre-concepts required by students	2/3	3	
Inclusion of environmental issues	3/3	3	
Importance of knowing about the big ideas	4/4	4	
			3.5
Conceptual teaching strategies			
Teaching strategies/method	3/3	3	
Questions to be asked	2/2	2	
Representations	3/3	3	
Assessment strategies	4/3	4	
			3.0
Student Understanding			
Difficulties	2/2	2	
Students misconceptions	1/1	1	
Questions to access thinking	3/3	3	
			2.0
Overall post PCK			**3.0**

An analysis of Mr Cele's pPCK and ePCK scores shows that most of the time, both his pPCK score and ePCK were the same. There is only one instance where his ePCK score was higher than his pPCK score. There are also two instances where his ePCK is lower than his pPCK (highlighted). This suggests that in identifying concepts that would be addressed during teaching and assessment strategies, Mr Cele was unable to draw sufficiently on his pPCK to demonstrate his ePCK.

6.3.4.5 An Interpretation of Findings from Mr Cele

Mr Cele's overall post-PCK was found to be developing. His highest score was in the component of knowledge and skills about the curricular saliency of the topic. This means that in this area, he could best transfer cPCK from the intervention to his own pPCK. According to the RCM, context plays a major role when teachers create their own pPCK. This context includes amplifiers and filters which shape teachers' pPCK. When looking at Mr Cele's biographical information, it is evident that he was a highly experienced teacher with more than 16 years of experience in teaching chemistry. Possibly, his experience acted as an amplifier and allowed him to draw sufficiently on the cPCK and transfer it to his own pPCK in this area. A possible amplifier can be found when looking through Mr Cele's post-PDI interviews. He stated, *"I have already started looking for some relevant topics in chemistry and biology".* This statement shows Mr Cele's interest, excitement and commitment to incorporating sustainability issues into his teaching subjects. According to Hong (2010), the interest and enjoyment one gets from an activity, and their commitment to that activity can act as an amplifier.

As mentioned in the previous section, there are also two instances (highlighted in Table 6.5) where Mr Cele's ePCK is lower than his pPCK. This means there is a possibility that filters existed, and he could not draw adequately on his pPCK to demonstrate his ePCK. The researcher, however, could not find any possible filters from his interview responses.

6.3.5 Ms Dube's Post-PCK

6.3.5.1 Post-PCK, as Inferred from Ms Dube's Interview

Ms Dube was asked if she thought her lesson planning experience would be different now that she was aware of ESD and the attributes of a good teacher. The first thing that she mentioned was regarding her teaching strategy; as she said, "*I will be able to choose teaching methods and teaching aids that will keep my learners interested in the lesson and actively participating in a different way than before".* She also mentions that she will try and address sustainability issues to *"open up the minds"* of her learners. Ms Dube's response demonstrates how her knowledge of conceptual teaching strategies for the topic has changed.

In her response, Ms Dube also acknowledges that, in the past, she never prepared her questions in advance by saying,

> *I will use questioning to find out what my students are thinking and also to assess their prior knowledge by preparing the questions before the lesson during my lesson planning, which is something I was not doing before. I was never preparing questions. We always assume that they know, but now I will have a list of questions to assess them and check if they know what I think they know.* (Ms Dube; Interview 2)

Although she admitted that she was unsure how she would incorporate it into her planning, she did mention that she has yet to find a way to help her *"identify the difficulties and misconceptions that the learners have"*. This response shows us that she is now aware of the role that students' thinking plays in conceptual understanding and the importance of accessing students' thinking to make the learning process more meaningful.

When asked about what she had learnt during the intervention, about sustainability and education for sustainability, Ms Dube admitted that she did not know about sustainability or education for sustainability before this training. She stated that, regarding sustainability, she was now aware that *"we can meet our needs, in terms of resources, without disturbing the earth for future generations"*. She continued to state that *"everybody should play a part in ensuring that the renewable and non-renewable resources are sustainable for future generations... our every action impacts sustainability"*. With regards to ESD, she said she learnt that *"it is interdisciplinary"* and *"promotes higher order thinking in learners"*. She concluded by saying, *"everyone should be able to make decisions with sustainability issues in mind... Learners need to be aware that they need to protect the environment for future generations"*.

Ms Dube's response demonstrates how her knowledge of the curricular saliency of the topic has changed. It also shows that she is now more aware that *"everyone"* is responsible for sustainability issues.

In response to what she learnt about being a good teacher, she said, *"A well-designed lesson is one thing a good teacher should do"*. She added that she learnt that it's not enough for a teacher to know the *"curriculum and subject content"*, as a good teacher should also *"know why that knowledge is important to them"* and *"issues that are relevant to the learners"*. This response again reveals how her knowledge of curricular saliency on the topic has changed.

She continued to explain that *"a good teacher must select teaching methods according to the strengths of the learners, to help them understand"*. She said teachers *"do not ask questions to find their pre-existing knowledge; we just assume that they know"* yet *"a good teacher must have questions to find the pre-existing knowledge of the learners"*. This response revealed aspects of knowledge on conceptual teaching strategies and student thinking.

In her responses, there was evidence that Ms Dube had gained knowledge on different aspects that fell under all three components of PCK.

6.3.5.2 Post-PCK, as Inferred from Ms Dube's Post-questionnaire

In this section, I discuss the modifications, made by Ms Dube to the responses in her pre-questionnaire. These modifications took place after she had completed the online intervention. The modifications were grouped according to the PCK component under which they fall for uniformity. Each modification was discussed to reveal whether the modification caused any changes to the scoring of the teacher's responses using the PCK rubric.

Curricular Saliency

Ms Dube made two minor additions under this component. Her first addition was in response to the question on the four most important components she would address when teaching. She added to the concept *"methods of extraction,"* which she had mentioned in her pre-questionnaire, the phrase "based on their position in the reactivity series". For this question, her score for the initial PCK was a two, and this addition did not change her score as her knowledge was still seen as basic.

When asked which concepts needed to be addressed before teaching learners about the extraction of metals, her pre-intervention response gave her a score of three. After the intervention, she decided to add to her initial response by mentioning a fourth concept, *"renewable/non-renewable resources including examples"*. According to the model answers and master CoRe it would be more appropriate for this concept to be addressed during the teaching of the topic of extraction of metals and not before. For this reason her addition did not change her score, and it remained a three. Figure 6.24 below shows Ms Dube's modified response.

Figure 6.24

Ms Dube's modification of pre-concepts needed by learners

What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?

1. Physical and chemical properties of metals
2. Renewable/non-renewable resources including examples
3. Oxidation/reduction, not limited to the gain/loss of oxygen. Transfer of electrons and transfer of hydrogen
4. The reactivity series of metals

Conceptual Teaching Strategies

Ms Dube also modified her response on the questions she considered important to ask her learners. After the intervention, she added the question, "*How does mining prevent progress towards sustainability*?" Her response in the pre-questionnaire did not make specific reference to either of the key ideas, leading to her score of one. This additional question was related to one of the key ideas and as such her score changed to a two. The rubric extract in Figure 6.25 shows the indicators that led to this change in scoring.

Figure 6.25

Rubric showing Ms Dube's post score for her knowledge on questioning

CTS2 - What questions, related to environmental sustainability (ES), would you consider important to ask your learners during your teaching?	- Questions listed are not specific to the key ideas - Questions are general - Sequencing is not evident	- Questions asked are related to one of the key ideas - No evidence of questions that require problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - No evidence of questions that require critical thinking and problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require higher order thinking and problem solving - Sequencing of questions is evident

She also modified her response on the representations she would use to teach Big Idea B. She added *"a choc-chip muffin"*. In her response, she described why she would use these representations and how the representation would be used to support conceptual development. Before the intervention, Ms Dube had a score of three in this area as she had listed three representations. With this additional representation, her list is considered extensive, and as such, her score is changed to a four.

When asked in the pre-questionnaire about the assessment strategies she would use, Ms Dube listed general assessment methods that were unrelated to the key ideas. For her initial response, she was scored a two. After the intervention, she added *"assignments"*. Although she mentioned that the assignment would be used to *"check their level of understanding with questions prompting them to design a plan"*, there was no evidence of the details of the plan and how it could be linked to the key ideas. Figure 6.26 shows her modification to her initial response. Her knowledge in this area was found to be basic, and her score remained a two.

Figure 6.26

Ms Dube's modification to the assessment strategies she would use

What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?

Would use formative assessment in form of topic test, questions also include the other learning outcomes for the topic.

Can also give learners assignments to check their level of understanding with questions prompting them to design a plan hence applying what they have learnt. This would also show misconceptions, if any, that the learners may have.

Student Understanding

Under this component, Ms Dube modified the question on the difficulties encountered and questions to assess student understanding. In response to the difficulties she could encounter, she opted to delete her whole pre-questionnaire response and replace it. Her score for the initial PCK in this area was a two. Her final response was that *"the learners cannot differentiate between climate change, greenhouse effect and global warming. I think they fail to understand clearly the meaning of these"*. This is an appropriate difficulty, and her explanation shows knowledge of students' understanding. Her knowledge in this area was now seen as developing, and her score was changed to a three.

She also modified the questions she would use to assess students' thinking and understanding about conserving resources and the impact that mining has on the environment. She added, *"Ask learners what they have learnt about the two and difficulties they had in* *understanding".* In the pre-questionnaire, she revealed basic knowledge in this area. Although her response could be linked to student thinking as it aimed to identify learning difficulties, no actual questions were given. Her score in this area remained two.

6.3.5.3 Post-PCK, as Inferred from Ms Dube's Lesson Plan

Curricular Saliency

Ms Dube stated the lesson's purpose to be for students to *"learn that mining affects the environment, human beings and vegetation and how it affects it".* Although she did mention the environmental and social effects of mining, she did not mention the knowledge and skills that students would gain to help them tackle the issues caused by mining. Her score based on the lesson plan is a two, which is the same as her score of two in the post-questionnaire; therefore, her score remains a two.

According to Ms Dube, the knowledge students should have to understand the impact of mining are *"Knowledge on renewable and non-renewable resources*, *Knowledge on conservation of resources"*, and *"Knowledge on sustainability and sustainability issues"*. These ideas were not appropriate as these concepts are not directly related to the impact of mining. This revealed that the knowledge enacted in this area is limited, but she scored a three in the post-questionnaire, and as such, her overall score was changed to three.

She gave two learning outcomes for her lesson: "*Describe how mining impacts the environment, vegetation and human beings"* and *"Explain ways to practice 'green' mining"*. She gave appropriate outcomes, and sequencing was evident. She scored two in the post questionnaire, and because all the important ideas were mentioned she was given an overall score of four.

Conceptual Teaching Strategies

Ms Dube chose to use question-and-answer, discussion and issue analysis as her instructional strategies for the lesson. As with the other participants, the researcher sought additional evidence of how these strategies were used and if they showed learner involvement under the activities section. She starts the lesson by stating, *"the link between mining and sustainability"*. She then moves on to question-and-answer and *"asks learners to list existing/old mines in the country and which resource was/is mined"*. She also ask students *"what they know about mining and what happens to a site before mining can begin"*. For the main activity, students would be given *"handouts with diagrams of mining sites before and* *after mining"*, after which they would be expected to write descriptions of how mining affects the environment, vegetation and human beings. She planned to end the lesson with a discussion on *"how acid mine drainage affects aquatic organisms, wildlife and humans"* and continue to discuss *"other impacts of mining"*. Although these teaching strategies were suggested as teacher and student activities, there is no evidence of participatory learning, collaboration and problem-solving, which are key characteristics of ESD. She scored one in the post-questionnaire, and because of her description of how these strategies would be used, she was given an overall score of two.

The questions that she thought were essential to her teaching were: *"What do you know about mining?, What do you think has to happen in the area before mining can take place?, How does mining impact the environment, vegetation and human beings"* and *"Can we mine for resources without disturbing the Earth?"* Although the questions listed by Ms Dube are related to the key idea, and there is evidence of questions that require higher order thinking, the questions do not encourage problem-solving. She scored a two in the post-questionnaire, and her response in the lesson plan was scored a three as her knowledge was seen as developing. Her overall score then became three.

She decided to use the EGCSE chemistry textbook, a worksheet and handouts as her resources for the lesson. Her description of student and teacher activities showed how the handout and worksheet would be used during the main activity to support the conceptual development of the lesson. Her description was considered inadequate as she did not mention how the students would use the textbook. Her knowledge in the area of representations was seen as basic in the lesson plan, but she scored a four in the post-questionnaire, and so her overall score was a four.

Ms Dube chose to assess her students' understanding using a research assignment where they would be required to *"design a plan on how 'green' mining can be done, i.e. mining without too much disturbance on the environment"*. She continued to describe that *"in their plan, they should discuss how mining prevents progress towards sustainability"*. Unlike her post-questionnaire response where she only mentioned that students would *"design a plan"*, this description elaborates on the plan, making it an appropriate assessment strategy that promotes research skills and encourages critical reasoning and problem-solving. This response provides evidence that her knowledge in this area is exemplary, and she scored a four, which was better than the score of two that she received in her post questionnaire.

Student Understanding

The questions she planned to ask during her introduction were, *"What did you learn about mining? What did you not understand about the lesson? Can we mine while not disturbing the Earth?"* and *"What do you think about the impacts of mining?"* For her main activity, she wrote, *"mark and grade learners' work from the worksheets"*. As the lesson plan template had asked for questions that would be used, the researcher decided to review the main activity again to determine whether the questions in the worksheet were mentioned. According to her description, students would be asked to *"describe how mining affects the environment, vegetation and human beings"*. They would *"write their interpretations in the spaces provided on the worksheet"*. During the conclusion of her lesson, she stated that she would *"give learners feedback on their responses, clearing misconceptions discovered during teaching and while marking"*. Although there was evidence of questions to elicit student understanding in the introduction, there was insufficient evidence of the questions being aligned to the teaching strategies and resources she planned to use. She also did not list the specific questions she would use during the main activity and conclusion. Therefore, her knowledge in this area was seen as limited, and she was scored a one. As she had scored a two in the post questionnaire, Ms Dube's overall score was a two.

6.3.5.4 A Summary of Ms Dube's Post-PCK

Table 6.6 summarises Ms Dube's post-PCK.

An analysis of Ms Dube's pPCK scores from the post-PDI questionnaire and her ePCK scores from the lesson plan shows that at times both her pPCK scores and ePCK scores were the same, and at other times her ePCK scores were higher than her pPCK score. There are, however, three instances where her ePCK is lower than her pPCK (highlighted). This suggests that in identifying the pre-concepts required by students, representations and questions to assess thinking, Ms Dube could not draw on her pPCK adequately to demonstrate her ePCK.

Table 6.6

A summary of the observations made on Ms Dube's post PCK using the rubric

Component of PCK	Score from questionnaire*(pPCK)*/ Score from lesson plan*(ePCK)*	Final score (PCK)	Overall score for PCK component
Curricular saliency			
Concepts addressed when teaching	2/2	2	
Pre-concepts required by students	3/1	1	
Inclusion of environmental issues	4/4	4	
Importance of knowing about the big ideas	2/4	4	
			2.8
Conceptual teaching strategies			
Teaching strategies/method	1/2	2	
Questions to be asked	2/3	3	
Representations	4/2	4	
Assessment strategies	2/4	4	
			3.3
Students Understanding			
Difficulties	3/3	3	
Students misconceptions	3/3	3	
Questions to access thinking	2/1	2	
			2.7
		Overall post-PCK	**2.9**

6.3.5.5 An Interpretation of Findings from Ms Dube

Ms Dube's overall post-PCK was found to be developing. Her highest score was in the component of knowledge and skills about the conceptual teaching strategies of the topic. This meant that of all three components, she could better transfer knowledge from the cPCK to inform her own pPCK. This suggests the existence of possible amplifiers. During her post-intervention interview, she said, *"I will be able to keep my learners interested in a different way than before"*. This response reveals information about her realisation that the teaching methods and representations she used in the past were not creating interest among the students, and this could have acted as a possible amplifier.

As mentioned in the previous section, Ms Dube had three instances, one under each of the three components, where her ePCK was lower than her pPCK. This means there could have been filters causing poor knowledge transfer and not allowing her to demonstrate her ePCK adequately. One of the instances was in the area of pre-concepts required by students. When analysing her post-intervention responses, we found a statement that could have revealed a possible filter in this area. The first was her statement, *"we always assume that they know"*. From this response, we could infer that this assumption could have acted as a filter in this area and may have led her to neglect to focus on accessing students' prior knowledge because she believed that the students already knew. Therefore, there was no need to ask questions.

Another instance where she had difficulty enacting her pPCK was in the area of representations. As mentioned above, she revealed in her interview that she now has the skills to choose representations that will keep her learners interested. This realisation that she lacked knowledge could have acted as a possible amplifier for transferring knowledge from the cPCK to pPCK because she may have been eager to gain new knowledge on representations. However, what could have acted as an amplifier earlier on may have acted as a filter when she attempted to draw on her pPCK and demonstrate her ePCK. This same realisation that she lacked knowledge could have caused a lack of confidence to employ the new knowledge about representations that she had gained. Perhaps this was because she never had these skills before and therefore had never used them.

The last instance where she could not draw on her pPCK and demonstrate her ePCK was in the area of questions that she could use to assess students' thinking. In her post-intervention interview she acknowledged that during her lessons she never attempted to assess students' prior knowledge and said, *"which is something I was not doing before"*. Although this realisation, on Ms Dube's part, could have acted as a potential amplifier, evidence from Table 6.6 shows that it may have acted as a filter instead. Perhaps, since questioning to assess student thinking was not something she did in the past, she may have lacked the experience and confidence to demonstrate her ePCK.

6.3.6 Mr Fakudze's Post-PCK

6.3.6.1 Post-PCK, as Inferred from Mr Fakudze's Interview

When asked whether his lesson planning would change and, if it would, how it would change, he mentioned that the content would be different. He said, *"I'm going to include sustainable development in topics that are relevant and also when I'm planning for the lessons I am going to incorporate it"*.

He continues to state that one part that intrigued him was the content on how and why to assess students' prior knowledge. This was his reason:

> *I'm going to include it because, as teachers, we are always behind in the syllabus. When we're teaching, we are always trying to catch time, and we sometimes don't assess our learners to ask what they know before we teach them. We always spoon-feed them all the time.* (Mr Fakudze; Interview 2)

This response demonstrates how his knowledge about students' understanding has changed. He acknowledges that he did not previously take time to assess students' prior knowledge.

When asked about what he had learnt during the intervention about sustainability and education for sustainability, he responded by acknowledging that he had always had a problem when it came to teaching sustainability-related topics such as *"conservation of resources"*. He added that he had learnt *"so many activities that were interesting"*. He particularly referenced the blueberry muffin activity, saying, *"it will make my teaching easier as it will be very interesting to them"*. This response shows evidence of how Mr Fakudze's conceptual teaching strategies about the topic have been enriched.

In response to what he learnt about being a good teacher, he emphasised the importance of what he called "pre-questions". He mentioned that good teachers must ask themselves: *"before going to teach my learners, the What? Why? When? How and Who?... for my lesson to be effective"*. He adds that the responses to these questions will help him *"select the right concepts"*. He mentioned that he also learnt that *"before I teach, I should ask my learners what do they know before going to feed them with information I have"*. He ends his response by admitting that these were things he never did. These responses are evidence of how Mr Fakudze's knowledge about curricular saliency and student understanding of the topic has been altered.

In his responses, there was evidence that Mr Fakudze had gained knowledge on different aspects of the three components of PCK.

6.3.6.2 Post-PCK, as Inferred from Mr Fakudze's Post-questionnaire

In this section, I discuss the modifications Mr Fakudze made to the responses in his pre-questionnaire. These modifications took place after he had completed the online intervention. The modifications were grouped according to the PCK component under which they fall for uniformity. Each modification was discussed to reveal whether the modification caused any changes to the scoring of the teacher's responses using the PCK rubric.

Curricular Saliency

Mr Fakudze made two modifications under this component. In response to the question on whether he agreed with the inclusion of sustainability issues into the curriculum and why, he altered his response to, *"as teachers we are agents of creating awareness to our learners about environmental issues".* For this question, his score for the initial PCK was a three. His alteration was well articulated and still in line with one of the aims of the EGCSE syllabus; as such, his score remained a three.

Mr Fakudze also chose to add a response to the question on why it was important for students to know about the big ideas. He added that *"They need to know that mining or use of natural resources, there should be a way or an alternative for the reclamation process in order for the resources to replenish"*.Mr Fakudze's score for the initial PCK was a two, and because this additional reason he stated was not clear, his knowledge in this area was seen to have remained basic, and he was scored a two.

Conceptual Teaching Strategies

He also modified his response on the teaching strategies he would use to teach the big ideas by adding to his choice of strategies. Mr Fakudze added to his initial teaching strategy of site visits for both big ideas. For Big Idea A, he added that he would also *"introduce renewable and non-renewable resources and add that resources are not only minerals but water, trees we have to conserve them because they are non-renewable"*. For Big Idea B, he added that he would *"introduce the blue berry muffin activity even if the school trip is not taken".* His response did not give any reasons why he would use these strategies. His addition to the big idea was not well articulated and revealed Mr Fakudze's misconception that trees are a non-renewable resource. His addition concerning Big Idea B corresponds to Mr Fakudze's interview response, where he said that he found the blueberry muffin activity very interesting. His initial score for knowledge of teaching strategies was a one, and although he added strategies, he did not justify his choices and as such his score in this area remained a one.

He also decided to modify his initial choice of the representations he would use to teach the big ideas. For Big Idea A, he added that he would *"introduce the shoe box mine activity"*. In his attempt to justify his choice, Mr Fakudze states that he would use his activity *"to show* *that mining without a reclamation process results in depletion of resources"*. For big idea B, he added the blueberry muffin activity. Although the representations added by Mr Fakudze were appropriate, his justification was insufficient, and the description of how they would be used to support conceptual development was inadequate. This modification did not affect his initial score of two.

He also modified his response on the assessment strategies he would use when teaching the big ideas. He added that he would set *"an assignment where students will describe the impacts of mining on the environment"*. He also planned to *"ask questions based on the shoebox mine activity"* (See Figure 6.27). His assessment strategies were appropriate and clearly indicated how they were linked to the big ideas, and for that reason, his score was changed from a one to a three.

Figure 6.27

Mr Fakudze's modifications on the assessment strategies he would use

What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?

1. Explain the effects of mining on the environment being vegetation, land, and water?
2. Setting an assignment where students will describe the impacts of mining on the environment (vegetation, human being and animals)?
3. For the conservation of resources ask questions based on the shoebox mine activity.

Student Understanding

When asked to review his responses to questions under this component, Mr Fakudze made changes to two questions. When asked what he found difficult about teaching Big Idea A, he added that he "*did not have enough knowledge about conserving natural resources"*. For Big Idea B, his initial response referred to his school not allowing visits to local mines. This was not a student difficulty but a challenge imposed by the school. His modification was not a difficulty; instead, he added that he might no longer solely rely on the field trips with his knowledge of the blueberry muffin activity. Although Mr Fakudze's difficulty for Big Idea A was appropriate, there was no evidence of justification and as such, his score in the area of difficulties remained a two.

Mr Fakudze also modified his questions to assess students' thinking. In the pre-questionnaire, he responded with a single question, but after the intervention, he added four more questions.

The questions were: "*What can be done to minimise the impacts that come with mining to the environment?, Define renewable and non-renewable resources?, Name the resources you know and classify them as renewable and non-renewable", and " What can be done to conserve non-renewable resources stated above?"*

His final response consisted of an extensive list of questions appropriate for eliciting student understanding. His knowledge in this area was exemplary, as the questions were linked to his choice of teaching strategy. His score was changed from a one to a four.

6.3.6.3 Post-PCK, as Inferred from Mr Fakudze's Lesson Plan

Curricular Saliency

For the lesson, Mr Fakudze stated the objectives *"to discuss the environmental impact of mining on vegetation, human beings and animals"* and *"to discuss possible solutions to the environmental impacts caused by mining"*. The reasons mentioned were appropriate as he mentioned the environmental and social effects of mining. There was also evidence of a link to the student's role with regard to finding solutions. His knowledge based on the lesson plan could have been exemplary, but there was no evidence of an in-depth understanding of the link between the environment and society, and as such, he scored a three. He scored a two in the post-questionnaire; therefore, his overall score was a three.

According to him, the pre-concept students should have to understand the impact of mining is the *"importance of conserving resources".* This concept is inappropriate as it is not a prerequisite for understanding the topic. He reveals a limited knowledge of pre-concepts in the lesson plan, and his score in the post-questionnaire was also a one, so his score remains a one.

Mr Fakudze stated two learning outcomes for his lesson. He said, *"to describe the environmental impacts of mining on vegetation, human beings and animals"* and *"to come up with possible innovative solutions to the environmental impacts of mining".* The outcomes he gave were appropriate and sequencing was evident, revealing his knowledge was exemplary. His score was changed from a one to a four.

Conceptual Teaching Strategies

The instructional strategies that Mr Fakudze chose to use for the lesson were a video, teacher-led discussions, simulation, group presentations and brainstorming. His descriptions of the activities of the lesson had evidence of learner involvement. He introduced the lesson with a teacher-led discussion on *"how a mine is established"*, starting with *"government hiring environmentalists who conduct an environmental impact assessment"* and a video covering the same discussion topic. The discussion would be followed by student group representatives presenting their *"summary of what they saw in the video"*. For the main activity, the teacher would explain that a *"mineral is found around the school, and government is interested in mining the mineral"*. Mr Fakudze would then *"assign each group to conduct an environmental impact assessment for the mine and identify the possible impacts of the mine on; vegetation, human beings, animals and classify them as short and long term"*. The lesson would end with group presentations where each group would *"present their environmental assessment to the class and their possible solutions"* to the *"impacts that will come with the mine".* The description of how these teaching strategies would be used shows evidence of participatory learning, collaboration, critical thinking and problem-solving, which are all key characteristics of ESD. His score in the post questionnaire was a one, and because of his description of how these strategies would be used, his score was changed to a four. It is worth mentioning that Mr Fakudze did not use the same conceptual teaching strategies for the post-questionnaire and lesson plan; they were completely different.

The questions that he thought were essential to his teaching were: *"How does mining affect the environment?"* and *"What are possible solutions to the environmental impacts that are caused by mining?"* These questions were related to the key idea, and there was evidence of questions that required critical thinking and problem-solving. His knowledge in this area was seen as exemplary, and his score was changed from a three to a four.

The resources that he chose to use for this lesson were a *"video on the environmental impact assessment and establishment of a mine"*, a *"handout on the impact of mining, showing different impacts on known mines in Eswatini"*, and a "*summary on impacts of mining on vegetation, human beings and animals"*. The descriptions of the activities that would be carried out by the students and teacher, and the questions that he would ask during teaching, gave sufficient evidence of both justification and how the video would be used to support conceptual development. There was, however, no description of how, why or when the handout or summary would be used. Mr Fakudze was scored a two in the post questionnaire, and the knowledge he displayed in the lesson plan was also seen as basic, so his score remained a two.

According to Mr Fakudze's lesson plan, as an assessment, the students would be given homework where *"each student will submit his/her possible solutions to the environmental impacts of mining on the environment, vegetation, human beings and animals."* This assessment strategy is appropriate as there are indications of how it is linked to the main concept being taught. It also encourages critical reasoning and problem-solving, which shows exemplary knowledge in this area, and as such, he scored a four.

Student Understanding

The questions Mr Fakudze planned for his introduction were, "*Why is an environmental impact assessment conducted before a mine is established?"* and *"Based on the video clip, how were human beings, vegetation and animals affected by the establishment of a mine?"* For his main activity, he planned to ask, *"How does mining affect the environment?"* During his conclusion, he would end with, "*Can the impacts of mining be avoided before the mining takes place? How?"* Although he only planned to ask one question during his main activity and conclusion, which was not extensive, this question would have required learners to recall and understand almost all the information they had learned from the beginning of the lesson. There was also evidence of questions to elicit student thinking, and the questions were aligned to the teaching strategies and resources he planned to use. The quantity of Mr Fakudze's questions was overlooked due to the quality of his questions, and for this reason his score was a four.

6.3.6.4 A Summary of Mr Fakudze's Post-PCK

Table 6.7 shows a summary of Mr Fakudze's post-PCK. The final score for each category was determined by selecting the higher scores received from the post-PDI questionnaire (pPCK) and lesson plan (ePCK).

An analysis of Mr Fakudze's pPCK and ePCK scores shows both his pPCK scores and ePCK scores were always the same, or his ePCK scores were higher than his pPCK scores. This suggests that Mr Fakudze was able to draw on his pPCK to demonstrate his ePCK.

Table 6.7

A summary of the observations made on Mr Fakudze's post PCK using the rubric

Component of PCK	Score from questionnaire*(pPCK)*/ Score from lesson plan*(ePCK)*	Final score (PCK)	Overall score for PCK component
Curricular saliency			
Concepts addressed when teaching	1/4	4	
Pre-concepts required by students	1/1	1	
Inclusion of environmental issues	3/3	3	
Importance of knowing about the big ideas	2/3	3	
			2.8
Conceptual teaching strategies			
Teaching strategies/method	1/4	4	
Questions to be asked	3/4	4	
Representations	2/2	2	
Assessment strategies	3/4	4	
			3.5
Students Understanding			
Difficulties	2/2	2	
Students misconceptions	1/1	1	
Questions to access thinking	4/4	4	
			2.3
		Overall post-PCK	**2.9**

6.3.6.5 An Interpretation of Findings from Mr Fakudze

Although Mr Fakudze's overall post-PCK was found to be developing, there was a component where he displayed an exemplary post-PCK. This component was that of knowledge and skills about the conceptual teaching strategies of the topic. This means that of all three components, he was better able to transfer knowledge from the cPCK and create his own pPCK. This suggests the possibility of the presence of amplifiers, which informed this knowledge transfer. On analysis of his interview responses, the researcher was unable to identify possible factors that could have acted as amplifiers. Although the components dealing with knowledge of curricuar saliency and student understanding did not yield the highest overall scores, there were instances where his post-PCK was exemplary. One instance was in the area referring to the concepts addressed when teaching. In the responses to his post-PDI interview, he said, *"we are always behind in the syllabus"*. We could infer from this response that this would mean that he has to focus on the teaching of content and, as such, this could have acted as an amplifier in this area.

Another area where Mr Fakudze showed an exemplary post-PCK was in the area of his ability to use questions to assess student thinking. This shows the possibility of the presence of an amplifier in this area. When analysing his interviews, he identified a possible amplifier, saying: "*we sometimes don't assess our learners to ask what they know"*. As seen with the other teachers, this realisation has acted as an amplifier and a filter. In the case of Mr Fakudze, it may have acted as an amplifier.

6.4 A Comparison of the Teachers' Post-intervention TSPCK

The interviews revealed that all teachers planned to make some changes to how they planned their lessons. Table 6.8 summarises some of the ways the teachers planned to change their teaching and the component it reflected.

Table 6.8

A summary of teachers' responses to the interview questions

Teacher	Response	PCK component
Mrs Zikalala	- Relate content to social and environmental issues	CS
	- Use problem-based learning	CTS
	- Assess students' prior knowledge	SU
	- Use inquiry-based and student-centred learning	CTS
Mrs Dlamini	- Assess students' prior knowledge	SU
	- Incorporate sustainability issues into topics	CS
	- Preparation of questions to assess students' thinking	SU
	- Use teaching methods that promote problem-solving	CTS
Mr Mavuso	- Use participatory learning, allow learners to share ideas and solve problems	CTS
	- Assess students' prior knowledge	SU
	- Discuss relevant issues in existing topics	CS
	- Use teaching strategies that promote meaningful learning	CTS
Mr Cele	- Use questioning that allows critical thinking and problem-solving	CTS
	- Incorporate relevant issues into topics	CS
	- Make the content relevant to real-life situations	CS

Teacher	Response	PCK component
Ms Dube	- Use participatory learning	CTS
	- Assess students' prior knowledge (said twice)	SU
	- Preparation of questions before the lesson	CTS
	- Discuss relevant issues	CS
	- Select teaching methods based on the strengths of learners	CTS
Mr Fakudze	- Incorporate sustainability issues into topics	CS
	- Assess students' prior knowledge (said twice)	SU

Although the participants focused on different aspects of the components of PCK, there were some common planned changes. Some of the most common changes that the participants anticipated making to the planning of their lessons were: incorporating relevant/sustainability issues into the lesson, using teaching strategies that promote problem-solving and participatory learning, and assessing students' prior knowledge. All these responses were not evident in the pre-intervention data; they only became evident after the teachers had undergone the PDI in the post-intervention data.

A teacher's post-intervention pPCK score was found by analysing their responses in both the post-intervention questionnaire and lesson plan. The post-questionnaire responses were analysed first and scored using the PCK rubric. This was followed by an analysis of the lesson plans that the teachers had created using the same rubric. The two scores were compared, and the better of the two scores was taken to be the post-intervention PCK of the teacher. In the tables above (Table 6.2, 6.3, 6.4, 6.5, 6.6, and 6.7), the outcome for each sub-component (component prompt) was shown. The averages for each component were then calculated to get scores for each PCK component. The researcher chose to use score averages rounded to one decimal place so that while comparing the pre- and post-PCK scores, even the slight changes to the teachers' PCK could be observed. Although most PCK studies have used whole numbers to represent pre- and post-PCK (Makhechane & Mavhunga, 2021; Mavhunga, 2019a), however, some have used decimals (Mazibe et al., 2020). Since the focus of this study was on the possible development of a teacher's pPCK after a PDI, any development, whether minimal or major, is important to the researcher. The use of whole numbers could conceal the fact that there was some development; therefore, averages to one decimal place were used. In this comparison only the PCK component scores for each participant are shown. A summary of the comparison of the teachers' post- intervention responses using the PCK rubric is given in Table 6.9 below.

Table 6.9

A comparison of the teachers' post-intervention responses per component

Component of PCK	Score					
	Mrs Zikalala	Mrs Dlamini	Mr Mavuso	Mr Cele	Ms Dube	Mr Fakudze
Curricular saliency	3.8	2.5	3.0	3.5	2.8	2.8
Conceptual teaching strategies	4.0	2.5	3.3	3.0	3.3	3.5
Student Understanding	3.3	2.7	2.7	2.0	2.7	2.3
Average post-PCK	3.7	2.6	3.0	2.8	2.9	2.9

The component referring to the knowledge and skills related to conceptual teaching strategies had the most teachers' highest PCK scores. Mrs Dlamini scored highest in the component of knowledge and skills related to students' understanding, and Mr Cele had his highest post-PCK score in knowledge and skills related to curricular saliency. Five of the six teachers had their lowest post-PCK score in the component of knowledge and skills related to student understanding, with Mrs Dlamini having her lowest score in knowledge and skills related to curricular saliency. Overall, Mrs Zikalala had the highest post-PCK score, and Mrs Dlamini had the lowest.

6.5 Chapter Summary

This chapter investigated the teachers' PCK after participating in a professional development intervention. The data was collected during and after the intervention through interviews, a post-intervention questionnaire and a lesson plan. During the interviews, teachers were asked if and how their lesson planning would be different in future and what they learnt from the PDI. The findings from each participant were first presented separately and then later compared in a summary table (Table 6.8), revealing three teaching aspects that the teachers were planning to change. These were; incorporating relevant/sustainability issues into the lesson, using teaching strategies that promote problem-solving and participatory learning, and assessing students' prior knowledge.

The PDI was considered a source of collective PCK (cPCK) as the content that made up the intervention was a combination of contributions from various professionals. Each teacher's post-intervention pPCK score was found by analysing their responses in both the post-intervention questionnaire and lesson plan. The PCK rubric was used to score these responses, and a pPCK score from the post-questionnaire and an ePCK score from the lesson plan was determined. According to the RCM (Carlson & Daehler, 2019), the level and quality of knowledge transfer between the cPCK, the pPCK, and the ePCK, depends on how amplifiers and filters act in the teachers' minds. These could be the learning context (Carlson & Daehler, 2019), a teacher's values, self-efficacy, commitment, emotions, knowledge, beliefs, micro-politics (Hong, 2010), enthusiasm (Sorge et al., 2019) and self-regulatory skills.

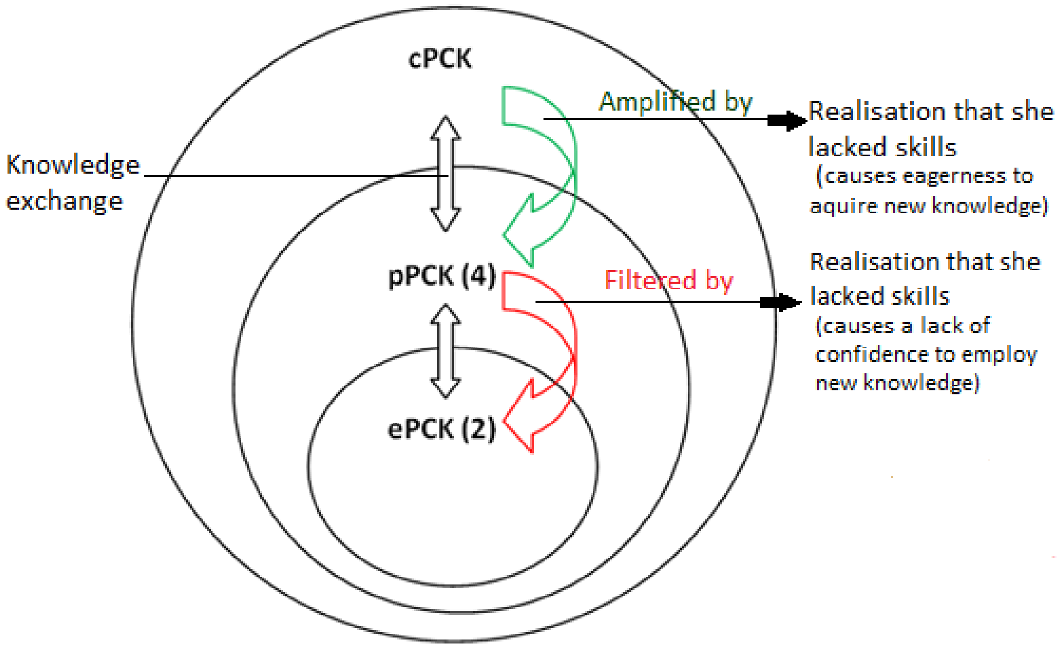
The final post PCK score was found by selecting the higher of the scores received from the questionnaire (pPCK) and the lesson plan (ePCK). This value can identify the post PCK of the teacher because ePCK is a subset of pPCK (Carlson & Daehler, 2019). The ePCK is used by a teacher when planning, teaching and reflecting on a lesson. During this enactment, the teacher only uses parts of the bigger realm of pPCK. This means that the ePCK makes up only part of the pPCK, just as the pPCK makes up only part of the cPCK. On further analysis of these two scores for each of the participants, there were three findings; the ePCK and pPCK scores were the same, the ePCK score was higher than the pPCK score, or the ePCK score was lower than the pPCK score.

If a teacher's ePCK and pPCK scores were the same, it could have meant that the teacher was able to draw sufficiently on their pPCK to demonstrate their ePCK. If a teacher had a higher ePCK than pPCK score, there is a possibility that some aspects of the teacher's pPCK were amplified in the ePCK since a teacher cannot enact a pPCK that they do not have. Mrs Zikalala, Mr Mavuso and Mr Fakudze were the only three participants who did not have instances where their ePCK was not fully demonstrated. Possible amplifiers for Mrs Zikalala could have been her beliefs about the nature of science content and her role as a teacher. Mr Mavuso's amplifier could have been a possible change in his teaching orientation from a more teacher-centred to a student-centred approach. Possible amplifiers for Mr Fakudze were not revealed to the researcher. Although three of the six participants had at least one incidence where the ePCK was lower than the pack, this did not mean they did not have instances where the ePCK was higher. Other possible amplifiers found were that of interest and commitment, from Mr Cele and knowledge of student attitudes, from Ms Dube. The cases of the teachers that displayed an ePCK that was either the same or higher than the pPCK were more frequent.

If a teacher had a lower ePCK score than the pPCK score, the teacher might have failed to draw on their pPCK to demonstrate their ePCK because of filters. As mentioned earlier, displaying a lower ePCK than pPCK could indicate the presence of filters. From Mrs Dlamini's responses, it was evident that her own learning experiences may have acted as a filter, as they may have affected how she views her responsibility as a teacher. In some cases, like Ms Dube, it was found that, in the area of representations, what acted as an amplifier for the transfer of knowledge from cPCK to pPCK, possibly acted instead as a filter for the transfer of knowledge from pPCK to ePCK. The presence of filters and amplifiers inform the PCK transitions between the three realms of PCK. Figure 6.28 illustrates how, in the case of Ms Dube's choice or representations, a factor that acted as an amplifier later acted as a filter.

Figure 6.28

Presence of filters and amplifiers informing transitions between the three realms of PCK



In other cases, such as Mrs Dlamini, Ms Dube and Mr Fakudze, there was the possibility of the same factor acting as an amplifier for one teacher and a filter for another. Lastly, it was found that a factor that acted as an amplifier for transfer of knowledge in one component of

PCK, acted as a filter in another component, for the same teacher. This was evident with Mr Fakudze and his focus on content delivery. It is worth noting that although filters and amplifiers inform knowledge transfer between the three realms of PCK, there were instances where the researcher could not identify filters and amplifiers from the interview responses.

To determine if there were any changes in the quality of the teacher's PCK about the topic, the researcher compared each of the teachers' pre-intervention PCK sores with their post-intervention PCK scores. This comparison was made to answer the fourth research question:

- How does a professional development intervention influence the development of an experienced chemistry teacher's topic-specific PCK of the extraction of metals?

Table 6.10 presents the pre- and post-PCK scores for all the participants concerning each PCK component. Each of the three components is divided into three columns, one for the pre-PDI score, one for the post-PDI score and the other to show the gain in PCK, if there was any. The last two columns also give person averages for both the pre-PDI and post-PDI scores. The average scores per component have also been included in the last row of the table.

Table 6.10

A summary of the shifts in the pre-post-PCK of the teachers

Component of PCK	Curricular saliency			Conceptual teaching strategies			Student Understanding			PERSON AVERAGE		
SCORE	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain
Mrs Zikalala	3.3	3.8	0.5	2.8	4.0	1.2	3.3	3.3	0.0	3.1	3.7	0.6
Mrs Dlamini	2.0	2.5	0.5	1.8	2.5	0.7	2.0	2.7	0.7	1.9	2.6	0.7
Mr Mavuso	2.5	3.0	0.5	2.0	3.3	1.3	1.7	2.7	1.0	2.3	3.0	0.7
Mr Cele	3.0	3.5	0.5	2.3	3.0	0.7	2.0	2.0	0.0	2.2	2.8	0.6
Ms Dube	2.8	2.8	0.0	2.0	3.3	1.3	2.3	2.7	0.4	2.4	2.9	0.5
Mr Fakudze	2.0	2.8	0.8	2.0	3.5	1.5	1.7	2.3	0.6	1.9	2.9	1.0
Average scores per component	2.6	3.0	0.4	2.1	3.3	1.2	2.1	2.6	0.5			

When comparing the pre- and post-PCK scores for the different PCK components, it was evident that three participants showed a positive gain in the quality of their PCK on all three components of PCK. Ms Dube, Mrs Zikalala and Mr Cele only showed changes on two of the three components. Ms Dube did not show any change in the quality of her PCK on curricular saliency of the topic, as both her pre- and post- score were 2.8. Mrs Zikalala did not show any change in the quality of her PCK on conceptual teaching strategies about the topic, as her score remained at 3.3. Mr Cele did not show any change in the quality of his PCK under the component related to student understanding. It can also be seen from Table 6.10 that five of the six teachers had pre-PDI scores that showed a basic PCK. Mrs Zikalala was an exception as she had a developing pre-PDI PCK score.

An increase observed between the pre- and post-intervention scores was evidence of PCK development. This indicates that the teacher was able to transfer knowledge from the cPCK, which was found in the intervention, to their own pPCK. The researcher knows that not all knowledge transfer can be attributed to the intervention. Since the intervention occurred during the COVID lockdown, when schools were closed, it is reasonable to assume that most of the PCK development could be attributed to the intervention as experiences such as teacher-teacher and student-teacher interactions were not possible at this time. The ability of a teacher to make this transfer of knowledge depends on amplifiers and filters. If a teacher showed an increase from the pre-PCK to the post-PCK, we could assume that there were amplifiers that allowed the teacher to draw on the cPCK and inform their own pPCK. If there was no increase that was observed between the pre- and post- intervention scores, this could have indicated that the teacher did not present evidence of PCK development. If the teachers' pre- and post- PCK were limited, this could have meant that when the teacher attempted to transfer knowledge from the cPCK to their own pPCK, the cPCK did not settle as pPCK because of the presence of filters. Another assumption would be that if the teacher's pre- and post- PCK were basic, the teacher did not find it necessary to present the information that would indicate a knowledge gain, which would be evidence of a lower level of PCK. If the teacher's pre- and post-PCK were developing or exemplary, perhaps the teachers existing PCK in that component seemed sufficient to the teacher and gave the teacher a reason to focus on other components in which they felt they were lacking.

The average PCK scores per component show that before the intervention, the participants had the highest average score in the component of curricular saliency. This component also had the lowest gain in the teacher's quality of PCK. The highest gain in the teacher's quality of PCK was on the conceptual teaching strategies of the topic, as their average pre-PDI scores were 2.1, and their average post-PDI score was 3.3. This finding was similar to Makhechane's (2021) findings concerning PGCE pre-service teachers.

The person averages, which are the overall pre-post-intervention scores, are also included in Table 6.9. From these person averages, it is evident that all participants showed an overall positive gain in their PCK's quality as a result of the intervention. This means that although in some instances participants failed to enact their pPCK in the lesson plan, all the teachers could draw on the cPCK, which was the intervention, and demonstrate their pPCK.

7 CHAPTER 7
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Overview

This chapter concludes my study by drawing on the findings reported in Chapters Four, Five and Six to answer the research questions that guided the study. The primary research question for this study was "How does a professional development intervention (PDI) influence experienced chemistry teachers' personal PCK about environmental sustainability, revealed through their planning of a lesson on the extraction of metals?"

This primary question was broken down into four secondary questions:

1. What are chemistry teachers' views about sustainability and education for sustainability?
2. What is the nature of personal topic-specific PCK about the extraction of metals with big ideas related to environmental sustainability, revealed in the teachers' planning prior to the PDI?
3. What is the nature of personal topic-specific PCK about the extraction of metals with big ideas related to environmental sustainability, revealed in the teachers' planning after the PDI?
4. How does a professional development intervention influence the development of an experienced chemistry teacher's topic-specific PCK on the extraction of metals?

The chapter starts with an overview of the purpose of the study. It follows with a discussion of the study's methodology and how it aligns with the framework used for this study. Each research question frames a section in this chapter, explaining how the data was collected and findings were used to answer that research question. The chapter then reflects on the methodology, using the grand rubric for PCK (Chan et al., 2019), using an online intervention and acknowledges the study's limitations. The study's findings are discussed and followed by the contributions that the study made in relation to these findings and the methodology and data analysis. The chapter ends with conclusions drawn from the data and suggestions for future research.

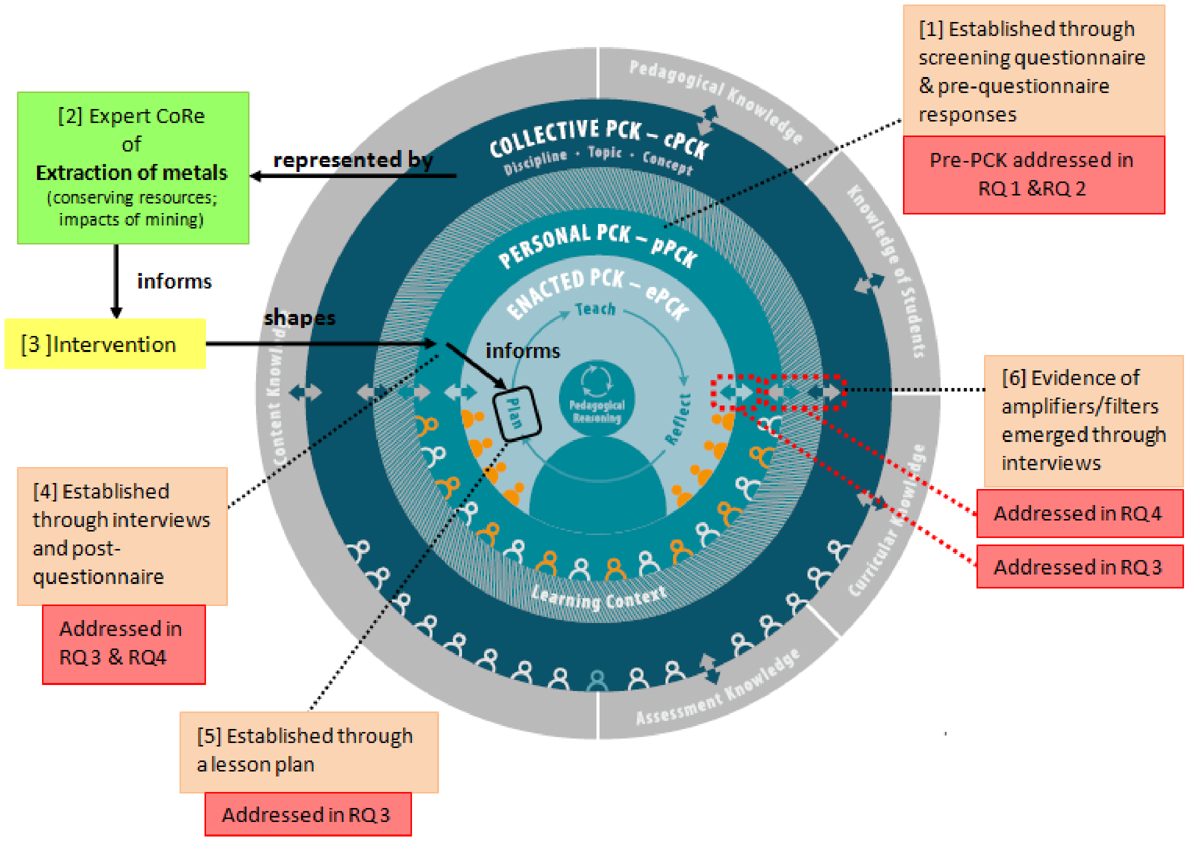
7.2 Summary

The study's main purpose was to explore chemistry teachers' personal and enacted PCK about the extraction of metals through teaching big ideas related to environmental sustainability before and after an online professional development intervention. Six chemistry teachers were purposively and conveniently selected as participants. The topic of the extraction of metals was primarily chosen because of the opportunities it provided, expressed as learning outcomes in the EGCSE physical science syllabus, for teachers to infuse big ideas related to environmental sustainability. These focus areas which informed the big ideas were: *the impact that mining has on the environment* and *the conservation of resources.*

The data collection for this qualitative study took place in three phases; before, during, and after an online intervention. Figure 7.1 shows how the research questions and data collection align with the study's conceptual framework, explained in Chapter 2. The personal PCK of the teachers before the online intervention was captured using the responses to the screening questionnaire (Appendix B) and a pre-professional development intervention (PDI) questionnaire (Appendix C). The responses from the screening questionnaire were discussed under Research Question 1, and the responses to the pre-PDI questionnaire were discussed under Research Question 2. The framework illustrates how the collective PCK, represented in the expert CoRe and model answers (Appendix I), informed the intervention (Appendix H) given to the six participating teachers. The researcher assumed that any development of the teachers' personal PCK was informed chiefly by the intervention because the schools were closed during the intervention due to the national COVID-19 lockdown. This meant that the participants had little to no interactions with either other teachers or students.

Figure 7.1

Diagram illustrating the alignment between the framework and research design



Interview protocols (Appendix E, F and G) were used to capture the teachers' personal PCK during and after the intervention. It was through these interviews that evidence of amplifiers and filters emerged. The amplifiers and filters that emerged during the knowledge transfer from the cPCK to pPCK were addressed under Research Question 4, and those that emerged during the knowledge transfer from the pPCK to ePCK were addressed under Research Question 3.

A post-PDI questionnaire was also used to capture the teachers' personal PCK after the intervention. These responses were discussed under Research Question 3. Although the initial hope for the study was for the researcher to observe the teachers as they enact their PCK, this was not possible as the schools were all closed. The researcher used a lesson plan template (Appendix L) to capture the teachers' enacted PCK during the planning phase of enactment.

The sequence of concentric circles in the framework symbolically situates one realm of PCK within another. This sequence illustrates the overlapping nature of the three realms of PCK, with each realm being a subsidiary of another. It shows that the three realms are co-dependent on each other, that ePCK is a subset of pPCK, and that pPCK is a subset of cPCK.

The data analysis used a validated PCK rubric (Appendix H) designed using the grand rubric for PCK (Chan et al., 2019). The components of PCK in the rubric used for this study were aligned to the CoRe prompts (Loughran et al., 2004), adapting them to elicit the knowledge of the PCK components. During the analysis, the researcher also referred to the expert CoRe of extraction of metals. These two instruments for analysis were developed to assess the quality of the participating teachers' PCK in the components of PCK. The components were as follows: skills and knowledge about curricular saliency, student thinking and conceptual teaching strategies in the topic. The scores given to the teachers for each component were averaged to get an overall PCK for each teacher.

7.3 Answering the Research Questions

As mentioned above, four secondary research questions were created to help answer the primary research question. The findings are summarised below.

7.3.1 Secondary Research Question 1

Secondary Research Question 1 was: *What are chemistry teachers' views about sustainability and education for sustainability?*

The teachers' views about sustainable development and education for sustainable development were assessed before the intervention through the screening questionnaire and after the intervention through interviews. Before the intervention, all the teachers agreed that sustainability issues were relevant to chemistry and that it was important for students to be taught about sustainability issues. The issues they considered relevant were preservation and restoration of the environment, renewable resources, fuels, pollution, extraction of metals, ozone depletion, climate change, conservation of natural resources and recycling. The issue raised most frequently by the teachers was the conservation of natural resources mentioned by four of the six participants. After the intervention, the teachers still agreed that sustainability was relevant to chemistry and it was important for students to learn about sustainability issues. When asked to name the issues that they considered relevant, the issues that were repeated, with four or five of the teachers mentioning them, were pollution, global warming and climate change. Notably, one of the participants, who had not mentioned any of these issues before the intervention, mentioned all three frequently mentioned issues, including conservation of resources, which was the most frequently raised issue before the intervention. Since the teachers were not at school and had no interactions with other teachers, the assumption is that the new knowledge revealed by the teacher was a result of the intervention. Sustainability issues revealed after the intervention, and not before, were those of acid rain, deforestation and biodiversity.

When asked which physical science topics could be used to address sustainability issues, most teachers mentioned the topic of 'metals'. After the intervention, in addition to the topic of 'metals', the topics of 'non-metals' and 'organic chemistry' were mentioned by four or five participants. Interestingly, the same teacher mentioned above, who had not given any response before the intervention regarding suitable physical science topics, mentioned all three of these frequently mentioned topics after the intervention.

Teachers revealed in the screening questionnaire that they had more uncertainties about ESD than SD. Three of the six participants were unsure whether ESD pedagogies were student centred, and two of the six were unsure whether ESD promotes participatory learning and higher order thinking skills. It seemed that the teachers were generally not informed about ESD and did not practice ESD in their teaching before the intervention. A reason for this general lack of information about ESD was that teachers had not paid attention to the aims of the EGCSE physical science curriculum made available to them at the beginning of every year by their administrators. This was revealed in some of the teacher's interview responses, where they admitted that syllabus coverage was their main focus.

In one of the post-intervention interviews, the researcher asked the teachers what they had learnt about ESD and how their lessons would be different moving forward. The most frequently mentioned response was that they would use teaching methods that promote problem-solving, critical thinking and participatory learning. These pedagogies are student centred and characteristic of ESD, and therefore show a gain in teacher's knowledge regarding ESD.

7.3.2 Secondary Research Question 2

Secondary Research Question 2 was: *What is the nature of personal topic-specific PCK about extraction of metals with big ideas related to environmental sustainability, revealed in the teachers' planning prior to the PDI?*

A pre-PDI questionnaire was given to the six teachers before the PDI took place. The responses to this questionnaire allowed the researcher to establish the level of teachers' personal PCK about the extraction of metals, through the teaching of big ideas related to environmental sustainability, before an online professional development intervention. The questions focused on obtaining information from the teachers about what they would consider when teaching lessons on “the extraction of metals” with a particular focus on *the environmental impact of mining* and *conserving resources*. All the questions from the Loughran et al.'s (2004) CoRe tool were modified to draw the teachers to these two sustainability issues, which were the big ideas. These big ideas allowed the teachers to incorporate sustainability into their reasoning and responses.

The PCK utilised a rubric to assess the quality of the teachers’ PCK using a four-point scale with scores of 1 for *limited*, 2 for *basic,* 3 for *developing* and 4 for *exemplary* (Park et al., 2011). It was found that all the teachers had a basic pre-PDI PCK, except for Mrs Zikakala who was found to have a developing PCK. When analysing their PCK per component, it was revealed that all the teachers had their highest scores in the component of knowledge and skills related to curricular saliency (CS). The one thing that these teachers had in common was that they were experienced teachers. It is possible that their experience with teaching chemistry and the topic of “the extraction of metals” in particular could be the reason for a high score in the component of CS. Mrs Zikalala, Mrs Dlamini and Ms Dube had their lowest scores in the component of conceptual teaching strategies, and Mr Mavuso, Mr Cele and Mr Fakudze had their lowest scores in the component of student understanding.

7.3.3 Secondary Research Question 3

Secondary Research Question 3 was: *What is the nature of personal topic-specific PCK about extraction of metals with big ideas related to environmental sustainability, revealed in the teachers’ planning after the PDI?*

This research question focused on transferring knowledge from the pPCK to the ePCK. The final post-intervention PCK score was found by selecting the higher of the scores received from the questionnaire (pPCK) and the lesson plan (ePCK). The post-intervention PCK of the teacher can be identified by this value because ePCK is a subset of pPCK (Carlson & Daehler, 2019). The ePCK is used by a teacher when planning, teaching and reflecting on a lesson. During this enactment, the teacher only uses parts of the bigger realm of pPCK. This means that the ePCK makes up only part of the pPCK. On analysis of these two scores for each participant, there were three findings; the ePCK and pPCK scores were the same, the ePCK score was higher than the pPCK score, or the ePCK score was lower than the pPCK score. The differences between the pPCK and ePCK showed the presence of amplifiers and filters in transferring knowledge between these two realms of PCK.

Mrs Zikalala, Mr Mavuso and Mr Fakudze were the only three participants who did not have instances where their ePCK was fully demonstrated. Possible amplifiers for Mrs Zikalala could have been her beliefs about the nature of science content and her role as a teacher. In her interview responses, she showed awareness of the abstract nature of scientific concepts and later stated that she believed it was her duty to make students aware of sustainability issues. Mr Mavuso's amplifier could have been a possible change in his teaching orientation from a more teacher-centred to a student-centred approach. Possible amplifiers for Mr Fakudze were not revealed to the researcher. Although three of the six participants had at least one incidence where the ePCK was lower than the pPCK, this did not mean they did not have instances where the ePCK was higher. Other possible amplifiers found were that of interest and commitment from Mr Cele, and knowledge of student attitudes from Ms Dube. The cases of the teachers that displayed an ePCK that was either the same or higher than the pPCK were more frequent.

From Mrs Dlamini's interview responses, it was evident that her own learning experiences may have acted as a filter, as they may have affected how she viewed her responsibility as a teacher. In some cases, like Ms Dube, it was found in the representations, what acted as an amplifier for transferring knowledge from cPCK to pPCK, possibly acted as a filter for the transferring knowledge from pPCK to ePCK. In other cases, such as Mrs Dlamini, Ms Dube and Mr Fakudze, there was the possibility of the same factor acting as an amplifier for one teacher and a filter for another. It is worth noting that although filters and amplifiers inform knowledge transfer between the two realms of PCK, pPCK and ePCK, there were instances where the researcher could not infer possible filters and amplifiers from the interview responses.

Possible amplifiers revealed from the teachers' interview responses were their awareness of the abstract nature of scientific content, the realisation that they lacked knowledge in some areas, awareness or new knowledge on different types of teaching strategies, and focusing on content delivery. Possible filters revealed were beliefs that students should be independent researchers, assumptions that students already know the content, lack of confidence to employ new knowledge, lack of experience and focusing on content delivery. Three possible scenarios were found regarding how amplifiers and filters affect knowledge transfer from one realm of PCK to another. Firstly, a factor that acted as a filter for one teacher may have acted as an amplifier for another teacher, or vice versa. This was seen with Ms Dube and Mrs Dlamini and their lack of experience in using questioning to assess students' prior knowledge. Secondly, a factor that acted as an amplifier for transferring knowledge from cPCK to pPCK, could also act as a filter for transferring knowledge from pPCK to ePCK. This was evident with Ms Dube, where her realisation that she lacked knowledge on teaching methods and representations that would keep her students interested acted as an amplifier in her transfer of knowledge from cPCK to pPCK. This same realisation could have caused a lack of confidence to employ the new knowledge gained as she displayed an ePCK that scored lower than her pPCK. Lastly, it was found that a factor that acted as an amplifier for transferring knowledge in one component of PCK acted as a filter in another component. This was evident with Mr Fakudze and his focus on content delivery.

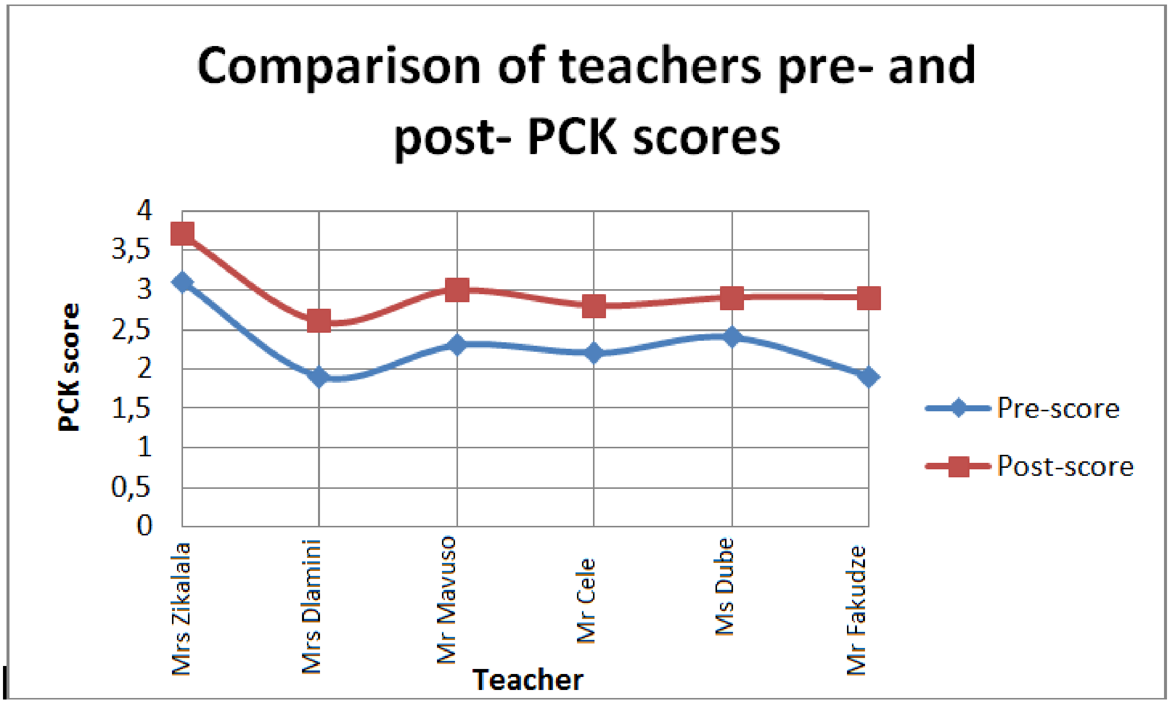
7.3.4 Secondary Research Question 4

Secondary Research Question 4 was: *How does a professional development intervention influence the development of an experienced chemistry teacher's topic-specific PCK on the extraction of metals?*

This research question focused on transferring knowledge from the cPCK to the pPCK. In this study, the cPCK was represented by the intervention. From the person averages, it is evident that all participants showed an overall positive gain in the quality of their pPCK as a result of the intervention. This means that all the teachers were able to draw on the cPCK and demonstrate their pPCK. Figure 7.2 summarises the difference between the teacher's pre-intervention PCK score and post-intervention PCK score. These scores are the overall PCK scores, with all PCK components included.

Figure 7.2

Comparison of teacher's pre- and post-intervention PCK scores



According to the RCM, science learning takes place within a context, and this context can serve as an amplifier or filter to the transfer of knowledge between these two realms. It is worth reminding the reader that during this intervention, the learning context for these teachers was not typical. The teachers were at home, due to the COVID-19 lockdown, with no exposure to students or other teachers.

From the interview responses, it was found that all the teachers believed that it was important for students to learn about sustainability and even gave reasons. They also agreed on the key role they needed to play in the implementation of ESD and that teacher's needed professional development on how to incorporate sustainability into their teaching. These views could have acted as amplifiers for the teachers as they show their beliefs about the purpose of teaching. Another amplifier could have been the flexibility of the online intervention, as five participants mentioned in interview responses that they could go through the intervention at their own pace when it was most convenient for them. When comparing the pre- and post-intervention scores for the different PCK components, it was evident that three participants showed a positive gain in the quality of their PCK on all three components of PCK. Ms Dube, Mrs Zikalala and Mr Cele only showed an improvement in two of the three components. An increase observed between the pre- and post-intervention scores was evidence of PCK development.

Before the intervention, the participants had the highest average score in the component of curricular saliency. This component also had the lowest gain in the teacher's quality of PCK. The highest gain in the teachers' quality of PCK was on the conceptual teaching strategies of the topic.

7.4 Discussion of the Study's Findings

As mentioned earlier, the study aimed to explore experienced chemistry teachers PCK of environmental sustainability, before and after an online intervention, when teaching about extraction of metals. The quality of the participating teachers' PCK was assessed using the components of PCK: skills and knowledge related to curricular saliency, student thinking and conceptual teaching strategies about the extraction of metals with particular focus on conserving resources and the impacts of mining. The simultaneous teaching of the topic of extraction of metals and environmental sustainability requires teachers' knowledge of the components of PCK about this topic and the concept of ESD. Although the teachers agreed that sustainability issues were relevant to chemistry and that it was important for students to be taught about sustainability issues, the findings show that the teachers had uncertainties about ESD before the intervention. This meant that the foundation for developing their PCK about environmental sustainability was not solid. These uncertainties also affected how they planned and conducted a lesson (Magnusson et al., 1999). After the intervention, the participants revealed through interviews why teachers were the key agents in the implementation of ESD and that ESD requires teaching methods that promote problem-solving, critical thinking and participatory learning. According to Burmeister and Eilks (2013), a positive attitude, knowledge of content, and suitable teaching strategies are requirements for infusing SD into teaching.

The study focused on how chemistry teachers reveal their PCK about environmental sustainability when preparing to plan a lesson on the extraction of metals. Their preparation for the planning was revealed in their responses to questionnaires and interviews, as these questions solicited information on how they would plan their lesson. The final outcome of everything that was done, the intervention, the questionnaire and the interviews, was the planning of a lesson. They revealed their PCK through various instruments in this process.

The teachers' pre- and post-intervention PCK were found to establish the extent to which they could transfer knowledge from the PDI to their pPCK. It was found that before the intervention, the teacher's knowledge of curricular saliency was better than their knowledge of conceptual teaching strategies and student understanding. This finding was similar to Makhechane's (2021) findings with PGCE pre-service teachers. This meant that the teachers had better knowledge about the important concepts that needed to be taught, the pre-concepts needed by the students to understand the new concept, the concept itself and how the concept could be sequenced in relation to other concepts.

The study found that the quality of the teacher's PCK improved after the intervention for all the teachers. This showed that the experienced teachers could draw on the knowledge they were exposed to in the intervention, which was based on collective PCK, to develop their pPCK and ePCK. Although there was a general increase in the overall PCK of the chemistry teachers, the study showed a varying increase in PCK development amongst the teachers. Similarly, Mavhunga (2019a) found that the improvement of pre-service teachers' PCK varied despite exposure to the same intervention.

The study also showed that some teachers had poor transferring of knowledge from their pPCK to their ePCK as they could not sufficiently draw on their pPCK to demonstrate their ePCK fully. Mazibe et al. (2018) had similar findings when comparing teachers' reported PCK and enacted PCK. According to Shulman (1987), before a teacher enacts a lesson, a reasoning process must occur. This process allows the teacher to make decisions about how the content will be delivered based on their knowledge bases. Pedagogical reasoning, therefore, drives the transfer of knowledge from pPCK to ePCK and can also be influenced by factors such as teachers' beliefs, context and affective factors (Mavhunga, 2019b). These factors are referred to as amplifiers and filters in the RCM (Carlson & Daehler, 2019). Possible amplifiers or filters include a teacher's values, self-efficacy, commitment, emotions, knowledge, beliefs, and micro-politics (Hong, 2010). An amplifier that was identified by Mavhunga and van der Merwe (2020) when investigating the translation of ePCK in the planning stage ($ePCK_p$) to ePCK in the teaching stage was teachers reflections, particularly reflection-for-action. Since these are unique to a teacher, the implication for PCK development is that it is individualised

There was also varying improvement across the PCK components. Similar to the findings of Pitjeng-Mosabala and Rollnick (2018), in this study the component of curricular saliency had the lowest gain in the teacher's quality of PCK. Most knowledge transfer from the PDI to the teacher's pPCK occurred in the component of conceptual teaching strategies. This finding was similar to that of Mavhunga and Rollnick (2013) in a study with pre-service teachers as well as that of Pitjeng-Mosabala and Rollnick (2018) in their study with 14 novice uncertified graduate science teachers. The assumption for this study was that the teachers may not have had much exposure to other sources that could influence their PCK development because the intervention was during the lockdown. This assumption meant that the knowledge they gained could have come solely from the intervention to which they were exposed.

7.5 New Knowledge Contributions to the Study

The study contributed to the field of PCK by providing evidence that it is possible to develop the pPCK and ePCK of chemistry teachers. This study focused on experienced chemistry teachers. In this study, an experienced teacher has been teaching for more than six years. Most previous studies that focused on PCK development investigated pre-service or novice science teachers. This study also used an online professional development intervention, whereas most previous studies have used face-to-face in-person interventions. This study, therefore, demonstrated that it is possible to use an online PCK-based intervention to develop the PCK of experienced chemistry teachers.

The study investigated how the teachers used the knowledge they gained from the PDI to inform their personal PCK. It also looked at how the teachers transferred knowledge from their pPCK to ePCK. The study showed that although all teachers' PCK developed, their PCK did not develop at the same level, as some teachers' PCK developed more than others, and some components developed more than others. It was also found that not all teachers could draw on their pPCK to demonstrate their ePCK. The researcher interpreted these differences based on the presence of filters and amplifiers which inform the transfer of knowledge from the cPCK to the pPCK and later from the pPCK to ePCK. This finding was in line with the RCM (Carlson & Daehler, 2019), which was the conceptual framework of this study.

Another contribution is that, as far as I could establish, this is the only study that explores science teachers' PCK about environmental sustainability using the chemistry syllabus topic "extraction of metals". In doing so, the study contributed an expert CoRe (Appendix I) of the extraction of metals with big ideas related to environmental sustainability. Since the expert CoRe was a contribution from teachers and experts in the field, it represents the collective

PCK. The content in the expert CoRe is an extensive yet not exhaustive representation of knowledge about teaching this topic.

In addition to the expert CoRe, a validated PCK rubric (Appendix H) was another contribution made by this study. The PCK rubric was designed to score the teachers' responses to the pre- and post-PDI questionnaire and later adapted to score the teachers' responses to the lesson plan they had created. The responses were repeatedly co-rated by three coders, leading to a revision of the level descriptors until there was consensus among the coders that the knowledge displayed by the teachers was in line with the level indicated.

7.6 Reflections on the Research Design and its Limitations

7.6.1 Reflection on Methodology

This section reflects on some aspects of the methodology, particularly the questionnaire used for data collection.

The CoRe-prompts (Loughran et al., 2004) were modified to design questions that were more specific and draw the participants' focus to the topic of the extraction of metals and the corresponding big ideas. The big ideas were predetermined by the researcher and taken from outcomes six and seven under the topic of the extraction of metals in the Physical Science EGCSE syllabus. These big ideas; *conserving resources* and *the environmental impact of mining*, were seen throughout the questionnaire.

Although most of the questions focused on the big ideas, the questions at the beginning of the questionnaire referred to the extraction of metals. The researcher realised that to come up with a good expert CoRe, all the questions should be directly related to the big ideas. The researcher separated these questions from the rest of the expert CoRe (Appendix I).

When analysing the questionnaire, the researcher found that some questions were not adequately addressed. For example, when teachers were prompted for reasons after a question, they did not respond. This was common for the questions about students' misconceptions and learning difficulties. This could suggest that the participants were not used to being asked to think about these types of issues before and therefore were unable to reveal their professional knowledge.

Another observation made by the researcher was related to how the teachers structured their questions. In response to the prompt, "What questions would you use to access students' thinking and understanding?” teachers did not structure their questions well. According to the framework for lesson planning proposed by Geddis and Wood (1997), questions should be accompanied by expected answers. The researcher, therefore, believes that if a similar study is conducted where teachers are required to list questions, the teacher should also explicitly be requested to provide the expected responses. This approach would help the teacher to structure good questions.

On completion of the pre-PDI questionnaire, the teachers were exposed to the intervention. The researcher later realised that an interview after reviewing the teachers’ responses to the pre-PDI questionnaire would have given the researcher more information and depth into understanding the teachers' initial PCK about environmental sustainability. It could also be a suggestion for future similar studies that interviews should be conducted after questionnaires to elicit further information on the responses.

7.6.2 Reflection on Working with the Grand Rubric

The grand rubric for measuring science teachers’ PCK is a tool proposed by Chan et al. (2019) to measure the different realms of PCK proposed by the Refined Consensus Model (RCM). Since the rubric is generic, it needs to be customised to best suit a specific study. In this study, the tool was customised to create a PCK rubric (Appendix H) that would be used to analyse data that was collected using a questionnaire and later a lesson plan. In the process of customising the rubric, some aspects of the rubric were maintained, and others were altered.

The rubric suggests several data sources for each component of PCK across the three realms proposed by the RCM. For this study, some of the data sources proposed by the rubric were maintained as a pre- and post-professional development intervention (PDI) questionnaire. Interviews and a lesson plan template were used to capture the six participating chemistry teachers’ pPCK and ePCK. The rubric also suggests that there should be performance levels. Although the grand rubric does not specify the number of levels, in this study, the PCK component prompts were rated using a four-point scale with scores 1 for limited, 2 for basic, 3 for developing and 4 for exemplary (Park et al., 2011).

The main aspect of the altered grand rubric was the number of components assessed. The grand rubric suggests five PCK components, yet the PCK rubric used in this study only focused on three: knowledge and skills related to curricular saliency, knowledge and skills related to conceptual teaching strategies and knowledge and skills related to student understanding of science. Since the researcher could not observe the lessons, the study focused on the teachers' pPCK and ePCK during the planning phase of teaching. Therefore, the component that deals with the integration between PCK components was not included. Although the researchers who proposed the grand rubric believed that pedagogical reasoning takes place during the manifestations of all other components, they positioned the PCK component of pedagogical reasoning as a standalone component. During the construction of the PCK rubric used in this study, the researcher opted to incorporate pedagogical reasoning into its respective components. This meant that the rubric level indicators catered for pedagogical reasoning within each of the other three components that were part of the rubric.

7.6.3 Reflection on Using an Online Intervention

The professional development intervention comprised four 15-20 minute online training sessions. The sessions were in the form of narrated PowerPoint presentations which were sent to the participants via email. Since schools were closed due to the COVID-19 pandemic lockdown and teachers were at home, the researcher was aware that the issue of network connections would be a significant challenge. It is worth noting that although most areas in Eswatini have network connections, the signal is poor, and data bundles are expensive. For this reason, the researcher opted not to deliver the intervention using real-time face-to-face methods like Google meet and Zoom, as these would require a robust, stable internet connection and a large amount of data. Although the researcher attempted to make the intervention delivery easier via email, the size of the presentations became a challenge when internet connections were poor. At some point during the intervention, four of the six teachers mentioned internet issues, and two of the six participants experienced problems during the cell phone interviews because of a bad connection, as their homes were in rural areas.

Three teachers had another challenge: an online intervention needs discipline and good time management skills. The teachers had to find time to check the email, download the presentation and then watch it. Despite this challenge, four of the six teachers found the method of delivery to be an advantage as they believed that once they had downloaded the presentation, they could watch it in their own time, at their own pace and even rewind if there was something they had missed. Another advantage mentioned by the teachers was that the intervention was cost-effective in terms of cutting costs for transport and food, as these were necessary when attending face-to-face interventions or workshops.

7.6.4 Limitations of the Study

Despite the appropriate research design and data collection methods, the nature of educational research means there will always be limitations. It is essential that these limitations are reported and acknowledged (Yin, 2018). For this qualitative research, two limitations should be taken into account. Firstly, the study constituted a total of six chemistry teachers. Although the small sample size of the teachers was chosen to get rich, in-depth data (Maree, 2007), this sample size limits the generalisability of the findings. Secondly, the study focused on the development of ePCK in the planning for a specific topic. This approach meant that it excluded the other aspects of ePCK, namely the actual teaching and the reflection. Although the researcher intended to explore the teachers' ePCK during the teaching of a lesson on the impacts of mining, this was not possible. The study had to be changed because the COVID-19 pandemic resulted in the closure of schools and restrictions surrounding the ease and safety of face-to-face interactions. This inability to observe teachers to determine whether the lesson plan they created would be enacted in the lesson became a limitation to the study. This resulted in the data from the lesson plan being the only source of the teachers' ePCK.

7.7 Recommendations and Suggestions for Future Work

I offer several recommendations concerning the professional development of experienced in-service teachers. The COVID-19 pandemic has shown us that teachers must be able to adapt to what is happening in the world and that teaching is not confined to a classroom. Teaching is changing; therefore, experienced teachers must be kept up to date with new developments in their profession, and innovative ways of exposing them to new ways of teaching must be found.

The first two recommendations are for in-service teacher development programmes. The findings from this study showed that using an online intervention can develop experienced teachers' PCK. The intervention need not be in synchronous online form because of issues of network connections and expensive data bundles. The intervention can be emailed to one teacher, who can share the information. The teachers can then have discussions with their peers and share practices.

Also, a focus on lesson planning, where the teachers are given a detailed questionnaire or lesson plan template, could be an innovative way for in-service departments to investigate teaching and learning. Again these instruments could be sent via email or the questionnaire could be sent as a Google form. This would inform the aspects of teaching that they need to focus on during their professional development interventions.

Another recommendation is for policy changes within schools and the Department of Education to support teacher development. Several studies have shown a link between a teacher's PCK about a concept and learner outcomes (Gess-Newsome et al., 2019). Therefore, professional development opportunities are necessary for teachers if schools want to enhance student learning and performance.

The final recommendation is for teacher education institutions. There is a need for research on the PCK of both novice and experienced teachers as this would help to gain insight into the PCK for teaching different topics or concepts in science. These findings could inform teacher educators and be used to support teacher preparation programmes.

This study only investigated the development of PCK in experienced chemistry teachers. Additional research on the PCK about the environmental sustainability of novice teachers would create a continuum of teacher knowledge and practice. Understanding this continuum from novice to experienced teacher would provide better information to support the development of teachers' PCK for pre-service and in-service teachers.

Also, research in the area of PCK about environmental sustainability is minimal. Research in this area needs to be extended to include other topics revealed by the teachers in this study that have opportunities to infuse sustainability issues.

The study showed that teachers have instances where there is a poor transfer of knowledge from their pPCK to the ePCK. Although the researcher's interpretations of these observed differences were based on the presence of filters and amplifiers between the three realms of PCK, this interpretation is inconclusive. Even though I do not have final answers, I do hope to alert researchers to issues that may be investigated. There is a need for research in this area to uncover the underlying factors that influence PCK development.

Other suggestions for future work emerged during the reflection on methodology. The first was that if teachers are prompted to give questions, the teacher should also provide the expected responses. This would help the teacher to structure good questions. Also, when a questionnaire is given out to participants, it is best to follow up with an interview to elicit further information about the responses. This would also help in cases where there are questions with no responses. Lastly, when tracking the development of PCK from the pPCK to ePCK, I suggest that all aspects of ePCK, teaching, planning and reflection should be investigated. This will provide more information sources when looking for evidence of amplifiers and filters.

7.8 Concluding Remarks

This study aimed to explore experienced chemistry teachers PCK of environmental sustainability, before and after an online intervention, when teaching about extraction of metals. The findings of this study revealed that the online professional development intervention enhanced the quality of the teachers' PCK about environmental sustainability through the planning of lessons on the topic of extraction of metals. The study showed that although all teachers' PCK improved, the PCK did not develop at the same pace or to the same level, despite being exposed to the same intervention. The differences in PCK development were attributed to the presence of amplifiers and filters that inform the transfer of knowledge between the three realms of PCK: collective, personal and enacted PCK. These results provide empirical evidence that supports the idea that the presence of amplifiers and filters inform the PCK transitions between the three realms of PCK.

This study explored the PCK of experienced chemistry teachers. An experienced teacher is not necessarily an expert teacher, and this was confirmed in this study when two of the six participants revealed in different data sources, at different times, that they had the misconception that "trees" or "firewood" is a non-renewable resource. Also, experience does not always ensure the development of PCK for chemistry teaching.

As an experienced chemistry teacher myself, I was able to view chemistry teachers through the eyes of a researcher rather than a practitioner. Through conducting this study, I gained a clearer understanding of the unique knowledge held by a teacher as identified by Shulman (1987) and consider ways that the findings of this study can inform and support in-service teachers. I plan to continue researching to contribute to in-service teachers' PCK development.

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8 Appendices

8.1 Appendix A- Excerpt from the EGCSE Physical Science 6888 Syllabus (2021-2023) pertaining to the topic on metals

C11.0 Metals
C11.1 Properties All learners should be able to: compare the general physical and chemical properties of metals with those of non-metals
C11.2 Reactivity series 1. place in order of reactivity: calcium, aluminium, copper, (hydrogen), iron, magnesium, potassium, sodium, zinc and gold by reference to their reactions, if any, with aqueous ions of other metals, reaction with: water, steam and dilute hydrochloric acid 2. account for the apparent unreactivity of aluminium in terms of the oxide layer adhering to the metal 3. deduce an order of reactivity from a given set of experimental results 4. design experiments to investigate the order of reactivity of metals
C11.3 Extraction of metals 1. describe the ease in obtaining metals from their ores by relating the elements to the reactivity series. 2. name metals that occur native including copper and gold 3. name the main ores of aluminium, copper and iron 4. describe the essential reactions in the extraction of iron in the Blast Furnace 5. outline the manufacture of aluminium from pure aluminium oxide using electrolysis 6. describe the importance of conserving resources 7. describe the environmental impact of the mining and extraction of metals on vegetation, human beings and animals
C11.4 Uses of metals 1. define an alloy 2. state the composition of elements in the following alloys: brass, bronze, mild steel and stainless steel 3. draw the structural diagrams to show how atoms of other elements can change the properties of the main element in an alloy 4. explain why alloying affects the properties of metals 5. state the important uses of alloys: brass, bronze, mild steel and stainless steel 6. state the uses of aluminium (electrical cables, aircraft bodies and food containers), and copper (electrical wiring, cooking utensils) related to their properties 7. state the uses of zinc for galvanising and making brass

8.2 Appendix B - Screening Questionnaire

QUESTIONNAIRE

Welcome to a study exploring experienced chemistry teachers' pedagogical content knowledge (PCK) about environmental sustainability. This questionnaire seeks to investigate chemistry teachers' attitudes, knowledge and skills about environmental sustainability.

Section A – *Background information*

Tick appropriate box [√]

Gender: [ ] Male [ ] Female

Qualification: [ ] STD [ ] BEd. [ ] BSc. [ ] BSc. + PGCE [ ] Other ....

Years of teaching: [ ] ≤ 2 [ ] 3-5 [ ] 6-15 [ ] ≥ 16

Teaching subject(s):[ ] Chemistry [ ] Biology [ ] Physics [ ] Maths [ ] Science

[ ] Other : ....

Section B – *Knowledge of ESD*

a) i)This section will determine the sustainability issues which you consider relevant to your teaching. Please indicate whether you agree or disagree with each of the following statements.

According to my understanding sustainable development advocates for:		Strongly agree	Agree	Not sure	Disagree	Strongly disagree
1	Maintenance of biodiversity					
2	Conservation of natural resources					
3	Alleviating poverty					
4	Recycling of waste products					
5	Balance between use and regeneration of renewable resources					
6	Transparency and accountability in government decision making					
7	A higher quality of life for all people					

According to my understanding sustainable development advocates for:		Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
8	Resilience to climate change and its impacts					
9	Full participation of women					
10	Responsible consumption and production patterns					
11	Preservation and restoration of the environment					
12	Protecting and promoting human health					

ii)

According to my understanding education for sustainable development:		Strongly agree	Agree	Not sure	Disagree	Strongly disagree
1	Includes all three spheres of sustainability- economy, environment and society					
2	Incorporates principles, perspectives and values related to sustainability					
3	Engages formal, non-formal and informal education					
4	Integrates critical issues into the curriculum					
5	Is locally relevant and culturally appropriate					
6	Is interdisciplinary					
7	Is student - centred					
8	Uses pedagogies that promote participatory learning and higher order thinking skills					

b) i) Do you think sustainability issues are relevant to the subject you teach?

[ ] Yes [ ] No [ ] Not sure

ii) Which sustainability issues do you consider to be relevant to Chemistry teaching?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

iii) Which of the sustainability issues mentioned above have you included in your teaching in the past?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

iv) Which Physical science topics afford opportunities to teach the idea of sustainability?

1. Particulate nature of matter [ ]
2. Elements compounds and mixtures [ ]
3. Experimental techniques [ ]
4. Physical and chemical change [ ]
5. The Periodic table [ ]
6. Atomic structure and bonding [ ]
7. Stoichiometry [ ]
8. Chemical reactions [ ]
9. Acids, bases and salts [ ]
10. Metals [ ]
11. Electricity and chemistry [ ]
12. Non-metals [ ]
13. Organic chemistry [ ]

vi) Which of these Physical science topics have you used to address sustainability issues?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

v) Do you think it is important for students to learn about sustainability and related issues? Why?

....

....

....

....

....

Section C

1. Are you teaching Form 4 this year (2019)?

   ....

2. Which topics from the syllabus have you covered to date? (You may refer to the numbers in the list in b (iv) above).

....

Will you continue with this group in 2020 or will another teacher be allocated to the class?

....

3. In which month of 2020 do you hope to be starting on topic 10 about 'Metals'

....

4. Would you be willing to allow your lessons on the topic on metals to be observed? If yes, may I have your email address and cellular phone number.

....

Email:

....

Contact: ....

Thank You!!!

8.3 Appendix C – Pre-PDI Questionnaire

QUESTIONNAIRE

Thank you for your willingness to partake in this study. Your input has been important in helping me understand how the topic is taught.

This study intends to explore how teachers plan and teach their lessons on the topic 'Extraction of metals'.

The learning outcomes for this topic as suggested by the EGCSE Physical science 6888 curriculum for examination in 2021-2023, p13-14, are as follows:

1. Describe the ease in obtaining metals from their ores by relating the elements to the reactivity series.
2. Name metals that occur native including copper and gold.
3. Name the main ores of aluminium, copper and iron.
4. Describe the essential reactions in the extraction of iron in the Blast Furnace.
5. Outline the manufacture of aluminium from pure aluminium oxide using electrolysis.
6. Describe the importance of conserving resources.
7. Describe the environmental impact of the mining and extraction of metals on vegetation, human beings and animals.

Please read the questions and answer by typing your response after each question, in a different colour.

1(a) Name the four most important concepts you would address when teaching "extraction of metals". Name them in the sequence you would teach them.

(b) What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?

2. In the EGCSE curriculum, environmental issues are included (See outcome 6 and 7 above). Do you agree with this inclusion and why?

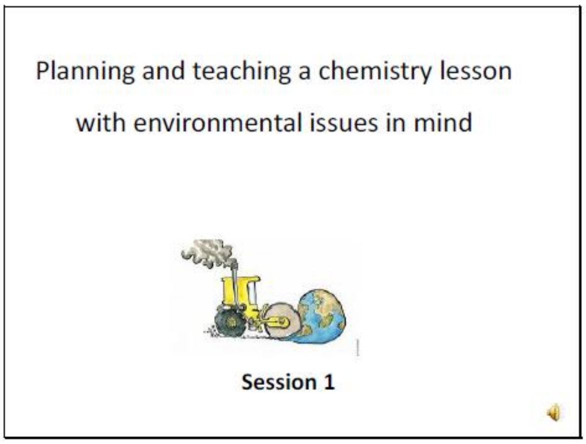
3(a) What teaching strategies would you use to teach *conserving resources*? Why?

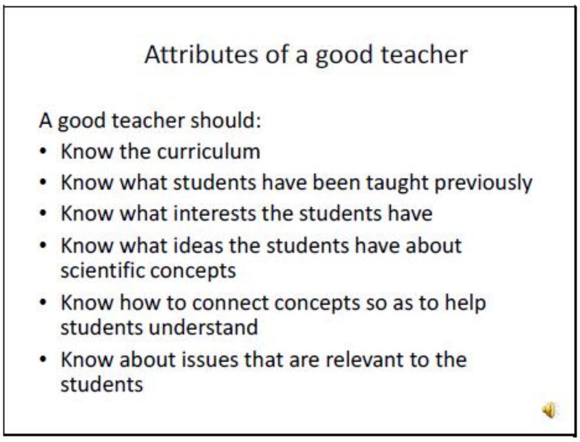
(b) What teaching strategies would you use to teach *the environmental impact of mining*? Why?

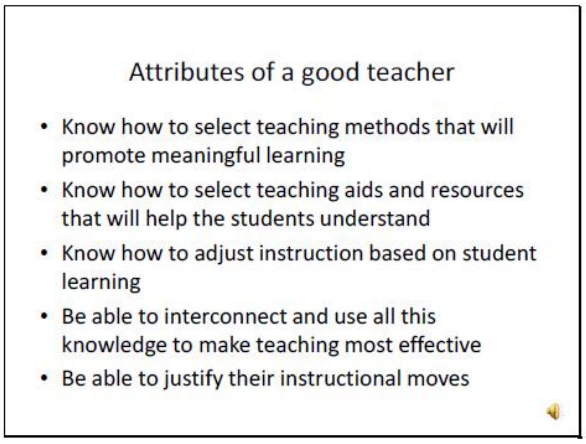
4. What questions, related to environmental sustainability, would you consider important to ask your learners during your teaching? Think of questions aimed at conceptual development and reasoning.

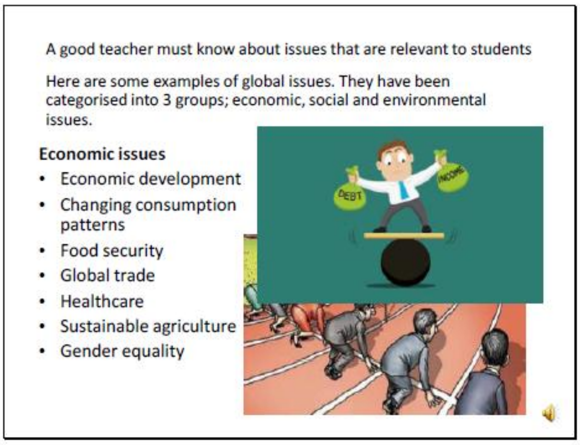
5(a)	What representations (analogies, examples, diagrams, etc.) would you use during your teaching *conserving resources*? Why? How?
(b)	What representations would you use during your teaching *the environmental impact of mining*? Why? How?
6(a)	What do you consider difficult about teaching *conserving resources*? Why?
(b)	What do you consider difficult about teaching *the environmental impact of mining*? Why?
7.	What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environmen*t?
8(a)	What questions would you use to access student thinking and understanding about *conserving resources* and *the impact that mining has on the environment*?
(b)	What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?
9.	Why is it important for students to know about conserving resources and the impact that mining has on the environment?

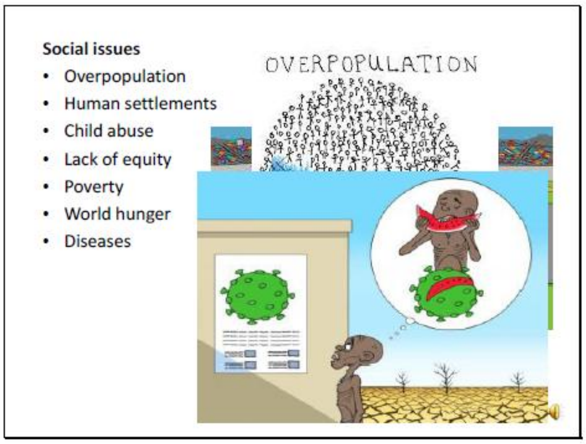
8.4 Appendix D– Professional Development Intervention Slides

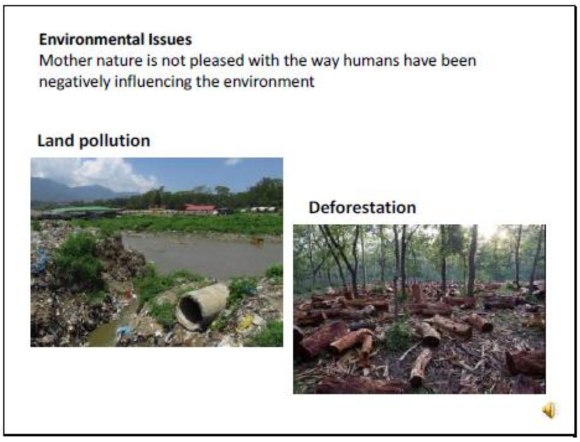












Global warming/ Climate change

Burning of fossil fuels has led to global warming.

Global warming is causing climate change and an increase in natural disasters.

Storms **Droughts** **Floods** **Wildfires**

Air pollution

Acid rain

Mining for resources has a number of environmental impacts

Loss of habitats/loss of biodiversity

Land degradation

Acid water pollution

What can be done?

We need to become **responsible citizens** and make better choices

- Stop deforestation
- Stricter government regulations
- Nature reserves
- Reduce waste production
- Refrain from use of non-renewable resources
- Alternative energy sources
- Educate and create awareness

We are teachers so education is our business! We are the ones responsible for creating an awareness.

- The United Nations (UN) has encouraged its member states, including Eswatini, to incorporate social, economic and environmental issues into their formal education systems.
- Inclusion of these issues into teaching is part of Education for Sustainable Development (ESD)
- ESD enhances the quality of education by making it more relevant to the learners
- A good **quality education** provides all learners with capabilities they **require** to become:
  - economically productive,
  - develop sustainable livelihoods,
  - contribute to peaceful and democratic societies, and
  - enhance individual well-being

- **ESD** stands for **E**ducation for **S**ustainable **D**evelopment
- It is based on the principles and values that underlie sustainable development (SD)
- Sustainable development is the idea that humans must live and meet their needs without compromising the ability of future generations to meet their own needs
- According to UNESCO, ESD is the process of ***learning how*** to make decisions that consider the long-term futures of the economy, the environment, and the society
- ESD makes education more relevant as it focuses on issues that affect people, their environment and their future.
- It also enables people to predict and respond to the challenges that life faces on our planet.

As teachers, our role is to:

- Create an awareness amongst our students about the issues that affect them, their environment and their future
- Help students develop skills such as critical thinking and problem solving

To do this:

- Teachers need to know about the perspectives, values, skills and issues of sustainable development
- Teachers need to know the characteristics of ESD
- Teachers need to know how to incorporate ESD into their teaching

---

- Did you find yourself wanting to know more after this session?
- Would you like to continue with me, onto the second session in this series?
- The second session will look at sustainable development, the characteristics of ESD and how you can incorporate environmental issues into your planning and teaching of chemistry.

Planning and teaching a chemistry lesson with environmental issues in mind

Session 2

Recap of session 1

- Attributes of a good teacher
- Global issues that are relevant to students
- Education for sustainable development
- Role of the teacher

Sustainable Development

- **Development that improves the living conditions of the present generation without compromising the resources of future generations**
- Development is NOT sustainable when we use all our resources now, leaving future generations with nothing
- UN member states drew up a document with a series of goals to help guide global efforts to ensure that people live better without damaging the planet
- These goals are known as the sustainable development goals (SDGs)

These are the 17 SDGs that the world hopes to achieve by 2030

Education holds a key position within each of these 17 goals
Goal number 4 is of utmost importance to us as educators
To achieve this goal teachers need to become advocates of sustainable development

What is ESD?

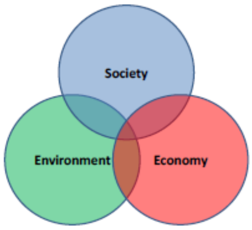
ESD is about teaching our students how to respect:

- Themselves
- Each other
- Future generations
- The planet we live on

Teachers are the cornerstones for effective implementation of ESD

Characteristics of ESD

- based on the principles and values that underlie sustainable development;
- includes all three spheres of sustainability



– with an underlying dimension of culture

Characteristics of ESD

- promotes participatory learning and higher-order thinking skills;
- is locally relevant and culturally appropriate;
- engages formal, non-formal and informal education;
- is interdisciplinary;
- addresses content, taking into account context, global issues and local priorities;
- promotes life-long learning.

A good teacher should know :

WHAT?

WHY?

WHEN?

HOW?

WHO?

What ?

(i) Select scientific concepts that are relevant to the students and;

(ii) Connect concepts to make them pedagogically appropriate

To do this successfully a teacher must:

- Know the curriculum
- Know about issues that are relevant to the students
- Know what students have been taught previously
- Know how to connect concepts so as to help students understand

Relevant issues can be found in the existing curriculum?

1) look closely at your existing curricula syllabi to identify where themes and issues of ESD are already included

C10.3 Extraction of metals
1. describe the ease in obtaining metals from their ores by relating the elements to the reactivity series.
2. name metals that occur native including copper and gold
3. name the main ores of aluminium, copper and iron
4. describe the essential reactions in the extraction of iron in the Blast Furnace
5. outline the manufacture of aluminium from pure aluminium oxide using electrolysis
6. describe the importance of conserving resources
7. describe the environmental impact of the mining and extraction of metals on vegetation, human beings and animals

Environmental issues that could be discussed:
- Loss of biodiversity/habitats
- Land degradation
- Acid drainage into water sources
- Human settlement
- Deforestation

Below is another extract from the syllabus. Can you identify an opportunity(s) for ESD integration

C12.2 Water
1. describe and perform a chemical test for water using anhydrous copper(II) sulfate or cobalt(II) chloride
2. distinguish between the ion content of soft and hard water
3. distinguish between temporary hardness and permanent hardness
4. state advantages and disadvantages of hard water as having health, domestic and industrial implications
5. describe how hard water can be made soft by boiling, distillation and by using an ion exchanger
6. describe, in outline, the purification of water in terms of filtration, sedimentation and chlorination

Outcome 4 - effects on human health; loss of profits due to regular maintenance and costly repairs

Outcome 6 - When outlining the purification of water you could also discuss the effects on human health of inadequate clean water supplies and how to purify water in the home

Select a scientific concept that is relevant to the students

C10.3 Extraction of metals
1. describe the ease in obtaining metals from their ores by relating the elements to the reactivity series.
2. name metals that occur native including copper and gold
3. name the main ores of aluminium, copper and iron
4. describe the essential reactions in the extraction of iron in the Blast Furnace
5. outline the manufacture of aluminium from pure aluminium oxide using electrolysis
6. describe the importance of conserving resources
7. describe the environmental impact of the mining and extraction of metals on vegetation, human beings and animals

Concept: Conservation of resources ✓

What do you want your learners to know about this idea?

Why is it important for my students to know this?

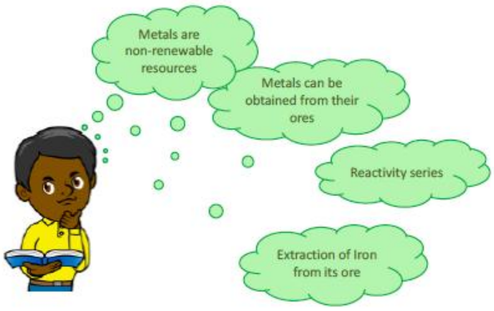
(i) To create an awareness amongst our students about the issues that affect them, their environment and their future

(ii) We want our students to learn to respect:

- Themselves
- Each other
- Future generations
- The planet they live on

(iii) Help students develop skills such as critical thinking and problem solving

What needs to be taught before I teach this idea?



Connect concepts to make them pedagogically appropriate

A teacher can connect the idea of conservation or resources to other scientific concepts (within a topic or across the entire curriculum)

Example:

The concept of conservation of resources can be linked to the topic on fuel to discuss renewable and non-renewable resources.

Conservation can also be linked to the environmental impacts of mining e.g loss of habitat/biodiversity, deforestation, land degradation and sustainability. The issue of pollution can be linked to another outcome in the syllabus relating to air pollutants and their effects

Thank you!

- Do you feel like you have a better understanding of ESD?
- What about integrating sustainability issues into the existing curriculum, do you see it as a possibility in your teaching?
- Join me in the next session where we will be looking at some other attributes of a good teacher and how you could develop more skills on how to teach for environmental sustainability.

Planning and teaching a chemistry lesson with environmental issues in mind

Session 3

Recap of session 2

- What is Sustainable Development
- Characteristics of Education for Sustainable development
- How to look for opportunities, in the existing curriculum, to integrate environmental sustainability
- Questions that a teacher should ask themselves before delivering content (What? Why? Previous knowledge?)

Shulman said that a good teacher should have an understanding of:

- the conceptions and preconceptions that students of different ages and backgrounds bring with them to learning
- what makes the learning of specific topics easy or difficult (Shulman, 1987 p. 9)

A teacher should also be able to:

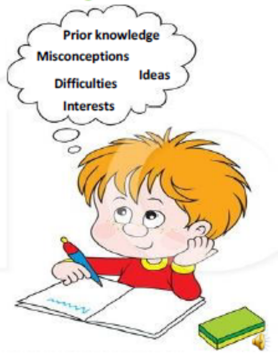
- identify and acknowledge variations in student learning
- adjust instruction based on student learning

WHO am I teaching?

A good teacher should:

(a) Know what their students are thinking

(b) Be able to recognise and engage this knowledge by creating opportunities for students to reveal their thinking



A teacher can use QUESTIONING to find out what the students are thinking

Questioning involves:

- **Asking** a question to reveal student thinking
- **Listening** to students response
- **Responding** to student thinking
- **Reflecting** on student thinking

The quality of questions we ask will determine the quality of the students thought

A good teacher will prepare some of their questions ahead of the lesson

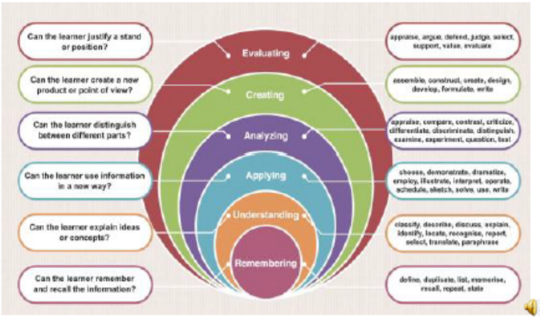
Before lesson

Assess Prior knowledge: What do your students already know?

- What do you know about mining?
- What do you think has to happen in the area before mining can take place?
- What do you think about the impacts of mining?
- Where did you learn this information?
- What do you think the word "conservation" means?
- What questions do you have about conservation that you hope we will discuss during the lesson?

'During'

Check for student understanding



Something to think about?

Remembering

Can the learner remember and recall information?

define, duplicate, list, memorise, recall, repeat, state

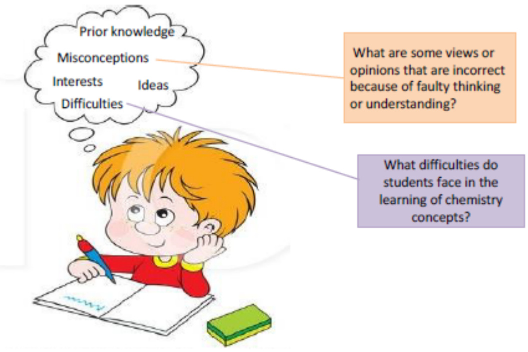
Questions

- Remembering - Recall the impacts of mining on the environment?
- Understanding - Describe how land clearing/ deforestation can lead to loss of habitats
- Applying - Solve the problem of acid drainage/water pollution?
- Analyzing - Compare the effects of mining on plants and on animals
- Creating - Design a reclamation plan for the Ngwenya mine
- Evaluating - Defend the statement 'the economic gains of mining outweigh its environmental impact'

After lesson

Reflect on the learning

- What did you learn about mining today?
- What was most interesting about the concept of conservation?
- Is there anything that was unclear or confusing?
- Does anything you learnt today connect to something you have learnt in the past?
- Is there any concept, information or skill you would like more time discussing or practicing?
- If you were asked to teach someone else on the impacts of mining and conservation, how would you teach it?



- A good teacher must be able to elicit and assess student difficulties and misconceptions

Common student misconceptions and typical learner errors under the topic 'Extraction of metals'

1. The reason that iron becomes a liquid when heated is because the bonds melt.
2. The name of iron ore is bauxite.
3. Lime instead of limestone is added to the blast furnace.
4. All mines leave the environment devastated.
5. Humans can fabricate rocks and minerals.
6. Climate change is linked to air pollution and not greenhouse gases.
7. Greenhouse gases cause ozone layer depletion.
8. Unable to recognise differences between these environmental terms: climate change; greenhouse effect and global warming.

Student difficulties

A student may fail to grasp a chemistry concept because of:

i. The nature of the students prior knowledge or the inadequacy of such knowledge in relation to the concept being taught.

A teacher can use questioning to access students prior knowledge and misconceptions, and then deal with these before teaching new concepts.

ii. The demand and complexity of a learning task in terms of information processing, compared with the student's information-handling capacity.

A teacher should carefully and purposefully structure information given to students. Avoid unnecessary information which may cause a memory overload

iii. Communication problems arising from language use

- a lack of understanding of familiar words used to convey meaning in chemistry,
- a lack of understanding of technical terms introduced in the study of chemistry,
- ascribing a familiar meaning to a common word used in technical sense,
- using everyday meaning to draw incorrect inferences about chemical events.

A teacher should give students opportunities to internalise and use scientific terms in activities like sharing ideas, discussing issues, solving problems and reporting through presentation

Recognizing and responding to these various causes of students' learning difficulties will not only reduce these difficulties, but also make our teaching more effective.

How can a teacher adjust instruction based on student learning?

If students are seen to be struggling with understanding the teacher could:

- Slow down pace
- Give more examples
- Provide visuals via the board
- Give more student work (written tasks)
- Provide written as well as oral directions
- Teach the use of acronyms to help visualize lists (OILRIG: **O**xidation **I**s **L**oss, **R**eduction **I**s **G**ain)
- Re-teach difficult vocabulary and concepts

Thank you!

- Did this session remind you that each student in your class is unique?
- What about the fact that for teaching to be successful it is important for teachers to know what students are thinking?
- Join me in the last session where we will be looking at how to keep your students interested in your lesson, by careful choice of the teaching methods and representations you use.
- We will also look into what goes on in the mind of a teacher during the teaching process.

Planning and teaching a chemistry lesson with environmental issues in mind

Session 4

- A good teacher knows *what, when, why, and how* to teach, taking into consideration *who* they are teaching
- We have looked at the WHAT and the WHO
- Now we need to discuss the

HOW?

WHY?

HOW?

A good teacher should be able to select:

(i) instructional strategies (teaching methods) that will promote meaningful learning and;

(ii) representations (teaching aids and resources) that will help the students understand.

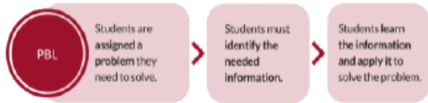
Teaching methods associated with ESD stimulate pupils to:

- **ask questions**
- **discuss**
- **analyse local contexts**
- **think critically**
- **apply their values**
- **be creative**
- **imagine alternative futures**
- **make decisions**
- **develop a sense of social justice and self-efficacy as community members**

ESD promotes teaching methods that are ;

- student centred
- encourage higher order thinking skills
- encourage participatory learning
- issue/ problem based

Problem based learning allows students to solve an authentic real-world problems through investigation



- class discussions
- issue analysis (picture, newspaper article, graphs etc)
- inquiry learning (research),
- simulation and role play, storytelling, educational drama

Classroom activities and practical learning experiences can be used to help students understand how their schooling applies in the real-world.

- The shoe box mine activity can be used to display both the mining and reclamation process
- Local field trips to the Bulembu asbestos mine, Ngwenya iron ore mine or Dvokolwako diamond mine
- Blueberry muffin activity allows students to 'mine' the blueberries and confirm that you cannot remove the blueberries without destroying the muffin

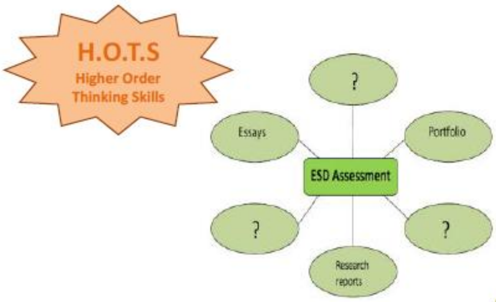
Select representations (teaching aids and resources) that will help the students understand

- Representations are the visual aids that you use to help students understand. E.g. photographs, diagrams, tables, charts, models, symbols, formulae and equations
- For a lesson on the impacts of mining on the environment, you could start my lesson with:
  - a picture of a deserted mine…
  - a table comparing pollutant levels in a river before and during mining…
  - a chart showing animal species in numbers before and after land clearing for mining…
  - a model of a mine…
- During the lesson you could use symbols, formulae and equations to show reactions that take place

Incorporating technology into your teaching is a great way to actively engage your students, especially as digital media surrounds young people in the 21st century.

Something to think about?

How do you think ESD influences the assessment of student learning?



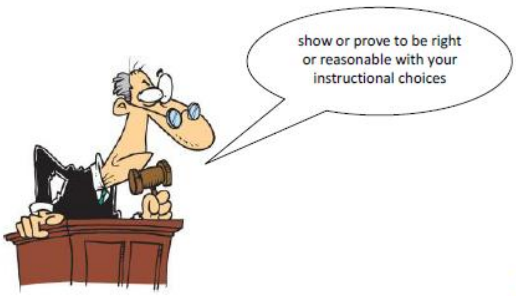
WHY did I teach this way?

- A teacher must make decisions about *what, when, why, and how* to teach
- A teacher should also consider the differences in student learning and thinking when making these decisions (*who*)
- These decisions are based on their knowledge, skills and experience
- A teacher uses their reasoning to transform the content into units that are understandable to learners
- This process is called *'pedagogical reasoning'*

Pedagogical reasoning takes during all phases of the teaching process

- Questions a teacher may ask themselves:
  - Which concept/ idea should I deliver first?
  - Which teaching strategies can I use?
  - What representations should I use to help with student understanding?
  - What questions will I ask to access student thinking?
  - What methods will I use to assess student understanding?
  - What would I do differently if I were to teach this lesson again?

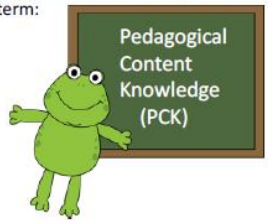
Pedagogical reasoning allows a teacher to be able to justify their instructional moves



Pedagogical reasoning relies on a teachers ability to interconnect and use all this knowledge to make teaching most effective

Teaching is an art

- What you have learned in these four sessions has developed your skills in this art
- The knowledge and skills that are needed for teaching have a special term:



The components of PCK

- When attempting to identify a teachers PCK, we look for the following abilities:
- 1) Select scientific concepts that are relevant to the students and connect them to make them pedagogically appropriate
- 2) Select of instructional strategies and representations that promote meaningful learning
- 3) Recognise and engage students' prior knowledge, misconceptions and interests
- 4) Adjust instruction based on student learning
- 5) Interconnect the components and justify teaching

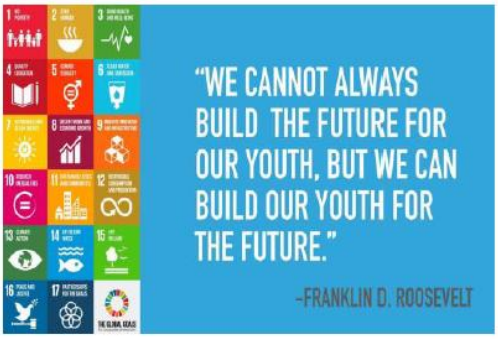
Thank you!

Thank you for taking time to go through the course.
Now that you are done, please let me know!

Next steps

1) Questionnaire - I will send back the questionnaire you filled and ask you to look through it and in light of the knowledge you gained during the training make changes by adding or deleting, if you feel it necessary

2)Telephone interview- I would also like to carry out a telephone interview. The main focus would be to get feedback on the training session and to get clarification on some of your questionnaire responses



8.5 Appendix E - Schedule for Interview 1

Telephone interview schedule 1

1 (i) Do you think it is important for students to learn about sustainability and related issues?

(ii) Why?

2 (a) (i) Do you agree with the statement that 'teachers are the key agents in the implementation of education for sustainable development'?

(ii) Why do you think so?

(b) (i) Do you think it is important for teachers to undergo professional development to help them understand how to educate for sustainability?

(ii) Do you have any suggestions on how the training should look, what should be the content of such training?

3 (i) Do you think sustainability issues are relevant to the subject of Chemistry?

(ii) Which topics in chemistry do you think are suitable for addressing sustainability issues?

4 Which global issues/ sustainability issues do you think you could discuss during your Chemistry teaching?

8.6 Appendix F - Schedule for Interview 2

<u>Telephone interview schedule 2</u>

1. (a) Do you feel the topics being discussed are relevant to you, as a teacher?

   (b) Why/Why not?

2. (a) Now that you are aware of ESD and some attributes of a good teacher, will your lesson planning experience be different?

   (b) How?

The following questions are to find out teachers' experiences and perceptions on using digital technology for PCK development. Digital technology means the use of computers, social media, multimedia and mobile phones to support learning.

3. (a) Have you taken part in a training that uses digital technology before?

   (b) What do you think are some advantages of digital learning/training over the more traditional forms, such as attending workshops.

   (c) What are some of the challenges you are facing while undergoing this intervention that uses digital technologies?

4. What are your views on using digital technologies as a professional learning and development tool for enhancing a teachers' knowledge and skills.

8.7 Appendix G- Schedule for Interview 3

Final Telephone interview schedule

1 (a) What did you learn during this intervention that you did not know before?

(i) About the topic of sustainability and educating for sustainability (ESD)?

(ii) About being a good teacher?

(b) The following questions are with regard to your overall feeling about this intervention

(i) Was the content well organized and logical?

(ii) Was the content easy to follow?

(iii) Did the trainer provide relevant examples during the training?

(iv) After this training, do you feel more comfortable teaching for sustainability?

(v) What did you like the most about the training?

(vi) How do you think this training can be improved?

(vii) Would you recommend this training to a friend or colleague?

* The questions that follow will be questions asking for clarification on some of the things that the participant mentioned in their questionnaire or lesson plan (if there are any)*

8.8 Appendix H - PCK Rubric

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Knowledge and Skills related to Curricular Saliency (C)	**CS1 -** Name the four most important concepts you would address when teaching "extraction of metals"	- Learning outcomes are simply repeated/ rephrased. - no evidence of sequencing	- Appropriate ideas are identified but more than one important idea is missing - reference to one of the big ideas - evidence of sequencing is present	- Appropriate ideas are identified but an important idea is missing - reference to the two big ideas - sequencing is evident	-Appropriate ideas identified - Identifies ideas that focus on understanding of both the big ideas. -sequencing is evident
	CS2 – What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?	- Ideas mentioned are not appropriate -sequencing is not evident	- Ideas mentioned are appropriate - sequencing of ideas is not evident	- Identified pre-concepts are required to understand the topic -List is not extensive - Provides logical sequencing of concepts	- Identifies pre-concepts that are needed to understand the topic -list is extensive (4+) - Provides logical sequencing of concepts
	CS3- In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	-No reasons provided - Reasons are unclear and not linked to the outcomes of the syllabus	- Reasons provided are well articulated - Reasons are not linked to the aims of the EGCSE syllabus	- Reasons given well articulated - Reasons given linked to one or two of the aims of the EGCSE syllabus	-Two or more reasons given - Reasons provided are linked to three of the aims of the EGCSE syllabus
	CS4- Why is it important for students to know about conserving resources and the impact that mining has on the environment?	-No reasons provided - Reasons provided are generic/not clear	- Only one/two reasons stated -Reasons provided indicate no link between environment / society(student) / economy - reasons not linked to students role	- Appropriate reasons are provided - No evidence of understanding of link between environment / society / economy -reasons show link to students role	-Reasons provided show in-depth understanding of link between environment/ society (student)/ economy - Reasons show students role with regard to these big ideas(need for solutions) and a sense of responsibility
Knowledge and Skills related to Conceptual Teaching Strategies (CTS)	**CTS1-** What teaching strategies would you use to teach *conserving resources* and *the environmental impact of mining*? Why?	- Lists one or two general strategies - No justification provided - Justification incomplete	- Lists general strategies - Reasons provided are generic and not necessarily aligned to ESD	- One or two strategies that are student centred - Evidence of learner involvement - Reasons not aligned to ESD specific strategies	- Presents relevant ESD teaching strategies to teach the required concept - Clear reasons, consistent with ESD specific strategies
	CTS2 - What questions, related to environmental sustainability, would you consider important to ask your learners during your teaching?	- Questions listed are not specific to the key ideas - Questions are general - Sequencing is not evident	- Questions asked are related to one of the key ideas - No evidence of questions that require higher order thinking and problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require higher order thinking but not problem solving skills - Sequencing is evident	- Questions asked are related to both the key ideas - Evidence of questions that require critical thinking and problem solving - Sequencing of questions is evident

PCK component	Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
	CTS3 - What representations would you use during your teaching *conserving resources* and *the environmental impact of mining*? Why? How?	- One or two representations mentioned - No reasoning identified - No explanation of how they will be used to support conceptual understanding	-One or two representations mentioned -Reasoning is insufficient/ redundant - inadequate description of how they will be used to support conceptual development	- An adequate selection of representations - Sufficient evidence of reasoning - Evidence of use of representations to support conceptual development	- An extensive selection of representations - Reasoning includes development of specific concepts with logical sequencing of events - Explanatory notes to make links to concepts being developed
	CTS4 - What ways would you assess student thinking and understanding about conserving resources and the impact that mining has on the environment?	- No assessment strategies provided - No evidence of appropriate assessment strategies	- Lists one or two general assessment strategies -No indications of how they are linked to concepts	- Lists appropriate assessment strategies - There are indications of how they are linked to concepts	- Lists assessment strategies with indications of how they are linked to concepts -Strategies encourage problem solving skills and critical reasoning
Knowledge and Skills related to Student thinking (S)	**S1** - What do you consider difficult about teaching *conserving resources and the environmental impact of mining*? Why?	-No difficulties identified - Identifies broad topics/statements -No reason given	- Identifies general learner/teaching difficulties with no relation to key ideas - refers to contextual constraints - Provides generic reasons	- An appropriate difficulty related to one of the key ideas is identified and clearly formulated. - Reasons for difficulty show an awareness of student thinking and aspects of curricular saliency	- Appropriate difficulties for both key ideas are identified and clearly formulated. - Reasons given show an awareness of student thinking/ learning and aspects of curricular saliency
	S2 - What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?	- No indication of knowledge about misconceptions - The response is poorly formulated	- Identifies common learner errors /misunderstandings rather than misconceptions - Misconception identified is not clearly formulated	- Identifies two misconceptions - An indication of knowledge about misconceptions is evident - Response not well formulated	- Identifies two or more misconceptions - Response is well articulated - An indication of knowledge about misconceptions is evident
	S3 – What questions would you use to access student thinking and understanding about *conserving resources* and *the impact that mining has on the environment*?	-No questions are given -Question(s) given are vague or irrelevant -Questions are not clearly formulated	-A list of 2 or 3 questions given -Questions not all clearly formulated - Questions not linked to student thinking and conceptual teaching strategies	- A list of 2 or 3 questions appropriate for eliciting student thinking - Questions are clearly formulated - Questions linked to student thinking/ conceptual teaching strategies	- An extensive list of questions is given - Evidence of questions appropriate for eliciting student thinking - Questions linked to knowledge of student thinking and choice of conceptual teaching strategies

8.9 Appendix I – Model answers and Master CoRe

Expected answers for some of the questions from the pre- and post- PDI questionnaire (not directly related to the CoRe)

Name the four most important concepts you would address when teaching "Extraction of metals".	- Sources of metals/ where and how the metals are found - Ease of obtaining metals from their ores can be found by relating the elements to the reactivity series - Iron can be extracted from iron ore in the blast furnace - Conservation of resources is important - Mining and extraction of metals has an environmental impact - Adverse environmental effects of mining can be minimised when mined lands are returned to a natural or economically usable state (Reclamation)
What concept(s) need to be taught to learners before teaching them about 'Extraction of metals'?	- a compound as a substance made of two or more different types of atoms that are chemically bonded together (Atoms, elements and compounds) - position of metals in the Periodic Table; alkali metals, alkaline earth metals and transition metals (The Periodic table) - naming of compounds; writing formulae of compounds; writing balanced equations (Stoichiometry) - reducing agents remove oxygen from other substance (Redox) - properties of metals (including those that make them useful to humans) - metals can be placed in order of their reactivity based on their reactions with water, steam and acid (Reactivity series) * uses of metals (importance of metals to humans) * ionic compounds can be broken down by the use of electricity (Electrolysis) Please note: concepts (Topics) marked with a * come after extraction of metals in the syllabus but could be taught before
In the EGCSE curriculum, environmental issues are included. Do you agree with this inclusion and why?	1. To develop skills and abilities that are useful in addressing environmental issues 2. To stimulate learner interest in, and care for, the environment 3. To promote awareness that the applications of science may be both beneficial and detrimental to the individual, the community and the environment

Master CoRe (Chemistry teachers' PCK about environmental sustainability within the topic of 'Extraction of metals')

PCK component	Component prompts	*'conserving resources'* (Big idea A)	*'the environmental impact of mining'* (Big idea B)
Knowledge and Skills related to Curricular Saliency (C)	**CS1- Why is it important for students to know about conserving resources and the impact that mining has on the environment?**	- learn that the earth is composed of several natural resources including plants, animals, minerals, rocks, and fossil fuels. -learn that materials important to humans are made of these natural resources. - explains how depletion of resources can affect society - explores how students can help conserve resources	-explains the effect that mining has on the environment (the by-products and pollutants) - explore the links between environmental impact and social impacts - explores the reclamation process

Knowledge and Skills related to Conceptual Teaching Strategies (TS)	**TS1- What teaching strategies would you use? Why?**	**What and Why?** **Discussion** to enhance the learners' knowledge and understanding about resources. Ask pupils questions about the different types of mineral resources they see on the chart, some of the issues surrounding mineral resources, and how they can be refined or renewed by recycling. This can promote participatory learning and higher order thinking skills. **Story- telling/video-clip** to stimulate the children's awareness about the importance of mineral resources and the consequences of them running out. It helps explain expectations, strengthen character and teach desired behaviour. The teacher can tell a story (show a video) to point out the need for proper conservation of the mineral resources	**What and Why?** **Field trip to mining sites:** to stimulate learner awareness about the mining process and the effects that mining has on the environment and surrounding communities. This shows the learners that the topic is locally relevant. **Cooperative learning:** Small group exercises in class that encourage students to work together, exchange views, and make presentations to the whole class. Students will break into small groups. **Role-play:** Teacher will explain that each group will represent a team of mining engineers who are in the planning stage of a mining operation. Each team will be assigned, one of the aspects; Human health hazards, Land/ soil, Pollution, Ecosystems, Vegetation Each group will address how each of these is affected by mining. This allows students to experience real-life situations. **Problem-based learning:** Encourages students to ask questions and investigate their own ideas. Helps improve their problem-solving skills as well as gain a deeper understanding of academic concepts. Both of which are important life skills. Student teams will brainstorm possible solutions to the problem in order to sustain the environment and ecosystems.

	TS2 - What questions, related to environmental sustainability, would you consider important to ask your learners during your teaching?	-What is a resource? -What is conservation? -What is resource conservation? -* Why must we conserve resources? -* How can you conserve resources in your daily lives? Please note: questions with an asterix(*) linked to environmental sustainability	-Why is mining important to humans? - How does mining affect the environment? -* How can we make mining more environmentally friendly? -*How can reclamation reduce the impact of mining and help sustain the environment and ecosystems?
	TS3 - What representations would you use during your teaching? Why? How?	**What?** A poster/chart **Why?** shows a collection of resources (both renewable and non-renewable) to help students visualise the resources **How?** Teacher will display the chart and lead a discussion with these questions: *-Can we name some of the resources on the chart?* *-Which of these resources are used extensively on earth?* *-Which resources are in danger of running out?* *-What do you think would be the consequences of these resources running out?*	**What?** A shoe-box mine **Why?** It is a visual representation of a mine. It will also allow students to "mine" and carry out small scale reclamation **How?** Teacher will display **shoe-box mine** and ask a student to assist by excavating the coal using a plastic spoon. *(Can the coal be removed without disruption to the plant life or existing ecosystems?)* After the coal has been recovered *(How was the plant and animal life affected?* *Did the lake become polluted by the tailings (be sure to point out any soil that accidentally fell into the cup)?* Have students demonstrate the reclamation of the shoe-box mine to its pre-excavation condition *(Is the mine restored to its previous condition?)*
	TS4 - What ways would you assess student thinking and understanding?	**Research project** Students choose one of the resources mined in Eswatini (Gold, Iron, Diamond or Asbestos) Should include 1. Where is it found? How is it found? 2. Describe the **recovery of the resource** referring to - why it is worth mining? - the location of the major mining activity in Eswatini? 3. How can this resource be conserved?	**A written report** that will be evaluated based on the extent that they addressed their problem and creativity in the reclamation process.
		Questioning – that elicits higher order thinking, critical thinking and problem solving	

Knowledge and Skills related to Student thinking (S)	**S1 - What do you consider difficult about teaching this idea?** ***Why?***	**Difficulties** *(related to students)* - student misunderstanding of terms (renewable vs non-renewable) - lack of prior knowledge on conservation issues/natural resources - students cannot relate to conservation. - promoting outdoor experiences and encourage students to become engaged in environmental activities	**Difficulties** *(related to students)* -Learners find it hard to express complex environmental issues in ways that are understandable (Biodiversity, deforestation, land degradation, acid-mine drainage, greenhouse effect, global warming etc)

		Why? - the new and difficult terminology - students environmental awareness is low (Abd Rahman et.al 2018) - students not ready to participate in desirable ecological actions -According to Stanišić & Maksić (2014) students do not have a clear picture about their role and possible contribution to the conservation and enhancement of the environment	
		Difficulties (*related to teachers)* -ensuring that the examples are relevant to the students -explaining terms/environmental issues -deciding on the best teaching approach -lack of support from school administrators in promoting environmental conservation programmes and practices (Abd Rahman et al. 2018) **Why?** According to Ham & Sewing (1988) difficulties faced when teaching about environmental issues are caused by: 1) conceptual constraints (teachers lack of understanding on the content) 2) logistical (such as time constraint, inadequate teaching materials, inappropriate class size, financial and transportation problems) 3) teachers' competencies (lack of pedagogical knowledge), and 4) commitment (and motivation)	
	S2 - What are typical student misconceptions you encounter when teaching about *conserving resources* and *the impact that mining has on the environment*?	- There is an infinite supply of Earth's natural resources - Some ecosystems have limitless resources and provide an opportunity for limitless growth of a population (Brody and Koch 1990) - Natural gas is a renewable resource (Tortop, 2012) -Humans can fabricate rocks and minerals.	- Environmental damage is irreversible -All mines leave the environment devastated. - Air pollution (and not greenhouse gases) cause climate change -Carbon dioxide (CO_2) is the only gas that increases the greenhouse effect - CO_2 depletes the ozone layer (Arslan et al. 2012) - During reclamation fauna will return unaided after the establishment of vegetation (Thompson & Thompson, 2004)
	S3 – What questions would you use to access student thinking and understanding?	- What are the natural resources that they throw in the trash the most? - Which resources do they use the most? - Why is it important to conserve natural resources? - What would happen to the earth if we used more resources than it could make? - How can we conserve natural resources in our daily lives?	- Who/what was impacted by the mining? - Is the mine restored to its previous condition? - How was the plant and animal life affected? - Did the lake become polluted by the tailings (Be sure to point out any soil that accidentally fell into the cup)?

8.10 Appendix J - Letter of permission from the Director of Education and Training

The Government of the Kingdom of Eswatini

Ministry of Education & Training

Tel: (+268) 2 4042491/5
Fax:(+268) 2 404 3880

P. O. Box 39
Mbabane, ESWATINI

12th February, 2020

Attention:
Head Teacher:

Mbabane Central High School	**Woodlands High School**
Somjalose High School	**Enhlanganisweni High School**
Kashiele High School	**Elangeni High School**

THROUGH
Hhohho Regional Education Officer

Dear Colleague,

RE: REQUEST FOR PERMISSION TO COLLECT DATA FOR UNIVERSITY OF PRETORIA – MS. ZOELLA GROENING

1. The Ministry of Education and Training has received a request from Ms. Zoella Groening, a student at the University of Pretoria that in order for her to fulfill her academic requirements at the University she has to collect data (conduct research) and her study or research topic is: "*Exploring Experienced Chemistry Teachers Pedagogical Content Knowledge about Environmental Sustainability*". The population for her study comprises of six chemistry teachers from the high schools mentioned above. All details concerning the study are stated in the participants' consent form which will have to be signed by all participants before Ms. Groening begins her data collection. Please note that parents will have to consent for all the participants below the age of 18 years participating in this study.

2. The Ministry of Education and Training requests your office to assist Ms. Groening by allowing her to use above mentioned schools in the Hhohho region as her research site as well as facilitate her by giving her all the support she needs in her data collection process. Data collection is one month.

MINISTRY OF EDUCATION TRAINING 2020 -02- 12 BOX 39 MBABANE SWAZILAND

DR. N.L. DLAMINI
DIRECTOR OF EDUCATION AND TRAINING

cc: Regional Education Officer – Hhohho
Chief Inspector – Secondary
6 Head Teacher of the above mentioned school
Dr. Corene Coetzee/Dr. Kgadi Mathabathe – Research Supervisors

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8.11 Appendix K – Consent forms for participants

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Dear Sir/Madam

RE: CONSENT OF CHEMISTRY TEACHERS PARTICIPATING IN THIS RESEARCH

You are invited to participate in a study entitled: EXPLORING EXPERIENCED CHEMISTRY TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE ABOUT ENVIRONMENTAL SUSTAINABILITY

Please read this form carefully and feel free to ask any questions you might have.
The study is conducted by Zoella Groening, who is a student in the Department of Science, Mathematics and Technology education at the University of Pretoria. The main purpose of this study is to establish the knowledge, skills and attitudes of chemistry teachers, in the Hhohho region, with respect to environmental sustainability. The study will start with a participant selection process where information will be gathered through questionnaires.

You are kindly requested to participate by completing a questionnaire. The total time commitment from you would be approximately 10-15 minutes. Your responses will be used but your identity, and that of your school, will be hidden. Codes will be used to ensure privacy and anonymity. You may withdraw from the study for any reason, at any time, without a penalty. If you withdraw from the study, at your request, the data you have supplied will be destroyed and no longer be used.
Kindly indicate your willingness to participate by signing in the space provided below.
Yours faithfully,
Ms. ZOELLA GROENING

I have read and understood the description provided above. I have been provided with an opportunity to ask questions and my questions have been answered satisfactorily.
I, ______________________________________ of ______________________________ high school consent to participate in the study conducted by Ms Zoella Groening on chemistry teachers' pedagogical content knowledge about environmental sustainability, understanding that I may withdraw at any time.

____ ____________________
Signature of Participant Date

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www.up.ac.za

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

8.12 Appendix L – Lesson plan template

<table>
<tr><td colspan="3">Topic:</td></tr>
<tr><td colspan="3">Purpose ("Why" of the lesson, where and how does it fit into the course/curriculum?):</td></tr>
<tr><td colspan="3">Prior Knowledge (Student knowledge that should be in place for students to understand new concepts)</td></tr>
<tr><td colspan="3">Learning Outcome(s) (What will students be able to do/know by the end of the lesson?):</td></tr>
<tr><td>Instructional strategies</td><td>Resources (clearly indicate how these resources will be used during the introduction and main activity)</td><td>Essential question(s)</td></tr>
<tr><td colspan="3">Introduction (Focus student attention)</td></tr>
<tr><td>Time:</td><td>Teacher activities</td><td>Students activities</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Main activity</td></tr>
<tr><td>Time:</td><td>Input from You (Main content: ideas, information, concepts, principles, procedures and examples)</td><td>Guided Practice (Application of knowledge: classroom activities for students, problem to solve, etc.)</td></tr>
<tr><td colspan="3">Conclusion (Recap key concepts, helps students consolidate knowledge)</td></tr>
<tr><td>Time:</td><td colspan="2"></td></tr>
<tr><td colspan="3">Check for Understanding (What questions will you ask and when to determine students understand?)
Introduction –

Main activity –

Conclusion -</td></tr>
<tr><td colspan="3">Assessment (How does this lesson relate to assignments/homework/readings)</td></tr>
</table>