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Teacher mediation of link-making between what learners do and observe during practical activities (the domain of observables) and the concepts learnt in theory lessons (the domain of ideas)

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CHAPTER1: INTRODUCTION

This study examines how I designed practical tasks and delivered the practical lessons so as to help learners make connections between what they observed during the practical activities and the science concepts on iron and gold extraction. The investigation was carried out at a state high school with Grade 11 physical sciences learners in Gauteng Province. I drew the work of Abrahams & Millar (2008) in the United Kingdom. They observed little evidence that science teachers helped learners to link what they observed and did with the apparatus/materials during practical work to the scientific concepts. Consequently, most practical activities contributed very little to the students' learning of science. Also in the South African context, Muwanga-Zake (2001) and Roychoudhury (1996) assert that science teachers make little/or no effort to help learners to make connections between the data and the scientific concepts. They suggest that the reason could be that most science teachers lack practical skills and subject matter knowledge essential for them to scaffold learners to make connections between what is observed during practical tasks and the science concepts. My own experience with physical sciences teachers engaged in a programme aimed to provide them with practical work skills revealed that teachers rely heavily on textbook 'recipe like' instructions for practical work. To these teachers, a practical activity is unsuccessful if results obtained vary from what is in textbooks, irrespective of the context. Such teachers regard the primary role of practical work as the verification of laws and the reproduction of data that are similar to what is in textbooks.

Teachers seem to lack the appropriate skills for designing practical activities as well as strategies of helping learners make connections between their practical work experiences and observations with the scientific concepts. This results in unproductive practical work with little learning of science taking place (Clackson & Wright, 1992; Harrisson, Fisher & Henderson, 1997; Muwanga-Zake, 2001; Berry, Mulhall, Gunstone & Loughran, 1999; Ng & Nguyen, 2006). As a result there is lack of continuity between practical lessons and the theory lessons. Scott, Mortimer & Ametller (2011) assert that continuity is necessary to help learners develop a deeper understanding of science concepts. It is therefore essential that science teachers help learners make connections between practical work experiences and the target concepts.

Abrahams & Millar (2008) posit that learners perceive practical work as a more interesting and useful teaching strategy compared to other teaching approaches. These sentiments are shared by science teachers who tend to believe that students understand things better when there is physical interacting with real objects (Millar, 2009). My personal experience revealed that practical work may produce memorable events which may help a learner to remember such events after a long time. For example, I still can remember the practical investigation I did in Grade 9 about osmosis after twenty–eight years. In addition to aiding memory, practical work may help learners to understand science concepts, like I still remember the process of osmosis based on the practical experience I had during my school days.

Millar (2009) asserts that most science teachers regularly use practical work as a teaching strategy in their classrooms but the quality of the practical work needs to be improved. In order to explore Millar's assertion for my own teaching I decided to conduct a study of my own practice with respect to design and delivery of practical lessons for two reasons. First I wanted to understand how I mediated learner link-making between practical tasks and the concepts taught in theory lessons. Secondly I wanted to explore ways to improve my mediation of this link-making process for my students. It is my hope that the findings of this self-study can be useful in helping other science teachers and me in the effective designing and usage of practical work as a means to help learners gain a deeper understanding of science concepts.

1.1 Research Questions

The main question guiding my research is: In what way(s) do I help learners make connections between what they do and observe in practical lessons to the concepts taught in theory lessons?

The main question was divided into the following sub-questions:

1. How does my planning of practical tasks help me to make connections between practical work experiences and science concepts in my teaching?

2. What is the nature of teacher-learner interaction during the practical lessons?

3. How does teacher-learner interaction facilitate for learners to make connections between their experiences during the practical activity and the science concepts learnt/or still to be learnt?

1.2 Rationale

The South African curriculum, the National Curriculum Statements (NCS) and subsequently the Curriculum and Assessment Policy Statements (CAPS) for Physical Sciences emphasise the need to integrate practical work in the teaching of Physical Sciences in order to reinforce the concepts taught (Department of Education, 2011). Also both policy documents require learners to develop high order scientific inquiry skills, like critical thinking skills, scientific reasoning, problem solving and planning investigations. Moreover, scientific inquiry and problem solving skills are now examined which makes practical work an important component of the Physical sciences curriculum. According to the Physical Sciences Examination Guidelines (Department of Education, 2009), learners are expected to use the practical work knowledge in examinations to formulate investigative questions, list possible variables, formulate testable hypothesis, design investigations, analyse data, draw conclusions and evaluate experimental designs and conclusions. In addition the new curriculum (CAPS) has increased the number of prescribed practical tasks which learners need to complete per year for assessment purposes. For example, at Grade 12 learners are now expected to do at least three formal practical tasks instead of two. Three more informal practical tasks should also be completed in the year. The increased curriculum emphasis on practical work demands that teachers should improve on their practical work skills and strategies to help learners to make connections between practical work experiences and the scientific concepts.

Although practical work is widely perceived to enhance the development of a range of skills, conceptual understanding and science knowledge in learners (Millar, 2004), introducing it without adequately preparing teachers on how to use it results in its poor usage. Muwanga-Zake (2001) asserts that most science teachers lack practical work skills and conceptual understanding. He reports that because of poor training, some teachers cannot use some science equipment and therefore need assistance from their subject facilitators on how to use them. From experience, with conducting

workshops for teachers on the use of practical work as a teaching strategy, I also observed that some teachers lacked familiarity with science equipment and even needed assistance just to assemble the apparatus. The majority of the teachers thought that the primary aim of practical work is to reproduce data similar to what is in textbooks. Any deviations meant that the investigation was unsuccessful.

I have observed that most science teachers in South Africa continue to use exemplar practical tasks for Grades 11 and 12. This is an indicator of the lack of practical work designing skills as reported by South African educational research. For example, Muwanga-Zake, (2001) reports that most science teachers lack practical work planning skills and that most practical work carried out in science classrooms lack specific outcomes. Such practical work tasks only manage to help learners to do what they are expected to do with the real objects but unable to use the scientific ideas to guide them on what they do. If used this way, practical work fails to develop learners' scientific knowledge. Learners are not motivated when they do activities which do not challenge them mentally and do not relate to their everyday life experiences (Abrahams & Millar 2008). There is a need to equip science teachers with the skills to design and use practical work to help learners develop the necessary scientific knowledge and practical skills. Research should focus on finding better ways of using practical work in schools to ensure that the quality of learning science can improve.

Millar (2004) reports that there does not seem to be a standard definition for practical work in science education and this makes it difficult to isolate the value of practical work in the teaching of science. It is important that curriculum designers explicitly specify what they mean by practical work in order for teachers to know exactly how to use practical work in their teaching of scientific concepts. Millar defined practical work as any teaching and learning task in which learners manipulate or observe real objects. Used in this sense practical work includes experiments, fieldwork or any laboratory activity. The Department of Education (2011) defines practical work as any activity which may take the form of a practical demonstration, experiment, or practical investigation which seems to be in line with Millar's definition. This is the definition I will adopt for my study. In this study 'observed phenomena' means any event or feature of matter that is observable and 'domain of ideas' means conceptual knowledge or theoretical knowledge.

I used the concept of pedagogical link-making as a lens to analyse my data. Scott, Mortimer & Ametller (2011) described pedagogical link-making as the ways in which educators and learners make links between learning / teaching interactions and ideas. They identified three types of pedagogical linking, namely; (1) to support knowledge building, (2) to promote continuity and (3) encourage emotional engagement. I used only pedagogical link-making to support knowledge building in my data analysis. I will discuss the six approaches to pedagogical link-making to support knowledge building in chapter two.

The research will help me to develop research skills needed in science education. Regular interaction with research materials and looking at my practice will help me to develop a positive attitude towards studying and self-improvement. The research will help to expose my weaknesses as a science teacher and help me in identifying the areas where I need to improve on. With the help of my supervisor and my research findings I can work on improving my planning and teaching of both practical work and theory lessons. The research findings can help science teachers in similar contexts to improve their expertise in helping learners to make connections between their experiences and science conceptual knowledge.

In chapter two I focused on literature review and theoretical framework of the research. Chapter three focuses on the research design and methodology adopted for this research. In chapter four I presented my results and discussed them. A conclusion is given in chapter five. At the end I presented a reference list and appendices.

CHAPTER 2: REVIEW OF LITERATURE

This chapter starts with a review of literature on the importance of practical work in science, how science teachers use practical work as a teaching strategy and the different forms of practical work. I then focused on the application of the constructivist and the socio-cultural learning theories to the teaching and learning of science before reviewing literature on pedagogical link-making. Finally I look at the learning and teaching of iron and gold extraction.

2.1. Practical work in the curriculum

Scholars have documented the usefulness and benefits of practical work in the teaching and learning of science. Abrahams & Millar (2008) assert that the main aim of practical work in school science is to help learners to make connections between real physical objects and happenings and the theoretical world of thought and ideas. School science should attempt to assist learners to make connections between what they perceive and experience to the scientific concepts for this assist them to apply their knowledge to new situations. In addition, this may motivate learners to enthusiastically learn the subject because of its usefulness in their lives.

Practical work and science conceptual knowledge are interdependent. Kirschner (1992) asserts that practical activities facilitate the building up of science conceptual knowledge and theory determines the kinds of practical activities carried out. Science teachers usually favour the use of theory lessons rather than practical work hence neglecting the interdependence between the two. Vhurumuku (2010) asserts that science teachers wrongly use practical work to verify theory. This concurs with Kirschner's findings that some science teachers use practical work as a means to get correct answers to a specific question. He lamented that this is a misrepresentation of science and may cause learners to hate the subject because of boredom. Science teachers need to know the interdependence of practical work and theory and the benefits of practical work if they are to use it correctly as a teaching strategy. On the contrary, Ng and Nguyen (2006) observed that some science teachers focus on concept application rather than practical work. Such teachers emphasise on the use of science theoretical ideas in solving problems while not affording learners with practical work experiences that guide them to make connections between experiences and scientific ideas.

Tamir (1991) identified five benefits for doing practical work in school science. These include: (1) enhancement of learners' understanding of complex and abstract concepts, (2) to help learners to develop scientific skills, attitudes and values (3) identification of learners' misconceptions, (4) motivating learners to learn and (5) assisting learners to develop thinking and creativity skills. Millar, (2009) asserts that practical work experiences should help learners to develop scientific knowledge. Teachers should be able to use learners' practical experiences to link between their observations and the science concepts in order to make the learning of complex abstract concepts easier. This is only possible if teachers have the skills of scaffolding learners to make connections between the observed phenomena and the domain of ideas.

There are different forms of practical work which are carried out for different purposes in school science. Roberts (2004) classified practical work into five categories namely; skills practical work, observation tasks, investigations and exploratory tasks, technological tasks and illustrative experiments. Each of these practical tasks has its own purpose in science education. Roberts asserts that practical work intends to help learners to develop certain scientific skills like reading an instrument. Investigations and exploratory tasks are long term, open ended tasks which demand that learners find relationships between variables and allow them to be creative. Technological tasks are practical activities that demand logical reasoning from learners. For example, learners can be asked to identify a faulty component in an electric circuit. Roberts posits that illustrative experiments are either teacher demonstrations or involve learners following well defined steps. Science teachers use these to help learners to understand scientific concepts or understand procedural ideas. Observation tasks are tasks that may require learners to recall ideas and/ or basic skills. Research shows that many science teachers lack knowledge of the variety of practical work and the skills needed to help learners reach the desired objectives of different practical activities (Abrahams & Millar, 2008). There is a need to help science teachers understand the different types of practical work to enable them to effectively use practical work as a teaching strategy.

Roberts (2004), reports that practical work is one way of teaching science. Practical activities can be used to help learners to develop a deeper understanding of scientific concepts among other reasons. Teachers who lack the skills to help

learners make connections between observations and the scientific concepts use practical work to obtain data only (Millar, 2004). This causes learners to perceive practical work as boring and unimportant. Learners will take practical lessons as 'free' periods where they sit and see what happens without thinking and reflecting on what they see in the light of the learnt concepts. Without good planning and making the outcomes of the practical explicit, practical work is unproductive (Hodson, 1991). In contrast, Millar (2004) asserts that practical work is more interesting and more useful to learners in comparison to other teaching and learning strategies when it is used correctly. He adds that learners construct complex mental representations of the world by acting on it.

Practical work makes science education unique (Millar, 2009), and science education researchers believe that practical work is an essential feature of science education (Abrahams & Millar, 2008; Kirschner, 1992). Other researchers in science education agree that practical work is a key teaching strategy which when used 'correctly' can facilitate theory development in learners (Ng & Nguyen, 2006; Millar, 2004; Abrahams & Millar, 2008). For this reason science curriculum reforms in the past years has shifted emphasis from teaching science as a body of knowledge to emphasis on experiences of the methods and processes of science (Kirschner, 1992). Although practical work has a range of pedagogical functions in science, Kirschner argues that it is not very useful in facilitating knowledge acquisition in learners. On the contrary, I believe that if teachers are equipped with the necessary practical work teaching skills, they can use practical work effectively to help learners understand science content knowledge better.

Kirschner (1992) asserts that properly planned practical work facilitates learners' deep understanding of science concepts. For learners to access the target concepts the objectives of practical activities should be well related to the curriculum objectives. There should be a provision for learners reflect on their experiences, engage in systematic thinking and relate their experiences to theory. It is the teacher's duty to facilitate this in the classroom. Millar (2009) asserts that although practical work may serve different purposes, the main purpose of practical work in school science is to help learners to make links between what they observe during a practical activities and the scientific concepts. According to Millar irreversible learning of science concepts rarely happens as a result of a single practical event.

He adds that a good teacher is one who makes the objectives of the practical explicit, designs relevant activities for learners with due consideration of the learning demands of the activity, logically structure the activities, plans what students will do with objects and ideas, suggest possible explanation of data and have different ways of presenting the practical activities. The teacher should have a good plan for discussions before and after the investigation to ensure its success. I believe these strategies can help learners to develop a deep understanding of the target science concepts and help learners to see the interrelatedness of the concepts and phenomena. This holistic approach to teaching can help to motivate learners to learn science.

Millar (2004) warns against starting with data gathering expecting that ideas will 'emerge' from data. This concurs with Kirschner (1992) who assert that practical experiences do not give theory meaning but it is theory that gives experiences meaning. This is in line with the constructivist theory of learning which views prior knowledge as important for knowledge construction. I have therefore located my study within a social-constructivist perspective of learning.

In the South African context Stoffels (2004) asserts that science teachers heavily depend on traditional teacher-centred transmission teaching methods with little attention given to practical work. In his investigation of teachers' response to curriculum change, Stoffels found that teachers emphasised learners' development of observation skills. Worksheets were used with learners following prescribed steps in the work sheet. Dudu & Vhurumuku (2012) also assert that some science teachers' cannot plan and use open ended inquiry activities in their teaching of science. In their study Dudu & Vhurumuku report that such teachers give excuses to their use of close ended inquiry activities. Some of the excuses include lack of time, overloaded curriculum or shortage of material resources. Teachers need to be trained in the use of practical work in their teaching.

The South African Physical Science curriculum has shifted from a teacher-centred theory loaded curriculum to a learner-centred curriculum (Stoffels, 2004). Despite the improvements made to the South African science curriculum, very little attention was given to in-servicing teachers to ensure that they have the required skills to cope with the changes implemented (Rogan, 2004). For this reason it seems each

individual teacher has to find solutions to his or her own problems. This may be one reason for teachers' failure to use practical work correctly leading to the loss of valuable learning opportunities for learners. While the intentions of integrating practical work in the teaching and learning of science are noble, teachers lack guidelines of what the integration should look like in practice and how they should go about using practical work in their different contexts. Dudu & Vhurumuku (2012) recommended that in-service training programmes should be established to teach educators on how to use practical work in their teaching, curriculum interpretation and interpretation of their own teaching. They add that although teachers may know the curriculum expectations, they may not know how to translate the goals into classroom instructions.

Some scholars however question the role of practical work in learning. Hodson (1991) asserts that in many countries research has shown that practical work is misunderstood, confused and does not produce the desired results in learners. These findings concur with Muwanga-Zake (2001) who found that in the Eastern Cape province of South Africa the majority of science teachers lack practical work skills and conceptual knowledge necessary to help learners to understand the science concepts. He reports that such teachers rarely do practical work. The effectiveness of practical work in helping learners to understand science concepts therefore depends on the expertise of the teachers in using it as a teaching strategy.

My study examines the lack of guidelines in the use of practical work as a teaching strategy by exploring the ways a physical science teacher might design lessons and assist learners to make connections between their practical work observations and the theory in teaching iron and gold extraction at Grade 11. In this study I focused on how I designed practical work tasks and how I used practical work experiences to mediate the learning of the target theoretical concepts. I looked at the ways I helped learners to develop a deeper understanding of science concepts, how I promoted continuity and encouraged learners' participation through link-making in my lessons. For example, I wanted to find out if learners had the opportunities to manipulate equipment and if they were afforded time to reflect and discuss what they have learnt.

2.2. Constructivism and the learning and teaching of science

Within the social constructivist theory I draw on both the cognitive theory of Piaget (1972) and social-cultural learning theory of Vygotsky (1978). Social constructivists believe that the learner is active in shaping the construction of new knowledge (von Glasersfeld, 1995). They hold that new knowledge emerges as the learner progressively develops hypotheses, examines the hypotheses in the light of prior experiences and re-shapes new understandings. Learners bring into the classroom prior knowledge which tends to influence their learning process. According to constructivism, learners are not passive recipients of knowledge and conceptual change is only possible if their prior knowledge is challenged. This results in the restructuring of the knowledge.

Social constructivism views the teacher's duty as that of providing learner-centred activities which take into consideration the individual differences of learners (von Glasersfeld & Steffe, 1991). The teacher should provide learners with opportunities for exploration, working in groups, discussing and solving problems to ensure that they are actively involved in the learning process. Constructivism asserts that it is the teacher's role to guide learners in the construction of knowledge by providing them with real life hands on activities which depict their everyday life experiences. This assists learners in assessing their own understanding and to refine their prior knowledge in the light new understandings.

According to Millar, (2004) practical work is a constructivist teaching strategy. He asserts that learners make mental representations of the world by acting on it. Learners' prior knowledge acts a framework for the building of new knowledge or for modifying current understandings in the light of gathered data. Millar posits that the sensory data gathered in practical work activities can either be assimilated into existing schema or mental changes are instituted to accommodate new knowledge and establish equilibrium between the external and internal data. The teacher's role is to mediate the active knowledge construction by learners (Moll, 1990). The teacher does not transmit knowledge but sets up opportunities to facilitate learning. He/she should start with what learners know and move on to what learners should know.

2.3. The teacher's role in the socio-cultural learning theory

Vygotsky (1978) asserts that scaffolding and mediation are necessary to help learners to attain knowledge and skills in the classroom. Through scaffolding teachers assist learners to learn ideas which are above what they can learn without a more capable person. Vygotsky suggested the concept of the zone of proximal development (ZPD) which suggests that learners can learn subject matter beyond their experiential range with the assistance of a more knowledgeable person who bridges the distance between what the learners can do or know without assistance and what they can do or know with help. He asserts that scaffolding assists in making learning easier. The teacher can achieve scaffolding by giving clues, providing information to guide them, beginning practice with simpler materials or demonstrating the task at hand during lessons. Once the learner has mastered the skills and knowledge, it is possible to move to a higher level of learning. Vygotsky views mediation as an intervention strategy in which the teacher asks questions to lead learners to derive answers using their own thinking abilities. The learners are expected to master the enquiry process and use it in solving future problems independently without the teacher's guidance. This can be done by giving learners opportunities to discuss a question raised, share notes or engage in group activities and discussions.

Vygotsky (1978) views learning as a social process which should involve the interaction of the learner, the teacher and the learning material. According to Scott, Mortimer & Ametller, (2010) the teacher's role in a teaching-learning environment is to impart knowledge in the classroom and help learners to construct their knowledge through link-making. In my study socio-cultural theory is used as an analytic lens to look into the types of interactions which take place during the observed lessons. The theory views learning and teaching as collaborative exercise where learners are given opportunities for discussions, doing practical work, reflecting on the work or do group work activities. Since the main aim of this research is to analyse the nature of the interactions the teacher and learners have in order to enable learners make connections between practical work experiences and the science concepts targeted, the concept of pedagogical link-making provides an appropriate framework to look into my practice.

2.4. Pedagogical link-making

Pedagogical link-making is a conceptual framework which “is concerned with the ways in which teachers and students make connections between ideas in the on-going meaning-making interactions of classroom teaching and learning” (Scott, Mortimer & Ametller, 2011, p.3). The concept is based on Vygotsky’s socio-cultural perspectives which suggest that learners build knowledge by making sense of new ideas in the light of what they already know. Scott and his colleagues identified three forms of pedagogical link-making, namely; to support knowledge building, to promote continuity and encourage emotional engagement. Pedagogical link-making to support knowledge building consists of six approaches discussed below. Pedagogical link-making to promote continuity involves making links to develop a specific story and to manage or organise the activities in the classroom. Pedagogical link-making to promote emotional engagement is composed of two approaches namely, pedagogical link-making to address substantive content and generic approaches.

Due to the scope of a Master’s project I could not explore all the three forms of pedagogical link-making. I used pedagogical link-making to support knowledge building and its six approaches to analyse my data. I strongly believe that the main purpose of teaching is to promote a deep understanding of scientific ideas by learners. So the use of pedagogical link-making to support knowledge building and its six approaches is essential to achieve this goal.

The six pedagogical linking-making approaches which address knowledge making in pedagogical link-making to support knowledge building during different classroom interactions are, making links between every-day and scientific ways of explaining, making links between scientific concepts, making links between scientific explanations and the real world phenomena, making links between modes of representation, moving between different scales and levels of explanations and analogical link-making. Making links between every-day and scientific ways of explaining (approach 1) entails the teacher assisting learners to make connections between scientific language and social language in order to help them develop a deep understanding of science conceptual knowledge. Scott, Mortimer & Ametller, (2011) assert that where the common-sense and scientific ways of explanations

coincide, the learner should integrate them and where the two ways of explanation are different the learner should differentiate them. Making links between scientific concepts (approach 2) involves learners developing an understanding to relate science concepts to each other. The teacher should help learners to see the interconnectedness of science concepts. This can be done by drawing mind maps to show the relationships between concepts. For example, concepts such as force, momentum, acceleration and velocity are related to each other.

Scott, Mortimer & Ametller, (2011) identified making links between scientific explanations and the real world as the third approach which entails the teacher helping learners to make connections between scientific ideas and the real materials relevant to their context. Making links between modes of representation (approach 4) concerns helping learners to make connections between the different ways of representing scientific knowledge. For example, learners should be able to interpret graphs, tables, chemical equations, fractions, negative numbers and molecular formula. Moving between different scales of and levels of explanation (approach 5) involves helping learners to make connections between the macroscopic properties (what learners can observe or measure) to the microscopic properties (what cannot be observed by our senses) and the symbols used in science. Teachers should make learners aware of the transitions they make between the different levels of explanation in order to assist learners to make connections between the different levels. The sixth approach is analogical link-making. Here the teacher should help learners understand the taught concepts by making use of familiar analogies which can assist learners to understand the target concepts.

2.5. The learning and teaching of iron and gold extraction

I could not find relevant literature about the learning and teaching of gold and iron extraction. From personal experience, the chemistry of the blast furnace and gold recovery usually poses challenges to learners at Grade 11 because of the complex nature of the equations involved. Gold is not found in school laboratories because it is expensive and rare. Iron ore reaction with carbon does not happen easily. For these reasons teachers use other copper (ii) oxide rather than iron (ii) oxide and gold ore to imitate the extraction of the two precious metals. Learners find it difficult to link practical work experiences to the concepts taught in this section. There is, therefore,

a need for teachers to help learners to link the observations and ideas from related chemical reactions to what takes place when the actual metals are extracted. This is often neglected by science teachers.

Treagust, Chittleborough & Mamiala (2003) assert that chemistry teachers refer to chemical phenomena at three different levels of representation namely macroscopic level, symbolic and at sub-microscopic level. At macroscopic level we look at the observables and/ measurable properties. For example, properties such as volume, shape, mass, and colour are macroscopic. At microscopic level matter is made up of tiny particles and we use models and theories to explain what we observe. All substances are represented by symbols. For example, copper is represented by the symbol Cu and iron by Fe. These levels of explanations are directly related to each other. If chemistry teachers fail to explicitly show the connections between the levels of representation to learners during explanations, learners may find it difficult to learn the intended concepts. Learners need to track teachers' explanations carefully in order to understand the reactions that occur. Teachers use symbols, chemical equations and words in an attempt to help learners understand the concepts. Learners usually get lost in the explanations and develop a negative attitude towards the subject.

Teachers often assume that learners can easily transfer from one level of representation to another (Johnstone, 1982). For example, in the chemistry of the blast furnace learners cannot easily notice the relationships between what they do with the chemicals and the complex equations and reactions which take place at different layers of the blast furnace. It is my opinion that science teachers should assist learners to make links between their practical work experiences and the target concepts in order to foster deep understanding of the concepts in learners. There is a need for science teachers to use the three different levels of representation in their explanations to help learners make connections between the levels in order to assist them to understand the concepts.

CHAPTER 3: RESEARCH DESIGN

Khothari (2004) defined research design as a specific outline explaining how the research method chosen is used to answer specific research questions. Research design includes research methodology, sampling procedures, data collection procedures, data analysis procedures and instruments used. Research methodology is a systematic way of solving the research problem which includes the research methods used.

Mine was a qualitative research study which adopted a self-study research design. In this section I start by explaining self-study and then describe the data collection procedures, research instruments used, sampling techniques used and their justification and how the data was analysed. I also describe how reliability and validity were ascertained for this self-study. I finally look into possible ethical issues considered during my study.

3.1. Self-study

There are multiple definitions of self-study in literature. Samaras (2002) defined self-study as the critical examination of one's practices and the context of the practices in an attempt to improve one's professional practice. Similarly, Beck, Freese, and Kosnik (2004) defined self-study as a personal on-going collaborative inquiry into one's personal professional practices in order to construct knowledge which can help in improving the teachers' practices. Both definitions put emphasis on the 'self', collaboration, and construction of useful knowledge. In addition the latter scholars assert that teachers do self-study in order to develop a deeper understanding of themselves for personal renewal, professional renewal and program renewal. In my study, self-study means the collaborative study of one's professional practices and one's professional ideas in order to generate new knowledge and understandings which can help to improve the professional practice of self and that of others.

Scholars report that there are methodological problems in self-study. For example, Pinnegar (1998) asserts that there is no correct way of doing self-study. Self-study uses methods borrowed from other research designs (Bullough & Pinnegar, 2001). The methods used to collect data bring into question the validity, rigor and trustworthiness of the conclusion drawn from such a study. This is because blending

of methods leaves it with no theoretical backing in isolating data. In addition, there arise the issue of bias and subjectivity in reporting data which compromises its integrity as a research design (Loughran, 2007). Bullough & Pinnegar, (2001) assert genuine self-study scholars should not look at the 'self' when carrying out research but focus on the distance between the self and the practice. One should be able to see beyond the self in order to get data and conclusions that can improve the professional practice of the self and that of others. This is only possible if the methods used are clear, there is collaboration with others, there is formalization of the research and multiple and ways of collecting data are used (Loughran, 2007). Loughran adds that self-study researchers can collect valid, credible and reliable data if the investigators isolate the specific aspect of practice to be looked at and identify the philosophy of the practice used and check it against traditional beliefs.

In my study, I specified the methods of data collection so that if anyone wants to do the same investigation in a similar context may get similar results. I isolated the specific aspect of practice which I was looking at as is recommended by Loughran (2007). In addition, I specified the theoretical framework used to look into my practice, I constantly engaged in reflection of my practice while collaborating with colleagues. Although self-study has so many limitations, I did my best to remove my personal biases and focused on pedagogical linking-making in my class.

3.2. Data collection

Samaras, Beck, Freese & Kosnik (2005) state that classroom teachers can carry out self-study by studying their classroom practices and strategies in order to reform the practices within the context of wider educational goals. They recommend that multiple methods of data collection be used in order to obtain rich data. Video recording, audio recording, personal reflections and lesson plans can be used for data collection.

In order to reduce bias it was necessary to use data collecting methods that allowed me to sit and observe my teaching after the lesson was over. I used video recorder and audio recorder to capture six consecutive lessons; three practical work lessons on the chemistry of gold and iron processing and three consecutive theory lessons which followed the practical tasks. I also looked at the forms of interactions which I promoted in order see how the interactions facilitated link-making. I did this by

recording some field notes when learners were carrying out practical activities and soon after each lesson. I then transcribed the recordings by playing the recordings repeatedly on the computer while typing all words. Long pauses and gestures were also recorded to provide me with additional information.

3.3. Validity, reliability and trustworthiness

I gave my videos to two colleagues and to my supervisor to seek alternative ways of representing the data for reliability and validity reasons. The two colleagues were college students doing second year Masters of Science in Education at university. This is in agreement with Samaras (2002) who asserts that for validity reasons there is a need to do the research in collaboration with colleagues who can give alternative interpretations to the findings. Lassonde, Galman & Kosnik (2009) assert that self-study may use narratives to express practical knowledge. The narrative approach raises a question of trustworthiness and validity of the findings. Feldman (2003) recommends that self-study researchers should clearly provide and describe how data was collected, describe clearly how data was represented, use multiple ways of collecting data and multiple ways of representing data and give evidence of the importance of changing teaching practices in order to improve on the validity and trustworthiness of the findings. In this study I made my inquiry methods transparent by allowing other science teachers to criticise the way I represented my data for validity purposes.

3.4. Context of the study and sample size

The study was conducted at a state high school in Benoni which I called Tinto High school so as to disguise its identity. The school is located in a farming area and comprises of learners coming from the neighbouring townships. The language of instruction is English. The research was conducted with one Grade 11 physical sciences class of 32 learners of mixed ability and gender. Focus was on the teacher practices and not the learners.

3.5. Ethical considerations

Ethical issues were taken into consideration in this investigation. I obtained clearance from Wits ethics committee to ensure that learners' rights were not violated. The learners were informed of the purpose of the research and asked to

complete the consent forms before the research began (Creswell, 2012). I was granted permission to carry out the investigation at the school from the principal of the school, the Department of Education, learners' parents/guardians and learners before carrying out the research. I respected the decisions of the participants by not video recording those who declined to be recorded without taking away their learning privilege. I ensured that the names of learners remained anonymous (Creswell, 2012). I made sure that safety precautions were adhered to, to avoid exposing learners to risk. All windows were open to allow free air circulation and learners were provided with safety goggles, cloves and aprons.

3.6. Analysis of results

To analyse data I used the six approaches of pedagogical link-making to support knowledge building as indicators. The six approaches include making links between every-day and scientific ways, making links between scientific concepts, making links between scientific explanations and real world phenomena, making links between modes of representation, moving between different scales and levels of explanation and analogical link-making (Scott, Mortimer & Ametller, 2011). The six approaches were discussed in chapter two. In my lessons I looked for the six indicators to determine the ways I helped learners to make connections between their experiences and the target concepts. I used the approaches to analyse the teacher-learner interactions in the classroom and find out how the interactions helped learners to develop a deeper understanding of the concepts.

To prepare data for analysis, I transcribed the videos into text data. I did this by playing the videos repeatedly on a computer while typing the proceedings of the lessons (Creswell, 2012). In my transcripts, I divided each lesson into five minute intervals. I included the field notes on the margins for specific lessons. After transcribing the data I used the six approaches as codes to organise my data. The six approaches to pedagogical link-making to support knowledge building, (1) making links between every-day and scientific ways of explaining, (2) making links between scientific concepts, (3) making links between scientific explanations and the real world phenomena, (4) making links between modes of representation, (5) moving between different scales and levels of explanation and (6) analogical link making were abbreviated as Ap1, Ap2, Ap3, Ap4, Ap5 and Ap6 respectively. I used

these as codes on the margins of my transcripts. The coding process was done by repeatedly reading the transcripts to look for any signs of link-making in the lesson. Field notes were also taken into considerations during the coding process.

After coding the data, sections of the data which contained link-making were recorded in Appendix B. The words and phrases that illustrated link-making were underlined and the corresponding codes were given on the margins. For each lesson, a brief description of what the lesson was about was given. In addition, I added a summary of what learners were doing and what I did (see Appendix B).

I summarised my coded data quantitatively in Appendix A. I did this by determining the frequency at which each pedagogical link-making approach was used for the segments of the lessons. For each code I specified what learners were doing or what I was doing. After coding my data, I gave my transcripts to two colleagues to look at the videos, the transcripts and the coded data to find out if I captured the transcripts correctly. I made few adjustments according to their recommendations before writing my discussion of results. My supervisor helped to revise my transcripts and code the data.

CHAPTER 4: RESULTS AND DISCUSSION

In this section, I discuss the trends emerging from my data analysis in terms of pedagogical link-making patterns in the sequence of lessons on mining. The focus of my analysis was on how I helped learners develop understanding of science content knowledge about the extraction of iron and gold. I observed my practice in a sequence of six science lessons which included three practical work lessons and three theory lessons. The use of a sequence of lessons is in agreement with observations in literature. For example, Millar (2009) who asserts that durable long term learning can only result from a series of lessons composed of a variety of activities.

Since I view pedagogical link-making to support knowledge building as key to facilitating understanding of concepts by learners, I focused only on its six approaches to analyse my data. The six pedagogical link-making approaches are: making links between every-day and scientific ways of explaining (Ap1); making links between scientific concepts (Ap2); making links between scientific explanations and real world phenomena (Ap3); making links between modes of representation (Ap4); moving between different scales and levels of explanations (Ap5) and analogical link-making (Ap6). I looked at the instances in the lessons where each of the six pedagogical link-making approaches is best illustrated and determined how effective it was in facilitating learner conceptual understanding. I described in detail the way how I analysed my data in chapter three. The approaches to pedagogical link-making to support knowledge building were explained in chapter two.

For purposes of anonymity, all learners have been assigned pseudonyms. They are code named L1, L2, or L3 where L represents a learner and the number distinguishes the learners. A general discussion of what learners were expected to learn in each of the six lessons was presented in Appendix B.

4.1 Summary of the emerging patterns

Pedagogical link-making to support knowledge building was observed in all lessons. Data analysis revealed a variable use of the different pedagogical link-making approaches in different types of lessons. The following themes emerged from the data:

1) That only two approaches were used in practical activities, that is, Ap1 and Ap2.

2) That all six pedagogical link-making approaches were used in theory lessons and in my introductions to all lessons. Some were used more often than others.

3) That pedagogical link-making approaches Ap3 and Ap6 were the least used in all lessons.

4) That pedagogical link-making Ap1 and Ap2 were the most frequently used in all lessons.

I now discuss the themes in detail.

4.2 Pedagogical link-making during practical work activities

During practical lessons learners worked cooperatively in groups of five following instructions to carry-out the tasks and discuss their findings. By practical work here, I mean activities where learners manipulated and observed materials and real objects in the laboratory only. During the practical lesson I helped learners in discussing and explaining their data. Learners used every-day language in describing and explaining observations. I also used everyday language as well as scientific language in giving instructions and explaining results. The excerpts from practical lesson (1) and (3) given below illustrate the use of Ap1 and Ap2 by both learners and myself.

In lesson 1, learners worked in groups of five to carry-out a practical activity to test for carbonates in two different stones using hydrochloric acid. This lesson was intended to introduce learners to mining processes such as grinding, milling and testing for minerals in rocks. I expected learners to develop an understanding of why stones containing mineral ore should be ground into powder before extracting the mineral. I introduced the lesson by providing learners with two stones which they had to examine before testing for carbonates. The extract below illustrates the link-making that took place in one instance during the lesson.

> 1. Teacher: We want to react each of the stones with hydrochloric acid. Can you suggest what should be done to each of them to make it react faster with hydrochloric acid? I believe

that you all know that it is not easy to dissolve lumps of salt in water. What should be done, say to make the salt dissolve faster?
2. L1: We put it in sulphuric acid.
3. L2: No! We should crush it into powder.
4. Teacher: Yes crushing it helps to make it react faster. Do we all agree?
5. Learners *(In a chorus):* yes
6. Teacher: Can you explain why powder reacts faster than chunks?
7. L1: *(used signs which I could not understand)*
8. L2: Its mass become greater.
9. Teacher: Does the mass change? Where does extra mass come from?
10. L4: I remember that grinding a substance into powder increases its surface area.
11. Teacher: Yes, L4 is right grinding a substance increases its surface area. For substances to react with each other, their particles must collide with each other. If the number of collisions per unit time increases, then the chances of the particles to collide and react with each other also increase. Think of the cooking of meat. Mincemeat cooks faster than chunks of meat and maize meal cooks faster than cooking maize grains. It is because powder reacts faster than lumps. Let us grind our stones into powder before adding to dilute hydrochloric acid.
(Excerpt from lesson 1: testing for carbonates)

In this excerpt my intention was to help learners to think about the observations using the correct scientific ideas. (Turn 1) I guided discussion with questions on the scientific ideas they should use to interpret their observations. I asked learners to predict what should be done to the stones in order to make them react faster. Making predictions encouraged learners to reflect on their prior knowledge hence promoting the linking of scientific ideas (Ap2). The use of learner predictions before doing a practical activity is supported by Abrahams and Millar (2008) in the United Kingdom who observed that this approach helps learners to think about scientific ideas while doing the practical activity. They also observed that explaining relevant concepts before doing the practical activity helped learners to think about the observables using appropriate ideas. I used an everyday life experience (Ap1), for example, the dissolution of salt in water to explain the scientific concepts needed to explain the grinding of reactants before a chemical reaction. This helped learners to think about ways of making the stones react faster. (Turn 11) I explained to learners the reasons why mincemeat cooks faster than chunks of meat. In doing so I used Ap1 to help learner understand the reasons for grinding the stones. Learners would need to use this knowledge in lesson. I therefore helped learners make links between the current lesson and the future lesson.

The explanations given by learners were based on their everyday experiences and prior knowledge. For example, L1 decided to use sulphuric acid because he knew from the previous lesson that it is a strong acid which reacts relatively faster than hydrochloric acid. Although the answer was incorrect, L1 was able to link back to concepts learnt in the previous lesson. Open ended questions was the strategy used

in this case to help learners to make links between every-day and scientific ways of explaining. (Turn 11) I also explained why the reaction happens faster which helped learners to make links between scientific ideas. In my explanation, I moved from the macroscopic (observables) to the microscopic (Ap5) and helped learners to recall that all matter is made up of particles which should collide for the reaction to occur. My reference to particles would help learners to make connections between scientific concepts (Ap2). In this excerpt I made use of Ap1, Ap2 and Ap5. Learners used Ap1 in their explanations.

The extract below was taken from lesson 3. In this lesson learners heated a homogeneous mixture of two powders, copper (ii) oxide with carbon in a crucible. Copper (ii) oxide reacted with carbon to produce copper metal, a brown solid and some carbon on top of the crucible burnt in air to produce a dim glow. As I passed by, a learner shouted for my attention with amusement:

1. L1: Sir, this thing changes colour sir…., It changes colour to red.
2. Teacher: Did you observe a colour change?
3. L1: yes……
4. Teacher: When did it happen? Record your observations.
5. L1: now…..now. Come and see.
6. Teacher: What do you think caused the colour change?
7. L2: *(hesitant)*….temperature.
8. Teacher: What does the temperature do? How does temperature cause this change?
9. L3: It is increasing……..
10. Teacher: Yes, high temperatures may cause certain things to glow but is it the case here? I want you to find out the cause of the colour changes. Remember that the burning of some substances produces a glow while others become red hot when heated –which is a physical and reversible change. Could this be due to something burning or the substances turning brown permanently due to a chemical change taking place? You can refer to textbooks and notes which I provided at the beginning of the lesson for explanations. You should be able to explain the changes in terms of the chemical reactions taking place if the change is permanent.

(Excerpt from lesson 3: imitating iron extraction)

In this extract learners drew from their everyday knowledge in explaining the colour changes which they observed (Ap1). Learner L2 could recall from every-day life experiences that when a substance is at a very high temperature it glows (Turn 7). He did not know or remember however, that temperature increase does not always cause things to glow. For example, high temperatures may cause things to burn, melt or react with one another. I then guided the learners to think about the correct scientific explanation about the change based on the possible chemical reactions taking place. I reminded learners to look back to the theory lesson for explanations (turn 10). In doing so, I was providing learners with a link between their observations

and the concepts learnt in the theory lesson which would be pedagogical link-making approach Ap3. I encouraged learners to refer to textbooks for explanations. I deliberately left the issue unresolved in order for learners to look for explanations. This was an example of Ap2.

In the excerpt above three approaches to pedagogical link-making to support knowledge building were used:

- Making links between every-day and scientific ways of explaining (Ap1)
- Making links between scientific ideas (Ap2)
- Making links between scientific explanations and real world phenomena (Ap3)

The next excerpt came from lesson 5. In this lesson learners carried out a practical activity to imitate gold extraction by using copper (ii) oxide. I helped learners to make connections between their prior knowledge and gold extraction processes. Learners had already covered work about reactions of metal oxides with dilute acids and displacement reactions. I had to link these reactions to chemical processes taking place during gold extraction as is illustrated in the excerpt below.

The following discussion took place soon after learners collected apparatus and chemicals. All chemical were in containers labelled with chemical formulae.

1. Teacher: Observe the chemicals which you received and record their initial colours before the reaction.
2. L1: Sir…..sir. What element is this?
3. Teacher: Read on the container….Is that an element?
4. L1: I am not sure. It is labelled CuO, sir.
5. Teacher: Can someone help him out, is this an element? What is its name?
6. L2: That is a compound sir. It is copper (ii) oxide.
7. Teacher: Good. It is copper (ii) oxide. The black substance is copper oxide. If you can remember well, we said compounds are made up of two or more elements that are chemically combined together……remember that elements are represented by a unique chemical symbol. You can look up for the symbols and names of elements on that periodic table. An element is made up of atoms of the same type.
8. L1: Ok so this is copper (ii) oxide….

(Excerpt from lesson 5: imitating gold extraction)

In this excerpt I helped learners to make connections between materials and their chemical symbols (turn1). I encouraged learners to observe the chemicals and record their initial colours. This was Ap3. Learner L1 could not recall the difference

between elements and compounds. He could not link the chemical symbols to the compound. Learners were introduced to compounds and elements in Grade 10, but L1 could not remember that elements are represented by a single symbol while compounds consist of more than one element symbols in their formulae. I engaged learners in a question and answer session to guide them to link their prior knowledge about compounds and elements to the new situation. In doing this they would realise that science concepts are connected. I used Ap2 in this case to assist L1 and others to understand how to differentiate elements from compounds.

It seemed that L1 used the term element from everyday language. By the term element, the learner meant one of the basic substances or units needed together with others for a particular purpose. For example, in geography learners use the term elements of weather to refer to things such as rainfall, temperature or wind speed which are measured to determine weather. I wanted the learner to understand that in physical sciences the term element is used technically to mean a pure substance that is made up one type of atoms. This would help learners to make connections between everyday ways of explaining and scientific ways of explaining (Ap1). By reminding the learner to read the label I wanted him to remember that when more than one symbol is used, the substance is a compound. In doing this he would make links between scientific concepts (Ap2). In this excerpt I used three pedagogical link-making approaches to support knowledge building namely:

- Making links between every-day and scientific ways of explaining (Ap1)
- Making links between scientific concepts (Ap2)
- Making links between scientific explanations and real world phenomena (Ap3)

4.3 Pedagogical link-making in lesson introductions

All my lesson introductions had the most pedagogical link-making approaches to support knowledge building. Since the purpose of the lessons was to help learners develop a deeper understanding of iron and gold extraction, I seemed to explain the underlying concepts which learners were to use for interpreting their data. Abrahams & Millar, (2008) state that lessons which start with learners doing the practical activity

expecting theory to emerge from the data usually fail to achieve the intended goals. This is because what teachers may perceive as obvious to learners may not be obvious. All the six link-making approaches were used in the lesson introductions. This is illustrated in the extract of lesson 5 given below.

> 1. Teacher: Good morning boys and girls. In the previous lesson we used our knowledge about chemical reactions to explain the extraction of iron. In today's lesson we will imitate gold extraction. We do not have gold so we will use copper (ii) oxide. This is because the reactions of copper (ii) oxide are similar to those of gold. In previous lessons we covered work on types of chemical reactions which includes acid and base reactions, redox reactions and displacement reactions. Who can remember what we said are the products of an acid and base reaction?
> 2. L1: Salt and water.
> 3. Teacher: Good! And what name is given to an acid and base reaction?
> 4. L2: It is called neutralization. I remember that the reaction releases heat energy. We said that neutralisation reactions are exothermic.
> 5. Teacher: Thank you L2. You have a good memory. Remember that we liked acid-base reactions as partner exchange reactions where cations and anions exchanged positions. We also learnt that when a more reactive metal is place into a salt solution of a less reactive metal, displacement took place. Can you recall what happened when L2 added magnesium to copper (ii) sulphate solution?
> 6. L1: Yes sir, I remember that the blue colour of the solution disappeared and heat energy was produced. I also remember that the magnesium powder disappeared
> 7. Teacher: Great! That is an example of a displacement reaction. Magnesium displaced copper in the solution and copper metal was precipitated. This is a redox reaction where copper was reduced and magnesium is oxidised (I wrote a chemical equation on the chalkboard to illustrate this). You can see that the oxidation number of magnesium increased while that of copper decreased. We should use these ideas to explain our results in this activity.
> (Excerpt from lesson 5: imitating gold extraction)

My main aim in lesson 5 was to help learners understand chemical reactions that take place during gold extraction. In the extract above I started by linking the previous lesson to the current lesson thus taking an Ap2 approach. Analogical link-making, Ap6 can be seen where I used copper (ii) oxide instead of gold (turn 1). Throughout this practical lesson I wanted learners to see the similarities between copper and gold extraction and make the link. In reminding learners about the different chemical reactions covered I wanted them to make links between the concepts. I helped learners to recall the reactions through question and answer. By asking learners to state the products of acid and base reactions I was helping them to use their prior knowledge about chemical reactions and link it to the current lesson. I was using Ap2 to help learners to link their knowledge about types of chemical reactions to the extraction of gold.

In this excerpt I also used everyday language to explain phenomena (turn 5). For example, I used the term "partner exchange" to explain acid and base reactions.

Most learners at the age of 15 to 18 are interested in relationships and I therefore used a term familiar to them to draw their attention. The use of the term “partner exchange” can both be viewed as analogical and use of everyday language to explain phenomena (Ap6 and Ap1). In turns 4 & 5 the learners and I used scientific language to explain phenomena. For instance, learners described neutralisation reactions as exothermic reactions and I explained oxidation and reduction in terms of oxidation numbers. This excerpt exemplifies the use of Ap1 and Ap6 in the lesson by both learners and the teacher. There were times when I allowed learners to give their ideas freely while at other times I informed learners about the ideas in an attempt to save time.

Also in the excerpt above, I used different ways of representing information. In addition to using words, I used chemical equations and oxidation numbers in order to help learners to understand the concepts (turn 7). The use of chemical equations helped learners to figure out the possible products of the reaction. The use of oxidation numbers helped to show learners the particles which were reduced, oxidised and those that remained unchanged. I drew from Ap2, Ap4 and Ap5 in helping learners to understand the concepts.

4.4 Pedagogical link-making in theory lessons

All six pedagogical approaches were used in theory lessons but some approaches were used more often than others. For example, Ap3, making links between scientific explanations and real phenomena and Ap6, analogical link-making, were used less often compared to others. In theory lessons learners reported data from previous practical activities, attempted to explain results with my guidance and engaged in class discussions. I helped learners with reporting data and guided them to correct scientific explanations. In addition, I explained new scientific term. The pedagogical link-making approaches used are illustrated in the excerpts given below.

The first excerpt was taken from lesson 2. In this lesson learners reported their group results to the whole class. They were required to explain observations using scientific knowledge learnt from theory lessons. My role was to steer the class discussions to the intended goal. I did this by sometimes rephrasing the statements or giving correct explanations where necessary. The aim of this lesson was to help learners to understand the physical and chemical processes involved in mining. I

expected learners to use scientific ideas learnt from previous lessons to explain their observations.

1. Teacher: In the previous lesson you added particles of the white stone to a solution of hydrochloric acid. What did you observe? You should report anything different which you detected using your senses.
2. L1: The solution changed from colourless to milky.
3. Teacher: Milky! Is there any colour called milky? Or are you likening the colour of the resultant solution to the colour of milk?
4. L1: No sir….I wanted to say that the colour of the solution changed from colourless to white.
5. Teacher: Do we agree with L1?
6. Learners: *(In a chorus)* yes sir
7. Teacher: *(The teacher writes the answer on the chalkboard).* What else did you observe? Let us get the answer from the next group.
8. L2: Bubbles of gas were produced. In addition, there were particles which moved up and down in the solution.
9. Teacher: What else you observed, next group! Anything different …..
10. L3: Salt was formed.
11. Teacher: Did you see salt?
12. Learners *:(In a chorus)* Yes sir.
13. Teacher: What colour was the salt? How did you know that salt was formed?
16. L4: We did not see salt but we know from the theory which we learnt that a salt is formed when a carbonate reacts with a dilute acid. That white stone is calcium carbonate. We once used one like that in Grade 10 last year.
17. Teacher: So you did not see salt. What you needed to report is what you observed using your senses not what you know from theory that it was formed. What else did you observe?
18. L5: A shii…i. sound was produced.
19. Teacher: You mean a fizzing sound like that produced by fizzy drinks like coke?
20. L2: Yes the sound was similar.
(Excerpt from lesson 2: introduction to mining)

In the excerpt above I started by linking the previous lesson to the current lesson to promote continuity. I reminded learners of what they did with materials in order to guide them on what to report. This way I wanted learners to connect the concrete to their observations and this was an Ap3 linking-making approach. My guidance was vital in helping learners to report data in a logical manner. Learners used both everyday language and an analogy to describe the colour changes which took place. They described the white colour produced as a “milky” colour (turn 2). Learners could relate the colour of the solution to a common substance they know. I helped learners to realise that milky is not a colour and guided them to state the correct colour changes (turns 3 & 4). The same analogical link-making approach was used by both the learners and me when describing the sound produced. For example, in an Ap1 & Ap6 approach I likened the sound to a fizzing sound produced by carbonated drinks (turn 19).

Learners used prior knowledge to identify the white stone as calcium carbonate and remember that a salt is formed. They could connect a chemical term to the material. Although they did not see salt, they identified salt as one of the products. This could be taken as a sign of successful link making of scientific concepts (Ap2). Learners were able to connect current work with what they learnt before. Although they used the scientific idea incorrectly, learners did make the links in describing their observations. I then helped them to understand that salt was not observed although it was one of the products. This excerpt illustrates how I used Ap1, Ap2, Ap3 and Ap6 in helping learners to understand the concepts.

The next excerpt came from lesson 6. In this lesson we drew on knowledge about chemical reactions to explain the changes observed in lesson 5. I used several link making approaches to assist learners to understand the concepts. Although learners had covered similar work in the previous two weeks, they found it difficult to remember displacement reactions. The extract below exemplifies the link-making approaches which I used to help learners with this difficulty.

1. Teacher: Now that we have reported all our observations we should be able to link the observations to the ideas about chemical reactions. Prior to this activity we looked at redox reactions. In this activity we combined copper (ii) sulphate solution and zinc metal. (The teacher writes the chemical symbols of reactants on the chalkboard as an equation). What do you think happened after mixing the two?
2. L1: Electrons were transferred from one substance to another.
3. Teacher: Why do you think this happened?
4. L2: It is because one substance has more electrons than others.
5. Teacher: Which one of the two has more electrons here? (Learners remained quite). Remember that the reactivity of an element is determined by the valence electrons and not the total number of electrons it has. The electronegativity determines whether the element reacts by gaining or losing electrons. Those elements with a higher electronegativity gain electrons when they react while those with a lower electronegativity lose electrons. Just before we started this section I explained to you about the reactivity of metals to help you with concepts to apply in this section. Have you forgotten already? Use your standard reduction tables please. (Learners and the teacher remained silent for a while).
6. L3: Sir! I can remember that a more reactive metal displaces a less reactive one from its salt solution.
7. Teacher: Good L3. In this case which one between copper and zinc is more reactive? We should use our standard reduction potential tables for this. You should compare the reduction potentials of the elements concerned. The particle that has a more positive reduction potential is most likely to be reduced while the one with a more negative reduction potential undergoes oxidation. So which is oxidized?
8. L4: Zinc undergoes oxidation while copper is reduced.
9. Teacher: Right, let us now use this equation to explain our observations. Let us complete the chemical equation and use it to explain the colour changes which occurred.
10. L5: Copper metal and zinc sulphate solution are formed.
11. Teacher: Good. (The teacher completes the equation on the board). Can you remember the different colours of each of the substances? Here are the samples with me, this is copper metal, copper (ii) solution and zinc metal. (The teacher shows learners the samples).
12. L6: Copper (ii) sulphate is blue; zinc is grey while copper metal is brown in colour.

13. Teacher: Can we now explain why the blue colour disappeared….
(Excerpt from lesson: gold recovery)

This excerpt is rich in pedagogical link-making approaches to support knowledge building. It starts with a reminder to learners about what we did in the previous lesson to show continuity. I then informed learners that they should use their knowledge about chemical reactions to interpret their data (turn1). This way I helped learners connect the scientific concepts (Ap2). I did this to illustrate that science concepts are interconnected to form a network; one concept can be used to explain another.

In my explanations I used scientific language to help learners to understand the concepts (turn 1). For example, I used terms such as electronegativity and valence electrons to help learners to understand the reaction between copper (ii) sulphate and zinc, thus Ap1 & Ap2 approaches were used. I also used chemical equations and chemical symbols to assist learners' understanding. For example, I wrote an incomplete chemical equation to represent the mixing of copper (ii) sulphate and zinc. In doing this I helped learners to connect materials to symbols used to represent them. From the symbols I could explain to learners that matter is made up of particles whose electrons are transferable. I moved from the macroscopic (observables) to the symbolic to the microscopic (molecules and electrons) in my explanations in order to help learners develop a deeper understanding of the concepts. For this I drew on Ap1, Ap2, and Ap4 & Ap5 approaches.

In turn 5, I used scientific language to explain the reactivity of metals. For example, I explained to learners that valence electrons determine the number of electrons transferred while electronegativity determines whether electrons are lost or gained. In addition, I helped learners to link the ideas of valence and electronegativity. I also asked learners to look back on the reduction potential tables to enable them to determine the substance that was oxidized and the one that was reduced. I explained that the element with a more positive electrode potential undergoes reduction while that with a less positive electrode potential undergoes oxidation. The concepts which I managed to link are electronic configuration, electro-chemistry and recovery of metals. In doing this I was helping learners to realise that science concepts are interconnected and that one concept can be used to explain another. I believe that if learners come to that realisation, then it becomes easier for them to

understand the science content. Link-making approaches Ap1, Ap2 & Ap4 were used.

In order to guide learners to explain the causes of colour changes that took place I used examples of materials such as copper (ii) sulphate, zinc metal and copper metals (turn 9). I used the materials together with the chemical equation to help learners to identify the colours of each substance. This would help learners to understand that copper (ii) ions are blue in colour when they are in water but copper metal, which is made up of many copper atoms is brown in colour; that zinc disappeared because it is oxidized into zinc ions that are colourless. I also used both scientific and everyday language to help learners to understand the concepts. I made use of other science concepts to give my explanations. Thus Ap1, Ap2, Ap3 & Ap5 were used in assisting learners to think about ideas I intended them to understand.

In Summary the discussion above illustrates how I managed to use all pedagogical link-making approaches to promote knowledge building. Although the selected excerpts covered a very short period of time it shows that I made many pedagogical link-making moves in my lessons. It is clear that more link-making approaches were used in theory lessons and lesson introductions than in practical lessons as is illustrated in the excerpts. The excerpts used show that I relied more on Ap1 & Ap2 in both theory lessons and practical activities. The least used approach was Ap3 and Ap6. Scott, Mortimer & Ametller (2011) assert that pedagogical link-making is fundamental in helping learners to develop deep understanding of science content knowledge. Better learner performance in class activities given to them was indicative of improved understanding of science concepts. I also witnessed improved learner participation from the time I consciously helped learners in the link-making process. Data shows that both learners and I were involved in link-making.

CHAPTER 5: CONCLUSION

The excerpts chosen show that the full range of pedagogical link-making approaches to support knowledge building was used by me. I used Ap1, making links between every-day and scientific ways of explaining and Ap2, making links between scientific concepts to large extend in an effort to help learners understand the scientific content knowledge which is usually alienated to learners' everyday life experiences. I used everyday language together with scientific language to bring the scientific knowledge to the level of learners. In some cases I looked for everyday life experiences familiar to them in order to bring science close to what they already know. For example, mincemeat was used to explain why grinding makes the reaction to happen faster. Learners are familiar with this example than the use laboratory chemicals. I did this by allowing learners to express their views freely in class discussions.

I allowed learners to reflect on their prior knowledge to help them to link scientific concepts. In many cases I used questions to direct learners to correct ideas. For example, I asked learners to explain how we can use reduction tables to identify the substances that are oxidized and those that were reduced. This helped them to look back into what they had learnt before and link the knowledge to the new situation. In some instances I ended up telling learners in order to save on time. I did this to help learners to see science knowledge as a unity and show the interconnectedness of concepts. For example, iron gold extraction can be explained in terms of electrochemical reactions, displacement reactions and redox reactions. Learners and I used terms such as reduction, oxidation, reducing agent, oxidizing agent, homogeneous mixture, precipitation, electronegativity, oxidation number and half-reactions in our discussions to show how they relate to each other. This is in agreement with Vygotsky (1987) who suggest that the teacher should address science concepts in the social plane in the classroom to enable them to engage with them on the personal plane.

It is evident in the extracts from lesson 1, 3 and 5 that with help learners were able to interpret their observations using science models learnt in theory lessons. I did this by introducing the ideas which I expected learners to use in the interpretation of data. For example, I started by presenting the equation for the reaction of copper (ii)

sulphate and indicated the colours of each substance before asking learners to explain the colour changes they observed. In doing so I used Ap4, making links between modes of representation. In addition to the use of Ap4, Ap5, moving between different scales and levels of explanation was used. Balanced chemical equations, half-reaction equations, chemical symbols and oxidation numbers were regularly used in explaining phenomena. I made it clear to learners that I am now moving from one level of explanation to another (Millar, 2008) to avoid confusing learners.

Although Ap3 and Ap6 were used in the selected extracts, they were not used regularly. For example, I used Ap3 when I wanted to demonstrate the colours of copper (ii) sulphate, zinc and copper metals. Learners found it easy to interpret their data after this demonstration. Unfortunately I did not use this approach regularly. I believe this could be the reason why physical sciences appear to be difficult to learners. It seems that as the teacher, I did not consciously make an effort to find concrete applications of the knowledge to learners' lives. Scott, Mortimer & Ametller (2011) found that learners find little motivation in doing a subject which is not related to their everyday life experiences. I realised that in future I should make an effort to use practical work and give concrete examples regularly in my lessons in order to motivate my learners. Data showed that learner participation and interest to learn increased when they carried out practical work.

Also, very few analogies were given in the excerpts above. Scott, Mortimer & Ametller (2011) posit that the use of analogies helps learners to develop a deeper understanding of science content knowledge through link-making. When I likened the sound produced to that of fizzy drinks and the grinding of stones to mincemeat, learners found it easy to understand the concepts by making links to the familiar examples. This is another area of improvement in my practice.

The purpose of my study was to find out the pedagogical link-making moves I make in helping learners to link observations in practical lessons and the theory taught in theory lessons. I did not find any similar research done other than that Scott, Mortimer & Ametller (2011) carried out in the United Kingdom. They investigated pedagogical link-making in Grade 7 science class taught by an experienced science teacher in a theory lesson and found similar results. They found that Ap1 and Ap2

were used more often (6 times for each) while Ap4 and Ap6 appeared once each. Ap3 and Ap5 were not used at all. Contrary to their findings, I found that Ap3 was applicable in practical activities while Ap5 can be used in theory lessons.

My study shows that for the teacher to be able to address all the six pedagogical link-making approaches to knowledge building there is need to have a deep understanding of the concepts and for careful planning. The use of Ap3 and Ap6 needs the teacher to carefully select examples relevant to the context. These examples are missing in conventional school textbooks. The main temptation is that the teacher disregards learners' prior knowledge and resort to traditional methods of teaching such as the transmission of knowledge. I also came to realise that if the teacher uses everyday ways of explaining together with scientific ways of explaining, real world examples, appropriate modes of representation and link scientific concepts, learners find it easy to understand scientific concepts.

Unlike Abrahams and Millar (2008) findings about the effectiveness of practical work that practical activities were effective in helping learners to manipulate materials and less effective in helping learners to understand scientific concepts, I found that with guidance learners were able use ideas to explain their observations. As I mentioned earlier, there is a need for the teacher to plan the practical work carefully. The teacher also needs to start the lesson by introducing the ideas that should be used to interpret data. In addition, teachers must inform learners about the aim and the purpose of the practical lesson before carrying it out. Learners need to be given the instructions in advance so that they can research about the ideas. Where possible I suggest that learners be given a related task to perform at home with materials found in their immediate environment. This will help learners to realise that science is applicable in their everyday experiences.

Both research and teacher development programmes can draw from findings of my study. Teacher educators could make students aware of link-making strategies and demonstrate them to student teachers. A possible area of further research is how learners themselves make links between practical work experiences and theory lessons.

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APPENDIX A

Quantitative analysis of data for link-making

The main purpose of this study is to find-out how I use practical activities to help learners make connections between the observables and ideas. Since the main thrust of the South African physical sciences curriculum is to help learners develop a deep understanding of concepts, I only used pedagogical link-making to support knowledge building in analysing data. All six pedagogical link-making approaches falling under this form of link making were used to analyse data. The six approaches are (1) making links between every-day and scientific ways of explaining, (2) making links between scientific concepts, (3) making links between scientific explanations and the real world phenomena, (4) making links between modes of representation, (5) moving between different scales and levels of explanation and (6) analogical link making. In this study the approaches were abbreviated as Ap1, Ap2, Ap3, Ap4, Ap5 and Ap6 respectively

Time in minutes	Lesson1:introduction to mining: practical activity to test the chemical composition of two rocks (Ap1,2,3,5 & 6 in introduction and Ap1&2 in practical activity)	Lesson 2: introduction to mining: reporting and explaining observations from lesson1 (Ap1,2,4,5&6)	Lesson3:practical activity: imitating iron extraction (a continuation of lesson 2) (Ap1&2)	Lesson4:iron extraction : reporting data and explaining iron extraction using the blast furnace (Ap1,2,4,5 &6)	Lesson5:Practical activity: imitating gold recovery (Ap1 & 2 ; Ap4 appeared once)	Lesson6: gold recovery and conclusion of mining processes (Ap1,2,3,4,5 & 6) Ap3 appeared once
0-5 introduction	Ap3- teacher showed learners various objects made of metals Ap1 &2 -teacher explained the existence of minerals in ores	Ap2-teacher recapped on previous lesson Ap1-learners reported on findings Ap2-teacher helped re-	Ap2-teaccher recapped on previous lesson. Ap1&2- teacher explained the application of chemistry to mining as was	Ap1&2-teacher recapped on the previous lesson Ap1&2-learners reported their results Ap1-teacher helped in	Ap2-teacher introduced the lesson by recapping on previous lesson. Ap2-teacher explained the importance of	Ap1&2-teacher introduced the lesson by reviewing the previous lesson Ap1&2-learners reported data Ap3-teacher

	Ap1-learners briefly described two rocks Ap6- learners gave everyday examples of ground substances that react faster.	phrasing learners' observations	done in lesson 1.Ap1- teacher stated the aim of the practical activity	rephrasing learners' descriptions Ap1-teacher recorded data on the chalkboard.	metals Ap2 -teacher reminded learners about reactions between metal oxides and dilute acids	shows learners two samples Ap1&2-teacher explained precipitation Ap4&5-teacher assisted learners to write word and chemical equations given to explain phenomena
5-10	Ap1-learners used every-day language to describe observations Ap1- teacher re-phrased observations Ap5-teacher used the microscopic model to explain effects of grinding a solid to reaction rate Ap2-teacher used the collision theory.	Ap1-learners reported results Ap2-teacher explained scientific terms Ap6- teacher likening sound produced to fizzy drinks Ap6-teacher referred to condensation taking place in a boiling cooking pot Ap1-teacher guided learners to correct scientific terms	Ap1- teacher gave instructions Ap1&2-learners followed instructions to carry out the investigation.	Ap1&2-learners reporting back findings Ap2-teacher and learners concluded that copper was formed Ap6- learners likened smell produced to a burning tyre	Ap1&2-learners worked in groups following instructions and carryout the practical activity Ap2-learners discuss results and recorded them Ap1&2-teacher discuss results with individual groups Ap4-teacher represented copper (ii) oxide both in words and in symbols	Ap1&2-teacher explained terms correctly Ap5- teacher helped learners to determine oxidation numbers. Ap1&2- learners explained terms
10-15	Ap1- learners followed instructions Ap2-learners made predictions	Ap1-learners reported results Ap2-explained terms	Ap1&2- learners predicted the outcome of the activity	Ap1&2-teacher explained redox reactions Ap1& 2-learners	Ap1&2-learners worked in groups carrying out the practical	Ap1&2- teacher helped learners to explain electron transfers

	Ap2-teacher reminded learners to apply prior knowledge	Ap1 &2-teacher wrote and re-phrased observations on the chalk-board	Ap1&2-learners followed instructions to carry out the practical activity Ap1&2-teacher guided learners and monitored their progress.	report results	investigation and collecting data	in redox reactions Ap4&5- I assisted learners in writing half equations using the redox tables.
15-20	Ap1-teacher gave instructions Ap1-learners followed instructions Ap1-learners collected and recorded data in groups	Ap1-learners reported on temperature changes Ap6-learners likened smell to rotten eggs Ap2&5-teacher described particle movement and writing chemical equations Ap1&2-teacher explained terms	Ap1&2-learners collected data and recorded it. Ap1&2-teacher guided and advised learners on data collection and recording	Ap4&5-learners wrote chemical equations Ap4&5 teacher helped learners to write balanced chemical equations.	Ap1&2-learners worked in groups collecting data and discussing the results	Ap1, 2, 4, &5-learners worked individually practising the writing of half equations. Ap4 &5-learners wrote chemical equations for reactions of zinc and copper sulphate Ap1,2 &6-teacher explains similarities between chemical reactions
20-25	Ap1-learners followed instructions and collected data Ap1 &2 – teacher guided learners on data collection and recording	Ap1-learners reported results Ap1&2-teacher explained terms endothermic and exothermic reactions Ap4&5-teacher	Ap1&2-learners looked for explanations of data Ap1&2 -teacher asked learners to use theory to explain data.	Ap1&2-teacher explained iron extraction Ap4-teacher used diagrams to explain the chemistry of the blast furnace	Ap1&2- learners worked in groups collected data and discussed results Ap1&2-teacher guided learners in data collection	Ap1&2-teacher explained stages in gold mining Ap1&2-learners explained why milling and grinding of ore takes place

		explained particle movement		Ap6- teacher used the copper oxide- carbon reaction as an analogy to iron extraction. Ap5-learners and teacher wrote chemical equations for iron extraction		Ap4&5- teacher asked learners to write down gold – cyanide reactions, balance them and explained the electron transfers that takes place
25-30	Ap1-learners followed instructions ,collected and recorded data Ap2-teacher guiding and discussing with groups	Ap4,&5-teacher helped learners to write chemical equations Ap2- teacher and learners identified phases of substances Ap2-teacher identified the colours of different metal ions and explained spontaneous reactions		Ap1&2-teacher explained why copper oxide formed at the bottom of the crucible Ap1,2 &6-teacher used the reaction in the crucible to explain the blast furnace reactions Ap5- teacher explained the reaction of C and CuO. Ap6-teacher likened these reactions to blast furnace reactions	Ap1&2-learners discussed and explained results in groups Ap1&2-teacher explained test for hydrogen	Ap4 &5-teacher helps learners to write chemical equations for gold recovery Ap2- teacher helped learners to state the oxidation states of reactants and products Ap2-teacher explained the oxidation states of gold Ap2-teacher helped learners to identify bases and acids in a chemical equation Ap2- teacher summarised the topic on iron and

						gold mining
30-35	Ap1&2-learners collected data and recorded it Ap1-teacher informed learners about safety	Ap1&2- teacher and learners drew conclusions		Ap2,4&5-teacher explained the reactions of iron oxides with carbon and carbon monoxide in the blast furnace Use chemical equations to explain the extraction of iron	Ap1&2-learners worked in groups and collected data Ap1&2-teacher assisted individual groups with data collection and recording	Ap1,2,4 &5-teacher summarised mining and the different processes which are used
35-40	Ap1&2- teacher reminded learners about types of chemical reactions Ap2-teacher gave a conclusion and linked the lesson to the next lesson	Ap1&2-learners summarised the lesson Ap2- teacher introduced the next lesson		Ap1, 2, 4&5-teacher summarised iron extraction. Learners answered to questions in their classwork books. Teacher briefly introduced the next lesson.	Ap1&2-teacher explained to learners how data should be kept Learners cleaned up and returned apparatus Ap1&2- teacher gave a conclusion	Ap1,2,4&5- I asked learners write a task on mining-gold and iron extraction

APPENDIX B

Analysis of lessons for link-making

Lesson 1: Introduction to mining: Testing the chemical composition two rocks

This lesson was an introduction to mining. Learners were expected to develop an understanding that miners and geologists need to apply their chemistry knowledge to test for the minerals in the soil before mining. Learners worked in groups of four or five to carry out the practical activity. The class was made of 14 girls and 18 boys of mixed ability. In this lesson learners were presented with two rocks A and B. They used dilute hydrochloric acid to test for the chemical composition of the rocks.

I expected learners to apply the knowledge they acquired during the course about the different types of chemical reactions. I wanted learners to link the knowledge they had acquired in the previous lessons to the science concepts covered in mining. We had covered work on acid-base reactions, redox reactions, displacement reactions, acid and carbonate reactions and stoichiometry.

I started the lesson by asking learners to predict the outcome of the practical activity and then collected data to see if their hypothesis was correct. In doing this I intended to trigger learners' curiosity to find-out if their guesses were correct. Millar (2009) concedes that this approach to teaching help learners to have "hands-on" and "minds-on" the activity. Learners were expected to make observations during the practical investigations and explain their observations based on the theory they had acquired in the course.

The main purpose of doing this practical activity was to help learners make connections between the observables and ideas. I wanted to help learners develop a deep understanding of concepts and for that reason I only used pedagogical link-making to support knowledge building in analysing data. All six pedagogical link-making approaches were used to analyse data. The six

approaches are (1) making links between every-day and scientific ways of explaining, (2) making links between scientific concepts, (3) making links between scientific explanations and the real world phenomena, (4) making links between modes of representation, (5) moving between different scales and levels of explanation and (6) analogical link making. The approaches were abbreviated as Ap1, Ap2, Ap3, Ap4, Ap5 and Ap6 respectively in data analysis.

Time in minutes	Pedagogical link making approach	Notes
0-5	Ap3 Ap3 Ap1&2 Ap1 Ap6	I introduced the topic by showing learners that metals are important materials to man-kind. I did this by asking them to look around and identify all things made of metals in the school laboratory. I then explained that these important metals naturally occur in ores combined with other substances. The ores can be found in rocks. I asked learners to observe the rocks labelled A and B and describe them. I also asked them to decide what to do with the chunks of stones to ensure that they react faster with acid. Some learners could remember that grinding the solid rocks into powder helped the reaction to be faster. They could link this activity to their everyday experiences with the dissolving of salt in water and the cooking of mincemeat.
5-10	Ap1, Ap2, Ap5	Some learners used faulty everyday ways of explaining their reasons and I helped them to use the correct scientific way of explaining their suggestions. Some thought that the mass of the substance increased after grinding it. I helped learners link the macroscopic (the chucks of stones) to the microscopic (particles making up the stones) by explaining that grinding increases the surface area thereby increasing the rate of the reaction. I explained that after grinding the solid, the surface area

	Ap5 Ap2 Ap2 Ap1	of the solids increase and that the particles can collide more often resulting in a faster reaction. I introduced the learners to the collision theory which they will learn in Grade 12 that for substances to react their particles should firstly collide with each other. In doing so I helped learners to develop the scientific ways of explaining the concepts. I also asked learners to prevent mixing the rocks so that they may not get biased results.
10-15	Ap1 & Ap2 Ap2 Ap1	I asked learners to make predictions of what outcome they expected from the reaction between the stones with dilute hydrochloric acid. I reminded learners to make connections between what they already know about chemical reactions and the new situation to make predictions. I gave learners written instructions to follow. I instructed them to carry-out the practical activity taking necessary precautions to prevent accidents. Learners carried out the practical activity to find-out whether the predictions were correct or not. They made observations. I moved from one group to another assisting learners and giving clues where necessary. Learners worked in groups, discussed their results and wrote down the agreed

		observations.
15-20	Ap1 Ap2 Ap1 & 2	Learners followed instructions, carried out the practical activity and recorded their observations in a scientific way. I instructed learners to use a flame to find-out what gas was produced during the reaction. I reminded learners to remember that carbon dioxide extinguishes a flame. (connecting what they already know to the new situation)
20-25	Ap1 Ap1&2	Learners continued to work co-operatively in groups carrying-out the investigation, making observations and writing down the agreed observations. Learners discussed their observations. I guided the individual groups in making meaningful observations and scientific ways of writing down the data.
25-30	Ap1 Ap2	Learners worked co-operatively in groups to carry-out the investigation, making observations and writing down the agreed observations. Learners discussed their observations. I moved from one group to another checking on whether they followed instructions. I discussed with them about possible explanations of the observations made.
30-35	Ap1&2	Learners made observations and recorded them for reporting back in the next lesson. Learners cleaned up the apparatus. I monitored learners cleaning up and informed them on safety precautions to take while

		tiding up.
35-40	Ap1, Ap2 Ap1 & Ap2	I asked learners to discuss on possible explanations of their results in groups. As I moved from one group to another I helped learners to recall some of the concepts they learnt in previous lessons and apply this knowledge to the new situation. I concluded the lesson by explaining the importance of the practical activity and informing learners that they should keep their results for reporting back in the next lesson. As homework, I asked learners go and research on the possible explanations to their observations and report their findings in the next lesson.

Lesson 2: Introduction to mining: Reporting and explaining observations about the practical investigation in lesson 1.

In this lesson learners reported their on observations. I helped learners in giving correct scientific descriptions of observations. This is because most learners used every-day language to report their observations. In some cases groups disagreed on some of the observations. Some possible reasons why some groups missed some observations could be lack of concentration and lack of observation skills in some learners. After making this observation I made an effort to help learners to develop good observation skills for future lessons

Some learners had challenges in linking the macroscopic to the microscopic and the symbolic representation of matter. This was evident in the way they explained their observations. These learners either used everyday language to explain results or they could not connect their findings to what they learnt in theory lessons.

Time in minutes	Pedagogical link-making approach	Notes
0-5	Ap2 Ap2 Ap1	I introduced the lesson by recapping on the previous lesson. I reminded the learners about the purposes of carrying out the investigation. I asked learners to report back on their findings. I recorded the agreed upon observations on the chalkboard for them to record in their books. Learners reported their observations, for example, hydrochloric acid reacted with the white rock to produce a white solution, bubbles of gas were produced, and temperature increased and that the gas produced extinguished a flame. I helped learners refine their descriptions in a scientific way either through questioning or re-phrasing descriptions.
5-10	 Ap1	Learners continued to report their group observations, eg, some water droplet were formed above the solution. I guided learners on the scientific way of reporting. For example, I

	Ap1&2 Ap2 & 6 Ap1 Ap2 Ap1 &Ap6	described the water droplets formed at the edges of test tube as a 'condensate' to remind learners that condensation took place. I reminded learners about condensation which takes place in a closed pot with boiling water when cooking so that they could link what happened to what they experience in everyday life. Some learners stated that a shiii…… sound was produced (everyday way of explaining). I described the sound as a fizzy sound similar to what is produced in fizzy drinks (giving an analogy to what learners already know.
10-15	Ap1	Learners identified the colour changes that took place when stone B was added to dilute

	Ap1 Ap2 Ap2 Ap1 Ap1 and Ap2	hydrochloric acid. This was done by stating the new colour formed only. I helped learners to state the original colour of the solution before stating the new colour formed. A learner identified the formation of solids on top of the hydrochloric solution. I asked the learners to give the scientific name given to solids formed in a solution. I reminded learners about 'precipitation' after none could remember the scientific term used although they had covered work on precipitation reactions. Learners disagreed about the formation of bubbles. Since I observed a few bubbles while I was monitoring learners' progress, I made learners aware that they need to pay attention to all changes which took place. I wrote the reported observations on the chalkboard after refining the descriptions with help of the class.
15-20	Ap1	Learners stated that they observed that no temperature change and that a smell was produced. I reminded learners that they need to

	Ap2	cautious with their language when reporting their findings. I told them that since they did not have a thermometer it will be inaccurate to say that there was no temperature change. Temperature changes might have taken place but it might have been very small to be detected by their sense of feeling.
	Ap6	Learners reported that there was a smell produced. I asked them to identify something common that has kind of smell. They likened the smell to that of rotten eggs or simply as a bad smell
	Ap1 &Ap2	I asked learners to explain the cause of these changes. One learner explained that temperature increased because of particle movement which happened during the mixing process in a restricted volume producing heat. When I asked the learner to differentiate temperature and heat, he just laughed. I helped learners differentiate between heat and temperature. I explained that heat is the transfer of energy from a region of high temperature to one at

		a lower temperature whereas temperature is an indirect measure of the average kinetic energy possessed by particles in a substance.
20-25	Ap1 &2 Ap1 & Ap2 Ap4&Ap5	I explained to learners that the reason why the temperature increased was because the reaction was exothermic. When asked what he meant he remained quiet. Some learners could not remember the meaning of the terms endothermic and exothermic reactions. I explained that an exothermic reaction is a reaction that gives out energy to the surroundings and an endothermic reaction takes in energy. I added that in an exothermic reaction energy is given out while in an endothermic reaction temperature decreases. I asked learners why particles moved up and down. Learners explained that the reaction was vigorous and released energy which caused particles to move up and down. One learner stated that the rock should contain a carbonate. When I asked how she came to this conclusion, she stated that because the gas

		produced.
	Ap1&Ap2	I explained to learners the gas produced in chemical reactions is not always carbon dioxide. I informed them that tests were taken to find out what gas it was. I explained that because the gas extinguished a flame is evidence that it might be carbon dioxide produced.
	Ap4	I told learners to assume that a carbonate was present and asked them to write down the word and chemical equation to represent what happened. Learners could provide the word equation.
25-30	Ap4 &Ap5	I helped learners to write down a balanced chemical equation on the chalkboard. I assisted
	Ap2	them in identifying the phases of all substances involved.
		I also guided learners to identifying that the reaction of rock A with HCl is spontaneous while the reaction of rock B is non-spontaneous.
	Ap2	Learners could predict the cause of the green colour in the solution of rock B. I explained to

	Ap2&5 Ap2 Ap2	learners that different metal ions on water have different colours. I informed learners that iron (iii) ions are reddish brown in water, copper (ii) ions are blue in water and chromium (iii) ions are green in colour. I explained that many tests are needed to find what elements and compounds are present in each of the stone. I informed learners that each specific mineral has its own unique chemical properties and is tested differently. I further explained that in mining relative amounts of the mineral should be determined before mining to assess for viability of the mine.
30-35	Ap1&2	I reminded learners about the aim of the practical activity and asked them to give a conclusion. I then guided learners through question and answer to draw conclusions. They came to a conclusion that rock A contained carbonates while rock B may contain traces of carbonates and chromium.
35-40	Ap2 &Ap1	I asked learners summarise the lesson in their

		notebooks. I also asked them to complete a written task as homework. I informed learners that the next lesson was going to a practical activity to extract iron.

Lesson 3: Practical activity: Imitating the extraction of iron.

Learners worked in groups of four or five to investigate the extraction of copper from copper oxide. Copper (ii) oxide was heated in the presence of carbon to produce copper. Copper (ii) was used because iron oxide was not available. This was used as an analogy to the reaction of iron oxide and carbon in the blast furnace. Due to the shortage of tripod stands, bricks were used as stands. The lesson was made shorter on this day to accommodate an HIV and Aids pragramme offered to all Grade 11 learners before the knocked out. This was offered by an external service provider.

Time in minutes	Pedagogical link-making approach	Notes
0-5	Ap2 Ap1 & Ap2 Ap1 & Ap2	I introduced the lesson by recapping on the previous lesson. I started by explaining that after identifying the mineral of interest miners should extract it from the ore by applying their knowledge of chemistry. I stated the aim of the

		practical activity. I informed learners that the activity was used as an analogy to illustrate extraction of iron.
5-10	Ap1&2	I provided learners with the apparatus. I informed learners that the lesson was relatively shorter and that they should work faster. I provided learners with the instructions and asked learners to work co-operatively in groups of four or five to carry-out the practical activity.
10-15	Ap1 &2 Ap1 &Ap2	I asked learners to firstly give a hypothesis and carryout the practical activity to find –out if their prediction was correct. Learners followed instructions to assemble the apparatus, carryout the practical activity and made observations. I moved from group to another discussing with them on their progress and guiding them on data collection. Some learners were enthused about the colour changes that took place. I informed them to observe carefully and record the

		observations.
15-20	Ap1&2 Ap1&2	Learners continued making observations and recorded them in their books. I moved from one group to another advising, guiding and discussing their observations. I informed learners to think of possible explanations about their observations using the theory they have learnt.
20-25	Ap1&2	Learners cleaned up and returned apparatus. I informed learners should keep their results to report back in the next lesson. I asked learners to find out the explanations to their observations from the theory they have learnt.

Lesson 4: Iron extraction: reporting data, explaining data and explaining iron extraction.

Learners reported on their group observations. I assisted learners in using the correct scientific terms to describing their observations. I emphasised the need to relate what they learnt now with what they already know. After recording the observations and explaining them I guided learners through iron extraction. I did this by linking the reaction of copper (ii) oxide with carbon to processes which takes place in the blast furnace. We discussed the chemistry of the blast furnace and on the importance of iron metal.

Time in minutes	Pedagogical link-making approach	Notes

0-5	Ap1&2 Ap2 Ap1	I introduced the lesson by reviewing the previous lesson. I then asked learners to describe their observations. I guided learners to link homogeneous and heterogeneous mixtures to what their observations. I explained to learners that for the reactants to react with each other there was a need to make sure that they are mixed evenly to make a homogeneous mixture. The reports learners gave revealed that they have limited scientific vocabulary. I supported them by rephrasing the statements they gave using everyday language into correct scientific statements. I recorded the corrected statements on the chalkboard for them to record in their notebooks.
5-10	Ap6 Ap1&2	A learner described the smell that he detected was like that of a burning tyre. Another learner claimed that he saw carbon monoxide. I explained to learners that CO is colourless and cannot be seen. I informed them that what he saw was smoke which may contain carbon

		dioxide and possibly contained carbon monoxide.
10-15	Ap1 &2 Ap1 &Ap2	All groups reported that a brown substance was formed at the bottom of the mixture. They however found it difficult to identify the brown substance. I helped learners to conclude that the brown substance is impure copper. I explained that copper is formed after the reduction of copper (ii) oxide. I referred learners to redox reactions.
15-20	Ap1 Ap4 &5 Ap5	I told learners that we use the microscopic to explain the macroscopic properties of matter. I asked learners to write down the chemical equation to represent the reaction. Most learners were not able write correct equations. Although some used the knowledge acquired when they covered during redox reactions most equations were faulty. I helped learners to write down the balanced chemical equation to describe the observations.
20-25	Ap1 &2	I introduced iron extraction basing my explanations on the reaction between CuO(s) and C(s). I

	Ap1 &Ap2 Ap4 &Ap5 Ap6	explained that iron is extracted using the blast furnace where iron ore (iron (ii) oxide) is combined with carbon. I further stated that the two reactants react to produce similar products to those they observed in the previous practical activity. I asked learners to suggest the possible word equations and chemical equations to represent the reaction. Some learners were able to write correct equations after referring to what they had covered in the previous activity. I used an analogy to help learners to understand the chemistry of the blast furnace.

25-30	Ap1 &2 Ap1& Ap2 Ap4 Ap1& Ap2	I asked learners to explain why the change was more visible in a narrow crucible than the wider one in the practical activity. Learners could not explain why the brown substance only formed in the narrow crucible and at the bottom of the crucible and not the top. I explain to learners that it is the copper (ii) oxide and carbon which was not exposed to atmospheric oxygen that reacted with each other while the carbon exposed to atmospheric oxygen reacted with it to form carbon dioxide. I had to describe the shape of the blast furnace and explain why it takes that shape. I used the diagram of the blast furnace to explain the reactions which take place at the different levels. I started by explaining the formation of carbon dioxide at the top followed by the formation of carbon monoxide at the middle and lastly the reduction of iron (ii) oxide near the bottom. I asked learners state the similarities between what they observed in the practical activity and what happens in the blast furnace.
30-35	Ap2	I referred learners to the first activity where they used

		rocks to test their composition. Learners could remember that after the reaction some solid wastes were left in the container.
	Ap2 Ap2 Ap2 Ap4&5	I <u>informed learners</u> that the iron (ii) oxide is found together with some rock particles. I <u>explained that</u> these wastes should be removed from the iron. From here I <u>stated that limestone</u> (rock A) in the first activity is used to react with the wastes to produce slag. I <u>helped learners to write down the chemical equation</u> to show the reaction of calcium carbonate (limestone) with the wastes.
35-40	Ap1& Ap2 Ap1 &Ap2	I <u>summarised</u> the extraction of iron using some flow diagram. We <u>discussed t</u>he uses and importance of iron. I <u>asked learners to use the knowledge</u> they acquired during the lesson to answer to questions about the extraction of iron.

Lesson 5: Practical activity: imitating gold recovery

I expected learners to use the knowledge they acquired from the previous lessons to perform the activity. Learners used copper oxide from the previous lesson to imitate gold extraction. They worked in groups of four to five to carry-out the practical activity. I

informed learners that gold ore was unavailable so we were going to use copper oxide which reacts the similar way as gold. I made learners aware that this reaction will be used as an analogy to what happens in gold recovery.

Time in minutes	Pedagogical link-making approach	Notes
0-5	Ap1 & Ap2 Ap1 & Ap2 Ap6 Ap1 & Ap2	I introduced the lesson by recapping on the previous lesson. I explained the importance of minerals to human kind and the application of knowledge of chemical reactions in order to extract the valuable minerals from their ores. I then informed the learners about the aim of the investigation and gave them instructions to follow and the apparatus needed. I informed learners that copper oxide was used instead of gold to imitate gold recovery because gold is rare and expensive. I reminded learners about the reactions of metal oxides with acids from previous lessons. This knowledge helped learners to connect what they learnt in previous lessons.

5-10	Ap4 Ap1 & Ap2 Ap1 & Ap2 Ap1 & Ap2	I stated the name of the compound (copper (ii) oxide) and recorded on the chalk board both the word and the symbol (CuO). I did this in order to help learners to make connections between the macroscopic (observables) and the symbolic. I gave learners instructions to follow and they carried out the practical activity. I moved from one group to another guiding and monitoring learners' progress. I also encouraged learners to be accurate in making observations. Learners discuss their observations and wrote them down.
10-15	Ap1&2 Ap1&2	Learners worked cooperatively in carrying out the investigation making observations and writing the observations in their books. I moved from one group to another to assist learners where necessary and discussing some challenges learners encountered in carrying out the investigation.
15-20		Learners worked in groups making observations. They discussed their observations before writing them down.

	Ap1&2	I discussed with individual groups and assisted where necessary.
20-25 Ap1 &Ap2		Learners continued working in groups and making observations. They discussed their observations; reach some agreement before recording them. I guided learners in making observations and in giving explanations.
25-30 Ap1 & Ap2 30-35	Ap1&2 Ap1&2	I informed learners to test for gas produced after zinc was added to the reaction mixture. Because most learners could not remember some gas tests I had to describe how hydrogen and carbon dioxide are tested. Learners continued to work in groups collecting data and discussing their results with the group members. I moved from one group to another assisting them where necessary. Learners discussed possible explanations of their results in groups. I urged them to write down the explanations for report back in the next class.
35-40	Ap1&2	I asked learners to clean up and return the apparatus

		they used. I concluded the lesson by explaining that the data collected should be kept and used in the next lesson. I encouraged learners to research on the possible identities of products formed and explanations for the observations made.

Lesson 6: Gold recovery: Report back on the practical activity (lesson5) and explaining gold extraction

In this lesson learners reported their observations, identified the possible products and give possible explanations for the observations. Learners were expected to use the knowledge they gained in the previous lessons in mining to give descriptions of observations and use words and chemical equations to explain results.

I used the results obtained from the practical activity to describe and explain gold extraction. Learners were asked to identify similarities and differences between what they observed in the practical activity and what happens during gold recovery.

Time in minutes	Pedagogical link-making approach	Notes
0-5	Ap1 &2 Ap3 Ap1&2 Ap4&5	I introduced the topic by briefly summarising the previous lesson. I then asked learners to report their observations. I started by asking learners what changes were observed after zinc was added to copper sulphate solution. Learners could not accurately identify the changes which took place until I showed them a sample. One learner stated that a precipitate was form on top of the reaction mixture. I asked learners to explain the term precipitate which they explained using the knowledge they acquired in previous lessons. I helped learners to write down the word equation and chemical equation to explain the results. I assisted learners write chemical equations of the reaction between sulphuric acid and copper (ii) oxide and that of copper sulphate and zinc.
5-10	Ap1,2&5	I asked learners to explain what happens to the oxidation numbers each of the substances involved

	Ap1 & Ap2	in the equation. Although learners covered the work on redox reactions, they struggled to explain the electron transfers. Learners could not remember what type of reaction it is. I explained redox reactions and showed them how to identify the oxidation numbers.
10-15	Ap4 &5 Ap1&2 Ap4 &Ap5	I asked learners to use the redox tables to write the half equations which many learners could not do correctly. I had to re-teach the use of redox tables and writing of the half equations. I gave examples of the equations and showed learners how to determine the reduction half and the oxidation half equations. I also explained to learners the electron transfer process during the reaction based on the half equations. I also helped learners to identify the oxidizing agent and the reducing agent.
15-20	Ap1 &2 Ap6	I explained to learners that the previous reaction imitated of gold recovery. The reaction of gold with cyanide is similar to that of copper sulphate and

	Ap2	sulphuric acid. I asked learners to do an activity of writing the balanced equation for the reaction between zinc and a copper sulphate.
20-25	Ap1&2 Ap2 Ap1& Ap2	I explained the stages involved in gold extraction starting with digging the ore to crushing and milling of the rocks. I asked learners to explain why grinding is necessary. Some learners could remember that grinding increased the surface area of the reactants and increases the reaction rate. I asked learners to explain why gold sinks to the bottom of the density separation tank. I helped learners to remember that substances with a high density sink to the bottom of a container while those with a lower density settle on top of the denser ones. Learners could remember that gold is a heavy metal and it sinks.
25-30	Ap4 &5 Ap1 &2	I helped learners to write the chemical equations for reaction of cyanide and gold. I asked learners to balance the equation.

	Ap1& Ap2 Ap1 &Ap2 Ap2	I explained the changes in oxidation states of each particle in the substances involved in the reaction. I explained why gold has more than one oxidation states. I asked learners whether the products are bases or acids. Learners could not remember that all hydroxides are basic and have a pH of above 7. I had helped them to identify bases and acids in the reaction. To conclude the lesson I summarised gold recovery, identified the uses of gold and explained the chemistry of gold recovery.
30-35	Ap1, Ap2, Ap4 &Ap5	I asked learners to answer questions on gold recovery in their classwork books.
35-40	Ap1,2,4 &5	Learners writing a classwork on gold and iron mining.