Exploring science teachers' pedagogical content knowledge in the teaching of genetics in Swaziland

by

KHETSIWE EUNICE FAITH MTHETHWA-KUNENE

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Supervisor
Prof. G.O.M. Onwu

Co-supervisor
Prof. J.J.R. de Villiers

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CERTIFICATION

This thesis has been examined and approved as meeting the required standard of scholarship for the fulfilment of the Degree of Doctor of Philosophy in Curriculum and Instructional Design and Development.

Professor G. O. M. Onwu

Supervisor

Date: _____

UNIVERSITY OF PRETORIA

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Full names of student: EUNICE KHETSIWE MTHETHWA

Student number: 25186737

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ABSTRACT

Recent trends show that learners' enrolment and performance in science at secondary school level is dwindling. Some science topics including genetics in biology are said to be difficult for learners to learn and thus they perform poorly in examinations. Teacher knowledge base, particularly topic-specific pedagogical content knowledge (PCK), has been identified by many researchers as an important factor that is linked with learner understanding and achievement in science. This qualitative study was an attempt to explore the PCK of four successful biology teachers and how they developed it in the context of teaching genetics. The purposive sampling technique was employed to select the participating teachers based on their schools' performance in biology public examinations and recommendations by science specialists and school principals. Pedagogical content knowledge was used as a theoretical framework for the study, which guided the inquiry in data collection, analysis and discussion of the research findings. The study adopted the case study method and various sources of evidence including concept maps, lesson plans, pre-lesson interviews, lesson observations, post-teaching teacher questionnaire, post-lesson interviews and document analysis were used to collect data on teachers' PCK as well as how PCK was assumed to have developed.

The data were analysed in an attempt to determine the individual teachers' school genetics' content knowledge, related knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties. The analysis involved an iterative process of coding data into PCK categories of content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties. The findings of the study indicate that the four successful biology teachers generally have the necessary content knowledge of school genetics, used certain topic-specific instructional strategies, but lacked knowledge of genetics-related learners' preconceptions and learning difficulties despite having taught the topic for many years. There were some instructional deficits in their approaches and techniques in teaching genetics. The teachers failed to use physical models, teacher demonstration and/or learner experimentation in their lessons (or include them in their lesson plans) to assist learners in visualizing or internalizing the genetics concepts or processes located at the sub-microscopic level. The teachers' PCK in genetics teaching was assumed to have developed mainly through formal university education programmes, classroom teaching experiences, peer support and participation in in-service workshops. The implications for biology teacher education are also discussed.

Key words: conditional knowledge, content knowledge, declarative knowledge, development of pedagogical content knowledge, genetics, learning difficulties, pedagogical content knowledge (PCK), pedagogical knowledge, preconceptions, procedural knowledge, successful biology teacher

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LIST OF ACRONYMS

CK:	Content Knowledge
ECOS:	Examinations Council Of Swaziland
IGCSE:	International General Certificate of Secondary Education
MOET:	Ministry Of Education and Training
PCK:	Pedagogical Content Knowledge
PK:	Pedagogical Knowledge
SGCSE:	Swaziland General Certificate of Education

DEFINITION OF TERMS

The following terms are operationally defined as used in this study:

Conditional knowledge: knowledge about both the 'how and why' of biological processes.

Content knowledge: the disciplinary knowledge including facts, relationships, processes, theories and principles about genetics that teachers teach to their learners and the ways these are presented to make it accessible to learners.

Declarative knowledge: knowledge necessary to state or declare facts about what things are, their attributes or any associations between them.

Development of PCK: the way in which science teachers gained their knowledge specific to the teaching of the biology topic, genetics.

Successful biology teacher: a biology teacher who has consistently produced at least 70% credit (Grades C and above) passes in the period 2007 – 2010.

Genetics: a topic in the Swaziland biology curriculum for the high school level leading to the school leaving certificate, which deals with the study of the inheritance of characteristics from parents to offspring and from generation to generation.

Learning difficulties: what learners are not able to easily comprehend during genetics lessons including misconceptions.

Pedagogical content knowledge: the topic-specific knowledge, which is a combination of content knowledge, pedagogical knowledge (knowledge of instructional strategies - representations of subject matter and activities), and knowledge of learners' preconceptions and learning difficulties that a teacher uses to make genetics concepts accessible to learners.

Pedagogical knowledge: the topic-specific instructional strategies teachers use to teach genetics concepts.

Preconceptions: the prior knowledge or prior conceptions about genetics topics that learners bring to genetics lessons or classrooms.

Procedural knowledge: knowledge about how biological processes work.

CHAPTER ONE
INTRODUCTION

1.1 Background to the study

A major concern in science teacher education is the development of teachers' knowledge base for improving classroom practice and learners' learning (Abell, 2007; Brown, Friedrichsen & Abell, 2013; Kind, 2009b). According to De Jong, Veal and Van Driel (2002), this concern has come about, first, as a result of empirical evidence, which shows that there is a strong relationship between what teachers know, and how they teach. Second, constructivist views on teaching and learning (Gullberg, Kellner, Attorps, Thoren & Tarneberg, 2008; Treagust & Duit, 2008) suggest that teachers' knowledge base should include knowledge of learners' prior conceptions or alternative frameworks of science topics to be taught, which could always be used as the basis of a teaching point on learners' behalf.

The three types of teacher knowledge, namely subject matter knowledge, pedagogical knowledge, and knowledge of learners' preconceptions, relate to what Shulman (1986) and others (e.g. Loughran, Berry & Mulhall, 2006, 2012; Magnusson, Krajcik & Borko, 2001) have collectively referred to as pedagogical content knowledge (PCK). Pedagogical content knowledge has been simply described as that teacher knowledge which allows teachers to assist learners to access specific content knowledge in a meaningful way (Miller, 2007). So pedagogical content knowledge is an important teacher knowledge base needed for effective teaching to take place.

Subject matter knowledge pertains to the disciplinary knowledge, which is usually acquired through formal education in universities and colleges (Ijeh, 2012; Ozden, 2008; Shulman, 1986). Pedagogical knowledge refers to knowledge about methods of teaching and learning. It is the type of knowledge a teacher requires and uses to execute daily educational tasks, which include instruction and classroom management (De Jong, Van Driel & Verloop, 2005; Penso, 2002). Pedagogical knowledge is normally obtained through formal educational training and from classroom teaching experience (De Jong, 2010; Schneider & Plasman, 2011). Knowledge of learners' preconceptions or alternative frameworks entails the knowledge teachers have about the ideas, views or beliefs learners bring along to the classroom from their (learners) own background experience, before they learn about

particular topics or concepts to be taught (Juttner & Neuhaus, 2012; Morrison & Lederman, 2003; Treagust & Duit, 2008). This knowledge of learners' conceptions is not one that is normally taught during teacher preparation programmes. It is acquired from classroom teaching experience (Morrison & Lederman, 2003; Penso, 2002), among other knowledge pursuits. This knowledge is built up over years through teachers carefully paying attention to learner feedback and thus becoming familiar with their learners' usual ideas about scientific topics or concepts.

Albeit the need for the development of rich pedagogical content knowledge is indicated for effective teaching in science (Loughran et al., 2006, 2012; Schmelzing et al., 2013), the lack of a clear definition of the construct PCK makes the achievement of such a standard somewhat difficult. Recent reviews (Ekis, 2012; Schmelzing et al., 2013) in science education have pointed out that there is no universally accepted definition of PCK. Barrett and Green (2009) asserted earlier that there are as many conceptions of PCK as there are researchers interested in it. This lack of consensus exists across and even within subject areas (Ball, Phelps & Thames, 2008). It is therefore important that PCK should be clearly defined in the context of any particular study that seeks to apply the construct. In the main, pedagogical content knowledge has been described by Shulman (1986, 1987) as an amalgam of types of teacher knowledge, that a teacher possesses about teaching a particular topic or content and how it should be taught so that effective and efficient learning can occur (Loughran et al., 2012). Thus PCK is topic specific.

Pedagogical content knowledge is unique and specific to teaching (Shulman, 1986, 1987). It distinguishes between an expert teacher in a particular subject area and a subject-area expert (Kind, 2009b; Park & Chen, 2012; Schneider & Plasman, 2011). For example, science teachers differ from scientists in the way their subject matter knowledge is structured and used (Cochran, De Ruiter & King, 1993). The subject matter knowledge of an experienced science teacher is ordered from a teaching point of view and is used as a basis for assisting learners to comprehend particular content or concepts (cf Ijeh, 2012). On the other hand, a scientist's knowledge is usually structured from a research perspective and is used mainly as a base for developing new knowledge in the area. A review of the literature suggests that little is known about how science teachers develop PCK in the context of teaching science topics (Ekis, 2012; Kind, 2009b; Schneider & Plasman, 2011). Hence, there is need for

studies to carefully identify and document the practices necessary for PCK development in science education (Kind, 2009b).

A number of writers in the area of teacher knowledge base (e.g. De Jong, 2010; Schneider & Plasman, 2011) assert that PCK develops through classroom practice. What this implies is that the more experienced teachers are more likely than novice or beginning teachers to have better or richer subject matter-specific PCK, or will at least have more ways of developing their PCK because of the many years of varied classroom teaching experience. Kind (2009b), however, reiterates that we need to understand how teachers with rich PCK develop it, with respect to specific topics, in order to use that information to improve teaching, particularly science topics that are considered difficult to teach and learn. Kind (2009b:181) did suggest that, "if we can distil a teacher's PCK and find out how this develops, then perhaps this, and/or hints about the process of gaining it, can be "taught" explicitly to trainee teachers", particularly in situations in science education where learners are underperforming (Economic and Social Research Council, 2008; King & Ritchie, 2013; Marope, 2010).

A cursory review of the literature suggests that it is not a straightforward exercise to identify or profile a teacher's PCK owing to its complex nature, which has been described by many researchers (Kind, 2009b; Loughran, Mulhall & Berry, 2004; Miller, 2007) as elusive, sinuous, and tacit. The changeable nature of PCK makes it hard to identify specific constructs for this type of teacher knowledge (Miller, 2007). In addition, differences may exist in the boundaries of PCK because of the several categories of knowledge that could be integrated into PCK (Loughran et al., 2004).

The need for better understanding of teachers' knowledge base and its sustained improvement has become something of an imperative in the context of the Swaziland science education system. Recent trends show that learners' enrolment and performance in science at secondary school level is dwindling worldwide (Barmby, Kind & Jones, 2008; Economic and Social Research Council, 2008; Kazeni & Onwu, 2013; King & Ritchie, 2013). In Swaziland, a recent World Bank report on the status of secondary education in the country concluded that Swaziland learners perform poorly in mathematics and science subjects in public examinations (Marope, 2010). The abysmal performance is evident in past Swaziland senior certificate examination results in the sciences, particularly in biology.

Table 1.1 below shows a summary of the Examination Council of Swaziland (ECOS) biology statistics over eight years (2005–2012).

Table 1.1: Summary of biology results for all schools in Swaziland in 2005–2012

Examination year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Average**
Total number of learners who sat biology examination	2680	2971	4944	4914	5892	6404	6684	7190	5210
Percentage (%) of learners who obtained credit passes (Grade C and above)	31	31	29	28	29	29	28	24	29

Table 1.1 shows that while the number of learners who wrote the senior certificate biology examinations has increased over the years, the number of learners who obtained Grade C and above in these eight years has remained virtually the same, around 29% on average. Grade C is the minimum symbol for entry into science-related degree programmes at universities in Swaziland. The remaining 71% of the candidates obtained Grades D or E or failed. Thus, less than one third of the candidates who sit the biology public examinations qualify for entry into biology-related courses and programmes in the natural sciences at undergraduate degree level.

The literature, in the South African setting (e.g. Fraser, 2007; Guo, 2007; Howie, 2003; Makgato, 2007; Onwu & Stoffels, 2005; Reddy, 2005), suggests that a myriad factors may account for poor performance in the sciences. Some originate from the learners themselves, such as poor grounding in science and mathematics, lack of interest and thus poor motivation, and limited facility with the language of instruction (Guo, 2007). Others stem from the teachers, such as an inadequate knowledge base, and ineffective instructional skills (Fraser, 2007; Guo, 2007). Contextual factors such as under-resourced large class size, and an environment that is not conducive to learning (Onwu & Stoffels, 2005) could also contribute to poor learner performance in science. The interest of this study was with investigating the teacher factor. Several studies (e.g. Guo, 2007; Howie, 2003) about the causes of poor achievement in the sciences and mathematics point to the teacher as a possible source of learners' poor performance.

Some background information on the Swaziland education system would help to put the discussion of the results of the study into perspective. In 2006 the Swaziland Ministry of Education and Training (MOET), in responding to the issue of access and performance, adopted and introduced the International General Certificate of Secondary Education (IGCSE), at high school level (Grades 11 and 12). This curriculum, in 2009, was later adapted into the Swaziland General Certificate of Secondary Education (SGCSE) to make it more relevant and appropriate to the Swaziland learner and the education system. The new SGCSE curriculum emphasizes inquiry-based education, and demands a strong content knowledge base and modern pedagogical skills from teachers for its implementation (Ministry of Education and Training, 2005). The philosophy underpinning the SGCSE programme demands a shift in teacher thinking: from seeing learners as empty vessels to be filled with knowledge to viewing learners as possessing some prior knowledge that will be used to construct new knowledge (Ministry of Education and Training, 2005).

Even with the introduction of the SGCSE, coupled with various teacher-related interventions by the Ministry of Education and Training – such as in-service workshops – overall learner achievement did not improve as anticipated (Table 1.1). Besides, Swaziland's chief examiners' biology reports over the years (ECOS, 2007, 2008, 2009, 2010, 2011) have concluded that learners' performance in biology has remained problematic in some topic areas, particularly genetics. The reports have consistently stressed that on questions about genetics 'most candidates … did not even attempt the question, and those who attempted either got one mark or nothing' (ECOS, 2009:15). Comments such as these invariably led to speculation about Swaziland teachers' competence and their preparedness to effectively teach school genetics topics at that school level.

Genetics is an important topic in biology because the understanding of it serves as a basis for many scientific careers that require its application (Dogru-Atay & Tekkaya, 2008; Tsui & Treagust, 2004). Despite its importance, many learners, as we have indicated, perform poorly in the topic both at school and at undergraduate level (Chu & Reid, 2012; Karagoz & Cakir, 2011; Williams, deBarger, Montgomery, Zhou & Tate, 2012), and that is a reason for selecting the topic for study. In light of recent developments in which genetics has become increasingly related to human affairs such as genetic engineering, including genetically modified food and cloning, learners need to have an understanding of basic concepts of

genetics for participation as scientifically literate citizenry (Venville, Gribble & Donovan, 2005).

But the findings of various studies in science education (De Jong, 2010; Kapyla, Heikkinen & Asunta, 2009; Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008; Usak, 2009; Van der Zande, Akkerman, Brekelmans, Waarlo & Vermunt, 2012) would tend to suggest that most science teachers at high-school level have inadequate PCK of certain science topics. Some of these topics may be subsumed under genetics, which research suggests are difficult to learn (Chu & Reid, 2012; Van der Zande et al., 2012). Therefore, science teachers' topic-specific PCK needs most research attention in teacher education. An understanding of how science teachers develop PCK and use it to make science content accessible to learners and improve learner achievement in science would be useful information for teacher education programmes to enhance quality.

1.2 The problem of the study

From the discussion so far, little is known about the teacher knowledge base that is required to make difficult biology topics such as genetics accessible to more learners. Pedagogical content knowledge is seen as the crucial category of teacher knowledge base that is needed for topic-specific teaching (Abell, 2008; Rollnick et al., 2008; Shulman, 1986). The development of this type of teacher knowledge is deemed critical because teachers are responsible for making concepts meaningful to learners (Hanuscin, Lee & Akerson, 2011; Miller, 2007). However, research has shown that little is known about how science teachers' PCK develops suggesting the need for more studies to be carried out in this area (Kind, 2009b; Schneider & Plasman, 2011).

While public examination performance in biology is generally poor for most schools in Swaziland, some schools consistently perform well. Despite the poor performance in genetics in Swaziland in schools indicated in the chief examiner's reports, there are teachers who teach biology and genetics very well and produce 'good' results. The question is, what do the biology teachers in these schools do and have to be so successful (defined below)?

This study therefore sought to investigate the PCK in genetics teaching that biology teachers in those high-performing schools possess and how they developed it. Specifically, the present

study attempted to identify the PCK that four selected biology teachers who are adjudged 'successful' have in the context of teaching some aspects of genetics. It also sought to establish how the teachers developed their rich PCK, if any.

Although being successful may not necessarily mean that the selected teachers are experts in genetics teaching, their selection as successful teachers was based on their final public examination results in biology over time. In this study, the term 'successful teachers' refers to biology teachers who have consistently produced at least 70% credit passes (Grades C and above) in the school leaving certificate biology examinations over four years (2007–2010) and were recommended by science specialists and school principals. In 2007, the first public examination was written for the IGCSE curriculum. The assumption is that successful teachers would have developed rich PCK in biology topics such as genetics to teach in ways that enhance learners' achievement (Hill et al., 2008). Learner achievement is usually used as an indicator of expert or successful teachers (Ornstein, 2003). A similar selection criterion has been used in other studies (Friedrichsen & Dana, 2005; Loughran et al., 2006; Morrison & Lederman, 2003). This research was an attempt to provide an in-depth study and analysis of what PCK the biology teachers selected for the study possessed and how they developed their PCK in the context of teaching genetics.

1.3 Statement of the problem

The problem of this study was to determine successful biology teachers' pedagogical content knowledge (PCK) in genetics teaching and how the teachers developed it in teaching the topic.

1.4 Research questions

The following research questions were derived from the statement of the problem:

1. What content knowledge of genetics do biology teachers who are considered successful have and demonstrate during classroom practice?
2. What instructional strategies do these teachers use in teaching genetics?
3. What knowledge of learners' preconceptions and learning difficulties, if any, do these teachers have and demonstrate during classroom practice?
4. How do these teachers develop pedagogical content knowledge in genetics teaching?

1.5 Significance of the study

The interest in PCK developed as a result of the researcher's role as an examiner in biology senior certificate public examinations in Swaziland. While candidates were generally performing poorly in genetics-related questions, there were some schools whose candidates consistently performed well in those items. This engendered interest and curiosity about the knowledge and skills the successful biology teachers in those schools have, and what they do in classroom practice, hence, the motivation to investigate the biology teachers' PCK.

Furthermore, reviews of science education research on teacher knowledge base have called for more research on science teachers' pedagogical content knowledge and its development (Abell, 2007; Ekis, 2012; Henze, Van Driel & Verloop, 2008; Juttner, Boone, Park & Neuhaus, 2013; Kind 2009b). The literature shows that PCK research based on biology is less frequent (Juttner et al., 2013; Kind 2009b), thus justifying further studies in this subject area. Recent reviews of research on PCK (e.g. Ekis, 2012; Schneider & Plasman, 2011) report that many of the studies are on pre-service teachers and few are on experienced teachers, particularly studies that 'reveal some teaching examples of teachers with rich PCK' (Ekis, 2012:12). Hence, this study sought to use teachers with many years of teaching experience in biology in Swaziland.

The study was considered significant based on the scientific contribution the findings hope to make to knowledge. This study extends knowledge in the field regarding the nature of PCK and its development in the teaching of genetics. The practical significance of the study is that it is hoped that the findings will inform improved teacher education programmes and practice. Science teachers with an interest in improving their practice might benefit from the concrete examples of successful teachers' PCK that this study provides in teaching particular genetics concepts – the advantages or disadvantages of using the particular approaches.

Despite the considerable amount of research that has been carried out to identify and characterize PCK during teaching, some authors continue to call for studies to develop methods of measuring PCK (Ekis, 2012; Miller, 2007; Schneider & Plasman, 2011). Miller (2007) asserts that PCK represents much more than a type of teacher knowledge but it provides a point of departure for research regarding teacher education. As a theoretical framework of this study, PCK offers a process for organizing research in teacher education.

1.6 The theoretical framework for the study

Various researchers (Appleton, 2008; Loughran et al., 2006, 2012; Magnusson et al., 2001; Oliver & Park, 2008) have attempted to develop models to measure teachers' PCK in the sciences and mathematics. The challenges mostly faced by these researchers are the difficulties the models present in distinguishing the boundaries that make up the several constructs (Kind, 2009b; Loughran et al., 2004). These difficulties include the changeable nature of PCK (Miller, 2007), which makes it hard to isolate definite constructs of this type of teacher knowledge. Also, because of the various types of knowledge that could be integrated into PCK, differences may exist in the boundaries of a PCK construct (Loughran et al., 2004). Furthermore, because teachers as learners construct their own knowledge, it is possible that there will be individual examples of teacher PCK.

Miller (2007), in a review of the research literature on PCK, found that the use of PCK in research and the data collection and analysis methods can be categorized into two forms. These forms are research on PCK as a type of teacher knowledge and research using PCK as a theoretical framework. Pedagogical content knowledge as a category of knowledge involves knowledge specifically constructed by teachers, but clearly different for each subject matter content area. Pedagogical content knowledge as a theoretical framework, on the other hand, is based on a number of assumptions. The major difference between these two ways of using PCK in research is that the first involves attempting to identify or measure PCK, while the second way uses the assumption that PCK exists, in order to study other facets of teacher knowledge (Miller, 2007).

The interest of the present study was twofold. First, it is premised on identifying teacher PCK in the context of teaching school genetics, which is assumed to exist, and, second, in determining the way in which the PCK was developed in teaching school genetics topics. To achieve this goal, the study used PCK as a theoretical framework, consisting of teacher content knowledge, pedagogical knowledge (knowledge of instructional strategies), and knowledge of learners' preconceptions and learning difficulties to explore the main research questions based on a number of assumptions.

The original model of PCK by Shulman (1986, 1987) identified PCK as the specific teacher knowledge that allowed a teacher to more thoroughly understand how to transform content

knowledge into a more conceptually understandable form for learners. As explained by Shulman (1987), PCK results from the combination of content knowledge and pedagogical knowledge. Thus, it is commonly believed that PCK represents the specific knowledge that is needed for a beginning teacher to advance into an expert (Loughran et al., 2012). Shulman's (1987) vision and Magnusson et al.'s (2001) description of teacher knowledge as a combination of different types of knowledge such as content, curricular, pedagogical and learner knowledge and PCK has forced many teacher education programmes to produce new instructional activities for improving classroom practice (Ijeh, 2012). This same vision of enriching classroom practice has provided a focus on education research. Unfortunately, PCK, because of its ill-defined nature, remains a type of knowledge that is hard to isolate and study (Miller, 2007). However, it provides a point of departure for investigators who wish to collect and analyse data on other aspects of teacher knowledge.

In this study, the teachers' classroom practice in genetics was therefore investigated in a series of lesson observations in order to explore what PCK exists and how the participating teachers demonstrated their PCK in the context of teaching genetics in school biology. The first consideration was that of identifying the categories of knowledge that the teacher has as defined in the teaching of genetics would yield information about teacher's PCK and how it is developed and used during classroom practice.

The use of PCK as a theoretical framework has provided researchers with a new perspective for collecting and analysing data about teacher knowledge or cognition (Brown et al., 2013; Friedrichsen & Dana, 2005; Friedrichsen, Abell, Pareja, Brown, Lankford & Volkmann, 2011; Garcia, 2004; Henze et al., 2008; Kind, 2009a; Loughran et al., 2004; Penso, 2002) and in mathematics education (Ijeh, 2012). The use of PCK as a theoretical framework allows researchers to focus on specific questions about a teacher's knowledge base and is based on a number of assumptions. Miller (2007) has pointed out that PCK embodies an epistemological approach to understanding teacher knowledge. For this reason, in this study, the teachers' PCK in genetics teaching and the way in which they developed it was conceptualized as comprising content knowledge, pedagogical knowledge, and knowledge of learners' preconceptions and learning difficulties in the context of teaching school genetics. These fundamental types of teacher knowledge were used as the theoretical framework that

provided a guide for data collection, analysis and discussion of what and how PCK in genetics teaching was developed.

Assumptions of the study

In using components of PCK as a theoretical framework, a number of assumptions were made in line with Miller (2007)'s thinking, notably:

- That "PCK represents a category of teacher knowledge that is the essence of an expert teacher" in a particular topic (Miller, 2007:91). It is assumed that the participating successful biology teachers have this category of knowledge (PCK) in genetics teaching.
- That PCK can be identified and measured using appropriate research instruments. A variety of research instruments, including lesson observation, interview schedules, teacher questionnaire and document analysis, were developed and used to measure teachers' PCK in genetics teaching, namely content knowledge, pedagogical knowledge (knowledge of instructional strategies) and knowledge of learners' preconceptions and learning difficulties.
- That "PCK provides a framework that can be used to describe the origin of this critical teacher knowledge" (Miller, 2007:91). Since "PCK represents an epistemological approach to constructing teaching knowledge" (Miller, 2007:91), it could be used to try to describe how the biology teachers developed their PCK.
- That PCK entails a constructivist process on the part of the teacher, and therefore the possibility of a continually changing body of knowledge (PCK) is ever present. In other words, PCK is not necessarily static and the teachers' PCK could change over time, all things being equal.

Shulman (1986:9) categorized PCK as a specific type of knowledge "which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching". Pedagogical content knowledge pertains to teachers' interpretation and transformation of subject matter in the context of teaching and facilitating learning. As a result, PCK is said to be one of the seven categories in Shulman's (1986) categorization of a knowledge base for teaching. According to Shulman (1986:9), PCK includes "the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations … the ways of formulating the subject that make it

comprehensible to others". It also includes an understanding of the conceptions and preconceptions that learners bring with them to the classroom. In other words, the main components of Shulman's conceptualization of PCK are:

1. Knowledge of representations of subject matter for teaching
2. Knowledge of relevant instructional strategies
3. Knowledge of learners' conceptions (preconceptions and misconceptions) and learning difficulties

These three components of PCK seem to be most appropriate in defining the PCK that may be used for teaching genetics in school biology, namely subject matter content knowledge, pedagogical knowledge (knowledge of instructional strategies) and knowledge of learners' preconceptions and learning difficulties. The three components cover the perspectives and constructs of PCK used by many researchers (De Jong, 2010; Penso, 2002; Halim & Meerah, 2002; Rollnick et al., 2008) in this area.

The operational definition for the construct PCK used in this study is that it (PCK) is an amalgam of subject matter content knowledge, pedagogical knowledge (knowledge of instructional strategies) and knowledge of learners' preconceptions and learning difficulties. The intention was to determine the PCK that successful biology teachers use in teaching genetics by observing and measuring the PCK that such teachers demonstrate in classroom practice. It is assumed that because such teachers are considered successful and have experience in teaching genetics, they would be able to integrate content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties in ways that contribute to the development of the PCK used for teaching genetics (Kaya, 2009; Penso, 2002; Rollnick et al., 2008). The teachers' development of PCK was inferred from the lesson observation, teacher interviews, questionnaires, reflective reports, and document analysis.

1.7 Chapter summary

This chapter provided an introduction to and background of the study. It oriented the reader to the research problem, and provided a backdrop for the rationale and significance of the study in relation to teacher knowledge in the teaching of genetics, a science topic considered difficult to learn. The chapter includes the theoretical framework, which guided the study in

the development of research instruments, data collection, analysis and discussion of the research findings as well as the assumptions of the study. It ends (below) with the chapter structure of the thesis.

The next chapter presents a review of literature related to the study.

1.8 Chapter organization of the study

The study is presented in six chapters. The first chapter provides an introduction to and background of the research problem, the research questions, and significance of the study. Chapter two presents the relevant literature, focusing on science teachers' pedagogical content knowledge and methods of assessing PCK, in the context of science learning and teaching. Chapter three is about the research methodology used in the study. It includes the research method and design, instrumentation, pilot study, and the administration of the main study. Chapter four presents the results and findings of the study. Chapter five presents a discussion of the results. Lastly, the sixth chapter contains a synopsis, conclusions and recommendations of the study.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

This chapter presents a review of the literature on teachers' pedagogical content knowledge (PCK) in relation to teaching and learning school science with particular reference to genetics topic. It begins with a review of the topic of genetics in the Swaziland school curriculum and research on genetics teaching and learning. Thereafter, it focuses on the conceptualizations of PCK in science teaching, followed by discussions of the components of PCK, in relation to the main research questions. The chapter ends with an integrative summary of the issues raised and discussed.

2.2 Genetics teaching in the Swaziland school curriculum

As in other countries (Kindfield, 1991), genetics is among the most fundamental topics in the Swaziland biology curriculum. Genetics is an important topic as its understanding serves as a base for many scientific careers that require its application. For example, improvements in agriculture are partly dependent on the science of genetics (Dugru-Atay & Tekkaya, 2008). But the genetics topic does not feature in the science syllabuses of Swaziland until Grades 11–12 (the last two grades of secondary education level). Many young people will not receive any formal instruction in genetics again, unless they happen to choose to specialize in biology at tertiary education level.

One of the purposes of the biology course for the Swaziland General Certificate of Secondary Education (SGCSE) is to enable learners to "be suitably prepared for studies beyond SGCSE in pure sciences, in applied sciences or in science-dependent vocational courses" (Examinations Council of Swaziland, 2009:4). For learners to further their studies in genetics-related fields, it is critical that they should acquire meaningful understanding of the basic concepts in genetics such as chromosomes, genes, and cell division (mitosis and meiosis). Kindfield (1991) asserted that chromosomes are the vital organization units of genetic information and the major elements involved in the processes of cell division (mitosis and meiosis). For this reason, Kindfield argues that it is important that learners have correct conceptions of chromosomes in order to develop a meaningful understanding of genetics. These basic concepts form the foundation for understanding more complex genetics concepts

such as monohybrid inheritance, variation and genetic engineering, which are topics included in the National Curriculum.

The Swaziland General Certificate of Education biology curriculum for Grades 11 and 12 is divided into two components: extended and core curricula. The extended curriculum is a fully fledged biology course, which covers all biology topics for high-school level. It is an option that allows learners to proceed with science-related choices and careers at the tertiary level of education. The core curriculum is a subset of the extended curriculum. It is considered a soft option in the sense that it covers biology topics in less depth and excludes some topics found in the extended one.

The SGCSE curriculum document (ECOS, 2009:21) states that at the end of this course the learner is expected to be able to:

- Define the terms:

- "Chromosome as a thread of DNA, made up of genes
- Gene as a section of DNA, which codes for the formation of a protein, controlling a specific characteristic of the organism
- Allele as an alternative form of a gene
- Haploid nucleus as one containing a single set of unpaired chromosomes e.g., in sperm and eggs
- Diploid nucleus as one containing pairs of chromosomes e.g., in somatic (body) cells

- Describe the inheritance of sex in humans (XX, XY)

- Describe mitosis simply in terms of the exact duplication of chromosomes resulting in identical daughter nuclei (details of stages are **not** required)

- Describe the production of gametes by meiosis simply; in terms of halving of chromosome number leading to variation (details of stages are **not** required)" (Examination Council of Swaziland, 2009:21)

The focus of this study was on the extended biology curriculum content. The study concentrated on the specific genetics topics of chromosomes, gene, mitosis and meiosis,

which are seen as the fundamental genetics concepts that form the basis for understanding others. However, research suggests that learners find them difficult to learn (Tsui & Treagust, 2004, 2007; Williams et al., 2012).

2.3 Research on teaching genetics in school biology

Globally, school genetics has been identified as an area of school biology that learners tend to struggle with (Chu & Reid, 2012; Clark & Mathis, 2000; Dogru-Atay & Tekkaya, 2008; Ibanez & Martinez-Aznar, 2005; Kindfield, 1991; Lewis, Leach & Wood-Robinson, 2000a, 2000b, 2000c; Lewis & Wood-Robinson, 2000; Riemeier & Gropengieber, 2008; Tsui & Treagust, 2004, 2007; Venville, Gribble & Donovan, 2005; Yilmaz, Tekkaya & Sungur, 2011). The concepts that learners usually have problems with have been identified and include "chromosomes, genes, alleles, homozygous, heterozygous, dominance, recessiveness, mitosis, meiosis and fertilization" (Yilmaz et al., 2011:607). Research shows that even after instruction many learners still hold certain common misconceptions about these genetics concepts (Dogru-Atay & Tekkaya, 2008; Riemeier & Gropengieber, 2008). Genetics has thus remained one of the most conceptually difficult topics in school biology worldwide (Tsui & Treagust, 2004; Williams et al., 2012).

In England and Wales, a number of earlier studies (Clark & Mathis, 2000; Lewis, Leach & Wood-Robinson, 2000a, 2000b, 2000c; Lewis & Wood-Robinson, 2000) investigated the knowledge and understanding of genetics among high-school learners and found that they held misconceptions about basic genetics concepts. Lewis and Wood-Robinson (2000) for instance identified some common confusions and alternative frameworks among the learners. Some of the identified errors and difficulties were:

- Uncertainty about the relationship between the concepts of chromosomes and genes. Some learners regarded genes as being bigger than chromosomes; others suggested genes were made up of chromosomes; a few said chromosomes were found in genes; and others were not aware that chromosomes contain genetic information.

- Confusion about the meaning of cell division and the terminology involved. For instance, learners had problems using the contradictory terms which are used to describe the processes of cell division in terms of chromosomes and genetic information. These terms include copy, share, divide, split, replicate, reproduce and

multiply. They also could hardly distinguish between processes such as cell division and fertilization.

- Identified alternative conceptions in the genetics concepts included: chromosomes and/or genetic information are not copied, but shared during the processes of mitosis and meiosis.

Similar findings were reported by Lewis, Leach and Wood-Robinson (2000a), who showed that learners were not sure about the function, structure, and location of genes. In sum, the learners' misconceptions include using 'gene' and 'chromosome' interchangeably; and failing to locate genes within the body. Some learners believed that not all cells contain any genetic materials or structures. These findings were consistent with those of Lewis and Kattmann (2004), who found that German learners used the words genes, DNA, chromosomes interchangeably in trying to explain how inherited traits are passed from one generation to the next.

Learners' difficulties with the processes of cell division were reported by Lewis, Leach and Wood-Robinson (2000b). These authors stated that learners had difficulties in understanding the purposes and products of mitosis and meiosis. According to them, while many learners were aware that mitosis was different from meiosis, they were not sure of the nature of that difference in terms of chromosome number or genetic information. Some could not distinguish between mitosis and meiosis based on chromosome number, genetic information, or location. In instances where learners differentiated between mitosis and meiosis, they recognized mitosis only as cell division and linked meiosis with reproduction and confused it with fertilization. Furthermore, even learners who noticed the differences between mitosis and meiosis were confused by the similarity of the two terms.

Various reasons have been advanced for the difficulty with genetics. These include primarily the abstract nature of genetics concepts (Duncan, Rogat & Yarden, 2009; Law & Lee, 2004; Van der Zande et al., 2012) which is usually left unspecified. Chu and Reid (2012) observed that while it is established that abstract ideas often pose difficulties, the statement does not explain why abstract ideas pose problems. They assert that 'in order to understand abstract ideas often requires the learner to hold several ideas at the same time and that may easily cause mental overload' (Chu & Reid, 2012:286). Other researchers (e.g. Chu & Reid, 2012; Karagoz & Cakir, 2011; Williams et al., 2012) explained that genetics is difficult because it

involves relations between the events of different levels of biological organization. According to Chu and Reid (2012), an analysis of genetics suggests that the ideas and concepts inherent in them exist on four broad levels. These four levels in biology are organismal (learners can see, touch, smell and describe); cellular (mental pictures explaining or describing macroscopic observations); biochemical (not directly visible at all in living organisms); and representational (observations represented by symbols, formulae, mathematics and graphs). These authors explain that limited working memory capacity makes it more or less impossible for a novice learner to operate on several levels at the same time. The problem with genetics is that its nature involves several levels, with the possibility that working memory will rapidly overload, leaving understanding as a casualty. The connectivity and ease of movement from one level to another is usually without difficulty for the expert or teacher, but rather difficult for the novice learner (cf. Yilmaz et al., 2011:607). Other sources of the difficulties include language in genetics terminology and teaching strategies (Chu & Reid, 2012).

To address the problem, some researchers (Banet & Ayuso, 2003; Knippels, Waarlo & Boersma, 2005; Lewis & Kattmann, 2004; Williams et al., 2012) have advocated for sequencing genetics instruction, starting from the context of a visible phenomenon at macroscopic level and slowly moving to the microscopic and sub-microscopic level. Such an approach, they maintain, would enable learners to become aware of the relationship between the basic processes of genetics and the biochemistry or physiology of the whole organism (Lewis & Kattmann, 2004). Others (Chinnici, Neth & Sherman, 2006; Kindfield, 1991; Law & Lee, 2004; Oztap, Ozay & Oztap, 2003) have recommended the use of visual representations such as pictures and models during teaching in order to help learners visualize intangible genetics concepts and enhance conceptual understanding. Dogru-Atay and Tekkaya (2008), Kazeni and Onwu (2013) and Yilmaz et al. (2011) suggest alternative teaching approaches that take learners' prior knowledge into consideration in presenting the lessons, rather than following the normal traditional form of instruction that assumes the learner's mind is *tabula rasa*. According to Dogru-Atay and Tekkaya (2008) and Yilmaz et al. (2011), teaching approaches that recognize learners' pre-existing knowledge are likely to promote meaningful learning and conceptual understanding of genetics concepts. Similarly, Lewis and Kattmann (2004) have said that teachers' knowledge of learners' preconceptions is a sine qua non for effective learning. Kazeni and Onwu (2013) suggest that context-based

teaching approaches using contexts with which learners are familiar are more effective in improving learner performance in genetics than traditional ones.

Through this study, the researcher intended to determine whether the participating biology teachers are aware of their learners' learning difficulties with genetics concepts such as chromosomes, genes, mitosis and meiosis and how they (the teachers) elicit and address these difficulties. Pedagogical content knowledge was viewed as an appropriate construct for this study because the topic-specific content knowledge of teachers effects what they teach in the classroom. It was therefore necessary to investigate the PCK of a biology teacher who demonstrates rich content-specific knowledge (Loughran et al., 2006, 2012) in order to determine how the teacher's PCK is enacted while teaching topics regarded to be difficult for learners to master.

2.4 Pedagogical content knowledge

2.4.1 Conceptualizations of pedagogical content knowledge

The notion of pedagogical content knowledge was first introduced by Shulman as a form of knowledge that connects a "teacher's cognitive understanding of subject matter content and the relationships between such understanding and the instruction teachers provide for students" (Shulman, 1986:25). In its original context, PCK represents that particular amalgam of content and pedagogy that is uniquely the province of teachers and distinguishes a teacher from a subject matter specialist (Shulman, 1987). Shulman argued that this amalgamation of subject matter knowledge and pedagogical knowledge empowers a teacher to help learners construct appropriate understandings. In other words, according to Shulman, PCK results from the blending of content knowledge with pedagogical methods. Through that combination of knowledge, teachers gain a perspective that enhances their abilities to present specific topics in a specific subject area (Miller, 2007).

In Shulman's conceptualization, PCK in science teaching for instance consists of representations of subject matter, which could be analogies, illustrations, examples, explanations, and demonstrations aimed at making it comprehensible for learners (Shulman, 1986). It also includes an understanding of what makes the learning of particular topics easy or difficult, which might be the preconceptions that learners of different backgrounds bring with them to the classroom.

Other researchers (Carlsen, 2001; Cochran, deRuiter & King, 1993) have elaborated on or criticized Shulman' conceptualization of PCK by suggesting different views of PCK or including in PCK other types of teacher knowledge base for teaching. Criticizing Shulman's view of PCK as static, Cochran et al. (1993) took a constructivist perspective of PCK, arguing that the word 'knowledge' in PCK was too rigid for the constructivist perspective. They proposed the term 'pedagogical content knowing' to imply that PCK was a continually changing construction of knowledge. Similarly, Carlsen (2001) contended that PCK should not be viewed as a fixed body of knowledge and its dynamic nature should be emphasized. Some researchers (e.g. Appleton, 2006) maintain that Shulman's conception of PCK has elements of constructivism. Appleton (2006) argues that by including in PCK teacher knowledge of learners and their preconceptions, Shulman's conception implies a learner-centred pedagogy that is perhaps constructivist in orientation.

Several other scholars (Hashweh, 2005; Juttner, Boone, Park & Neuhaus, 2013; Juttner & Neuhaus, 2012; Magnusson, Krajcik & Borko, 2001; Rohaan, Taconis & Jochems, 2009) have elaborated on Shulman's model of PCK in terms of the domains of teacher knowledge base for teaching and/or the components of PCK they include in their conceptualizations of the construct. For example, in addition to content knowledge and pedagogical knowledge, Grossman (in Lee & Luft, 2008) has included knowledge of context and Cochran et al. (1993) have included knowledge of learners and the learning environment. Further, Magnusson et al. (2001) have described PCK as consisting of five components: orientations toward science teaching, knowledge of science curriculum, knowledge of assessment for science, knowledge of science instructional strategies and knowledge of learner science understanding. In recent publications, these perspectives of PCK and PCK-related research have been comprehensively reviewed and summarized (Kind, 2009b; Lee & Luft, 2008; Schmelzing et al., 2013).

From the discussion so far, it is safe to conclude that there is no universally accepted conception of what constitutes PCK. The lack of consensus in the definition of PCK in science education research has been reported in various reviews of research on PCK (Abell, 2007; Ekis, 2012; Kind, 2009b; Schmelzing et al., 2012). Despite the inconsistency in the definition of PCK, most science education researchers have embraced Shulman's conception (Abell, 2007; Kaya, 2009; Van Driel, De Jong & Verloop, 2002) and have used it as a basis

for their conceptualizations, depending on their research questions (Juttner et al., 2013; Lee & Luft, 2008). Juttner et al. (2013) and Schmelzing et al. (2013) have indicated that there is agreement about two critical aspects of PCK: knowledge of students' understanding and knowledge of instructional strategies.

Lee and Luft (2008) asserted that all the perspectives of PCK can be classified as integrative or transformative. In the integrative viewpoint, teacher knowledge of teaching is simply the mixing of types or domains of knowledge such as subject matter knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties with regard to a specific topic. In this view, PCK is seen as a mixture of types of knowledge that tend to exist as separate units. This view suggests that PCK components can be measured separately. Lee and Luft (2008) argued that a teacher's ability to integrate the components of PCK is determined by their knowledge about the individual components. During teaching, the teacher integrates knowledge of all the various domains individually to create efficacious learning opportunities (Rollnick et al., 2008).

In the transformative view, several categories of teacher knowledge such as content knowledge, pedagogical knowledge and knowledge of context are transformed into a new type of teacher knowledge, which is referred to as PCK for the purpose of instruction (Appleton, 2006). PCK is thus viewed as a synthesized knowledge base for teaching (Lee & Luft, 2008). According to Lee and Luft (2008), the integrative model might represent the PCK of novice teachers, because research indicates that novice teachers usually rely more heavily on one category of knowledge rather than concurrently drawing from all domains. The transformative model portrays the PCK of expert teachers who usually draw from various categories of knowledge in their teaching. It would therefore be illuminative to see the extent to which the teachers (described as successful) who participated in this study exhibited the characteristics or features of either of those models of PCK.

In biology education, some investigators (Juttner et al., 2013; Juttner & Neuhaus, 2012; Schmelzing et al., 2013) have conceptualized PCK in terms of the three knowledge dimensions of declarative, procedural and conditional knowledge (Alexander, Schallert & Hare, 1991; Paris, Lipson & Wixson, 1983). Using Shulman's (1986) definition of PCK as a basis, they viewed PCK as consisting of three components, namely declarative PCK, procedural PCK and conditional PCK. Declarative PCK is defined as 'knowing that' or propositional PCK, which essentially is factual knowledge that can be expressed in sentences

or indicative propositions (Schmelzing et al., 2013). It includes propositions, correlations, rules, and theoretical knowledge of ideas and principles and focuses on sense making – in other words, 'knowing it'. Procedural PCK is described as 'knowing how' and is also known as practical knowledge. Schmelzing et al. (2013) emphasize that procedural PCK describes automated skills and action routines that are exercised in the performance of biology tasks. In other words, procedural PCK is the ability to do something in the context of knowledge application. Juttner et al. (2013) define conditional PCK as a control or operational knowledge that can be described as 'knowing how and why' (Paris et al., 1983). It is a type of meta-knowledge that is "used to tie together and co-ordinate" declarative and procedural knowledge (Juttner et al., 2013:49). This conceptualization of PCK seemed appropriate and relevant in the context of this study for classifying teacher knowledge base in implementing the curriculum in the biology classroom. To this end, this study used this three-component conceptualization to analyse the participating teachers' content knowledge.

Biology has a special standing concerning teachers' subject matter content knowledge (Abell, 2007) because 'it is the only science subject that includes both substantive and syntactic structures' (Juttner et al., 2013:47). According to Juttner et al. (2013), substantive structures suggest ways of organizing biological concepts and principles, while syntactic structures indicate ways by which extremes such as truth and falsehood in the discipline are established. Munby, Russell and Martin (2001) also suggested, somewhat differently, that substantive knowledge entails the explanatory structures or paradigms of the field and syntactic knowledge refers to the methods and processes by which new knowledge in the field is generated. Thus, content knowledge is not only "to understand that something is so; the teacher must further understand why it is so" (Shulman 1986:9). In other words, to teach biology effectively teachers are expected to know the 'what', 'how' and 'why' of the content they teach (Juttner et al., 2013).

Veal and MaKinster (1999) developed a taxonomy for science teacher development that focused on PCK in particular topics. In their taxonomy, they distinguished three types of PCK: general PCK, domain-specific PCK and topic-specific PCK. Based on their definition of these types of PCK, general PCK relates to science as a subject; domain-specific PCK deals with different domains in science, namely biology, physics and chemistry; and topic-specific PCK relates to the topics, concepts or terms in a domain. Topic-specific PCK is said to be the most distinct level of PCK because it applies only to the teaching of specific

concepts (De Jong et al., 2002). In other words, topic-specific PCK is distinctly different for each specific content area (Miller, 2007). Topic-specific PCK is described as teacher knowledge about how to teach particular content in ways that lead to increased learner understanding, which teachers develop over time and through experience (Loughran et al., 2012). It includes what teachers know about their subject matter and how that knowledge is transformed into classroom curricular actions (Munby et al., 2001). This study focused on the topic-specific PCK of biology teachers with regard to the topic of genetics.

This study examines what PCK biology teachers have and how they developed it in the context of teaching genetics at the high-school level. In this study, PCK is viewed as the blending of content knowledge and pedagogical knowledge in ways that make the content accessible to learners. It also includes knowledge of learners' preconceptions and learning difficulties with regard to that content or topic. This means that content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties are important during the development of PCK. These elements of PCK were also used by Ijeh (2012) in his doctoral work on school mathematics teachers' PCK and development in school statistics teaching. Based on the notion of amalgamation, the elements of PCK can exist independently of one another or as a unit. The ways in which the participating teachers used the components of PCK were determined by trying to describe their PCK profiles as evident in their genetics lesson plan and teaching.

2.4.2 Development of science teachers' pedagogical content knowledge

A substantial amount of research exists on the development of science teachers' PCK, in the contexts of both pre-service and in-service education (Arzi & White, 2008; Brown et al., 2013; De Jong, 2010; De Jong, Van Driel, & Verloop, 2005; Drechsler & Van Driel, 2008; Henze, Van Driel, & Verloop, 2008; Kind, 2009a). In the literature, PCK development has been investigated in at least two ways. One way is through longitudinal studies in which the growth or gain in teachers' knowledge is traced over time or years (e.g. Appleton, 2008; Arzi & White, 2008; Brown et al., 2013; De Jong, 2010; Henze et al., 2008; Leonard et al., 2009; Lowery, 2002). These studies indicate the factors that influence or promote the development of science teachers' PCK. To develop teachers' PCK, it is argued that two main ingredients are necessary: subject matter knowledge; and experience in teaching (Davis 2003; De Jong, 2010; Miller, 2007). Drechsler and Van Driel (2008) emphasized that the impact of teachers' classroom teaching experience on PCK development is enhanced by reflection on their own

teaching and on students' difficulties. Other authors (Leonard, Boakes & Moore, 2009; Loughran et al., 2012) have supported the role of reflection in developing science teachers' PCK. Leonard et al. (2009) noted that teachers can develop PCK by reflecting upon their own practices with learners in formal and informal settings. Other factors or sources of PCK include professional development or workshops training, curriculum documents, textbooks and collaboration with in-school colleagues (Appleton, 2008; Arzi & White, 2008; Burn, Childs & McNicholl, 2007; De Jong, 2010; Kind, 2009a; Leonard et al., 2009; Lowery, 2002).

The other approach in which teachers' PCK development has been investigated is by studying how teachers developed their existing PCK (e.g. Drechsler & Van Driel, 2008; Ijeh, 2012). Drechsler and Van Driel (2008) for example explored how experienced chemistry teachers perceived to have developed their PCK in teaching acids and bases focusing on teachers' knowledge of teaching strategies and learners' difficulties with regard to the topic. During interviews, they asked the teachers to explain how and why they changed their teaching methods year after year. The findings of their study showed that the teachers changed the experiments, the way in which a topic was explained, and the examples for calculations. Their reasons for change included reflection on learners' difficulties; collegial discussions; research; reflection on teaching; textbooks; stimulation; the media; and simpler experiments. In addition, Kind (2009a) investigated the sources of pre-service science teachers' subject matter knowledge in teaching within and outside their specialisation. A questionnaire required them to select sources they used during lesson preparation from a given list of sources including curriculum documents, textbooks and colleagues. Kind validated the questionnaire data by interviewing the teachers about their sources of subject matter knowledge. Furthermore, Ijeh (2012) used interviews and asked mathematics teachers how various factors or sources might have contributed to the development of their PCK in statistics teaching. While the first approach might be better for investigating PCK development since it would clearly show how the teacher's knowledge grows over time, given the time and resource limitations under which this study was conducted, the second approach was the only practical option. This study investigated the participating teachers' existing PCK in genetics teaching. It sought to first identify the 'what' of the teachers' PCK in teaching some aspects of genetics and, second, to determine how they possibly developed their PCK. It was assumed, based on the literature, that factors such as disciplinary courses, classroom teaching experience, professional development, and collaboration with in-school

colleagues might have influenced the development of the participating teachers' PCK in teaching genetics.

2.5 Methods of assessing teachers' PCK

Since the introduction of the notion of pedagogical content knowledge (PCK) by Shulman (1986, 1987) more than twenty years ago, research on teachers' PCK has increased over the years. The rise in this kind of research is driven by the belief that PCK is essential for effective teaching, including science teaching (Abell, 2007; Loughran et al., 2012; McConnell et al., 2013; Park & Chen, 2012; Park & Oliver, 2008).

Most PCK studies (e.g. Ball, 2000; Ball et al., 2008; Baumert, Kunter, Blum, Brunner, Voss, Jordan, et al., 2010; Hill et al., 2008; Ijeh, 2012; Schwarz, Wissmach & Kaiser, 2008), however, have been conducted in the field of mathematics. Only a few comparable studies have been conducted with science teachers, particularly biology teachers (Juttner et al., 2013; Schmelzing et al., 2012). Moreover, Loughran et al. (2012) contend that while there is extensive research on PCK, there is a dearth of research providing concrete examples of PCK in subject areas on how 'successful' teachers teach particular content topics in ways that promote learner understanding and improved performance. To fill this gap in the literature, this study examined successful biology teachers' PCK in genetics teaching and how it was developed. It provides descriptions of the participating teachers' PCK profiles in teaching the topic.

The way PCK has been used in research and the data collection and analysis methods that result can be classified in two components: research on PCK; and research using PCK as a theoretical framework (Miller, 2007). According to Miller (2007), research on PCK involves trying to identify or measure PCK, while research using PCK as a theoretical framework assumes that PCK exists in order to study other aspects of teaching science, as in the present study. As stated in chapter one (Ref. 1.1), it is not easy to measure and assess PCK, owing to its nebulous and sinuous nature (Kind, 2009b; Loughran et al., 2004; Miller, 2007). The boundaries of PCK components are indistinct because of the various categories of knowledge that could be integrated into PCK (Loughran et al., 2004). Even so, several studies (Juttner & Neuhaus, 2012; Kaya, 2009; Loughran et al., 2006) have attempted to identify and measure PCK.

The data collection methods and instruments that have been used to assess and measure PCK have been reviewed and summarized by Baxter and Lederman (2001) and Miller (2007). Miller (2007) observed that in current research, various methodologies have been used to identify PCK constructs, to establish how these constructs are developed by teachers, and to investigate how they affect student learning in the classroom. He classified these methodologies into three categories: convergent and inferential techniques; visualization techniques; and multiple-method evaluation. Convergent and inferential techniques are said to entail the use of predetermined verbal descriptions of teacher knowledge categorized as PCK. Examples of this class of methodologies are the Likert-scale survey, pre- and post-assessment, multiple choice and short-answer tasks.

Visualization techniques include drawing concept maps, using vignettes, and constructing analogies, which provide a physical representation of teacher knowledge. Multiple-method evaluation involves multiple sources of data and is the most frequently used method of data collection and analysis for PCK research. It combines the use of interviews, observations, reflections and course materials with visualizations, and convergent and inferential techniques. After weighing the advantages and disadvantages of each category of methodology, Miller (2007) suggested that the multiple methods may be recommended because they provide for triangulation of data, which is useful to validate research findings and conclusions. The use of multiple methods in PCK research has also been commended by other authors (Abell, 2007; Baxter & Lederman, 2001). In this study, multiple sources of data collection – such as concept mapping, lesson plans, interviews, lesson observation, reflective journals and document analysis – were used for triangulation.

2.5.1 Teachers' PCK and content knowledge

Content knowledge, often called subject matter knowledge, is seen as a crucial component of teachers' professional knowledge (McConnell, Parker & Eberhardt, 2013; Shulman, 1986). Content knowledge can be defined as the facts, concepts, principles, relationships, processes, procedures, and applications that learners should know in a given subject area or topic (Munby et al., 2001; Ozden, 2008) or simply what teachers should know about what they teach (Penso, 2002).

A number of studies (e.g. Ball, 2000; Ball et al., 2008; Ijeh, 2012; Juttner et al., 2013; Kapyla, Heikkinen & Asunta, 2009; Kind, 2009a; Ozden, 2008; Rollnick et al., 2008) have

been carried out into teachers' subject matter or content knowledge in relation to PCK in science and mathematics teaching. The literature has shown that teacher subject matter knowledge influences their PCK and classroom practice (Ball et al., 2008; Gess-Newsome & Lederman, 1995; Kapyla et al., 2009; Kaya, 2009; Ozden, 2008; Rollnick et al., 2008). For instance, Kaya (2009) has reported a significant positive correlation between the subject matter and PCK of pre-service science teachers. Generally, scholars agree that content knowledge "is necessary, but not sufficient for effective teaching" (Abell 2007:1120). Its deficiency affects teachers' ability to improve their practice (McConnell et al., 2013).

A deep understanding of science concepts or sufficient content knowledge is one of the characteristics of effective science teachers (McConnell et al., 2013). McConnell et al. (2013) assert that a teacher's facility to identify, explain and apply concepts is crucial in the teaching process including designing, implementing and assessing instruction. They contend that teachers with deep and coherent content knowledge are likely to give clear explanations of complex ideas and connections among core ideas. They are able to identify relevant and accurate examples of concepts. They organize and implement meaningful instruction, which includes multiple representations and models of the concepts, which give accurate depictions of scientific concepts; assess learners' understanding and identify misconceptions reflected in learners' verbal and written statements; and engage learners in inquiry that results to deeper comprehension of concepts. This discussion suggests that teacher content knowledge influences teachers' knowledge of instructional strategies and learners' preconceptions and learning difficulties. Teachers need to develop adequate content knowledge in order to teach effectively (Halim & Meerah, 2002; Kapyla et al. 2009).

While content knowledge is seen as critical in effective teaching and forms the base for the development of PCK (Davis, 2003; De Jong et al., 2002; Kind, 2009b), some studies (Halim & Meerah, 2002; McConnell et al., 2013; Rollnick et al. 2008) have shown that many teachers, including science teachers, do not have sufficient knowledge of the content they are required to teach. Those who have taken only introductory science courses or are teaching out of their fields usually have ideas of science content that may reflect misconceptions (Halim & Meerah, 2002; Kind, 2009a). These teachers may avoid teaching science or may give superficial treatment to complex concepts, because weak content knowledge contributes to anxiety and low levels of self-efficacy, resulting in less effective teaching (Kind, 2009a;

McConnell et al., 2013). This study was interested in assessing biology teachers' content knowledge of genetics.

Assessing teacher content knowledge poses a number of challenges (McConnell et al., 2013) and past studies have used varied methodologies to evaluate it. It is therefore sometimes difficult to synthesize the outcomes of such assessment procedures (Juttner et al., 2013). For instance, some investigators (e.g. Baumert et al., 2010) have used the number of courses completed to determine a teacher's content knowledge level. In contrast, others have attempted to directly measure content knowledge using tests utilizing right/wrong answers and/or multiple choice items (e.g. Hill et al., 2008, Ijeh, 2012; Juttner et al., 2013; Ozden, 2008). But Miller (2007) has stated that multiple choice and short-answer tests have a number of loopholes, such as lack of criterion-related validity because they may not be an authentic measure of the specific skill being analysed by the investigator. McConnell et al. (2013) posited that while these instruments may be reliable and efficient, they do not reveal depth of knowledge.

As investigators employed theories of 'conceptual understanding' (Abell, 2007, 1110) to a greater extent, they tended to include more open-ended items (e.g. Baumert et al., 2010; Kapyla et al., 2009; Rollnick et al., 2008; Schwarz et al., 2008), which require participants to explain their responses. Yet others (e.g. Ijeh, 2012; Rollnick et al., 2008) have used interviews and observations to study content knowledge. McConnell et al. (2013) assert that interviews and observations provide deep understanding of content knowledge, but are time consuming. Despite these disadvantages, researchers have continued to successfully use interviews and observations to assess science and mathematics teachers' content knowledge (Ijeh, 2012; Kapyla et al., 2009; Loughran et al., 2006; Ozden, 2008; Rollnick et al., 2008).

Ozden (2008) utilized lesson plans, content knowledge tests and semi-structured interviews to assess the effect of the amount and quality of 28 science student teachers' content knowledge on pedagogical content knowledge on a particular topic, that is, phases of matter. The student teachers were first asked to write individual lesson plans for a two-hour teaching period on the topic. They were given one hour to write the lesson plans without books or other material. Immediately after the lesson plan, a content knowledge test was used to determine their understanding of phases of matter and alternative conceptions. During semi-structured interviews, participants were asked to describe their lesson plans and state any difficulties they (student teachers) experienced in writing them. The purpose of the interviews was to

determine the student teachers' content knowledge, PCK (knowledge of teaching activities and learners' conceptual difficulties), and difficulties in lesson planning, as well as anticipated problems in teaching. Ozden (2008)'s study may be commended for the use of multiple methods of data collection (Abell, 2007, Miller, 2007). However, Ozden (2008) did not use lesson observation, which would have provided direct and first-hand information about the participating teachers' content knowledge and PCK (Creswell, 2008; McMillan & Schumacher, 2010). In this study, classroom observation was as a main source of data on teacher content knowledge.

Kapyla, Heikkinen and Asunta (2009) used multiple methods of data collection, including lesson plans, questionnaire and interviews, in their study to investigate the influence of the amount and quality of content knowledge on pedagogical content knowledge of student teachers in the biology topic of photosynthesis and plant growth. The lesson plan was written without assistance from books, and was followed up immediately by the administration of two questionnaires. The first questionnaire sought information about the student teachers' background information, such as their university studies, teaching experience and familiarity with the topic. The second questionnaire was about their own understanding of the topic of plant growth and photosynthesis, and their knowledge of learners' prior knowledge, misconceptions and learning difficulties within the topic.

Content knowledge was assessed through lesson plans, questionnaires and interviews, while knowledge of teaching activities was assessed through lesson plans and interviews. Data were analysed using the predetermined categories of content knowledge, knowledge of curriculum, knowledge of teaching methods, and knowledge of learners' conceptual difficulties. Once again, a deficiency of this study was the lack of lesson observation.

In two case studies, Rollnick et al. (2008) investigated the influence of subject matter knowledge on teachers' PCK in chemistry. One case study was about two high-school teachers' subject matter knowledge of the mole. The other study was about chemical equilibrium and a lecturer in a tertiary institution. Methods of data collection included pre- and post-lesson interviews, lesson observation, and document analysis. The participants were observed teaching two or more lessons on the topic and were interviewed before and after each lesson. The pre-lesson interview sought information about the teachers' understanding

of the topic and their planning strategies, explanations, and resources used in their lessons. Lesson observations were recorded using videotapes and audio-recordings. The post-lesson interviews included a stimulated reflection on the lesson. A written reflection was obtained from one teacher about her teaching.

In the analysis of data, Rollnick et al. (2008) used pedagogical and professional-experience repertoires (PaP-eRs) and content representations (CoRes) to capture and portray the PCK of the participants (Loughran, et al., 2004, 2006). To develop CoRes, Loughran et al. (2004, 2006) engaged small groups of experienced science teachers in activities that were meant to assist them articulate and share with others how to teach specific science topics. This exercise led to the identification of 'big ideas' for teaching certain topics and afterward, to the development of framing questions. CoRes are concerned with teachers' understandings of the content and contribute to the content-specific nature of PCK. PaP-eRs on the other hand, are narrative accounts of practice that are designed to bring to life the ideas in the CoRes. In this study, CoRes were used in the analysis of pre-lesson interview transcripts in line with the three components of PCK as defined.

The research methodologies used by Ozden (2008), Kapyla et al. (2009) and Rollnick et al. (2008) informed the methodology of the present study. They provided the basis for assessing content knowledge, pedagogical knowledge, and knowledge of learners' preconceptions and learning difficulties as integral components needed to develop PCK for teaching. However, there were limitations in the studies. For example, as already indicated, Ozden (2008) and Kapyla et al. (2009) did not conduct lesson observation, which could triangulate what the teachers said in interviews. The use of lesson observation would have provided the investigators with opportunities to determine how the student teachers used their PCK in classroom practice, such as in preparation and presentation of lessons (Ijeh, 2012). In an attempt to avoid the deficiencies pointed out in these studies, this study used lesson plans, pre-observation interviews and lesson observation to assess the participating teachers' content knowledge of genetics.

Juttner et al. (2013) described content knowledge as consisting of two aspects. One aspect focuses on what might best be described as a cognitive taxonomy concerning three types of knowledge: declarative, procedural and conditional knowledge (Juttner & Neuhaus, 2012)

which has been discussed (ref. 2.4). The second aspect concerns biology topics that teachers see as relevant to the biological curriculum (Juttner et al., 2013).

In the present study, the content knowledge cognitive taxonomy proposed by Juttner et al. (2013) was used to analyse the lesson observation transcripts to assess the participating teachers' content knowledge. To this end, the content knowledge was defined in terms of the three dimensions of declarative, procedural and conditional content knowledge.

In this study, for the sake of triangulation, teachers' content knowledge was also assessed using concept maps. In their examination of the various techniques used to assess and measure PCK, Baxter and Lederman (2001) pointed out some criticisms of the use of concept maps to assess teacher knowledge that are reiterated by Miller (2007). Concept maps are seen to be somehow restrictive because they often require a particular format (hierarchical, static or two-dimensional) or the use of particular ideas in the representation of one's conceptual schema; and they may lack reliability in terms of representing all that an individual teacher knows about the content knowledge being assessed. However, Baxter and Lederman (2001) also noted that "Although concept mapping and card sorts have traditionally been used for research, the work of … Gess-Newsome and Lederman (1993) suggests that such representations may prove to be useful tools in teacher education" (Baxter & Lederman, 2001:153-154). Gess-Newsome and Lederman (1993) successfully used concept maps to assess biology pre-service teachers' subject matter structures. Their findings showed that at the beginning of their teacher education programme the teachers' subject matter structures were often vague and fragmented and during this programme, they developed more coherent and integrated subject matter structures.

Recent research in science and mathematics education has continued to use concept maps to assess teachers' content knowledge (Dickerson, Dawkins & Annetta, 2007; Greene, Lubin, Slater & Walden, 2013; Hough, O'Rode, Terman, Weissglass, 2007; Kaya, 2008; Zak & Munson, 2008). According to Greene et al. (2013), concept maps are consistent with enduring psychological theories about the structure of human knowledge and the process of learning. Since concept maps were introduced in the field of education in the 1980s (cf. Novak, 2005), they have been used widely in science and mathematics education research as tangible representations to demonstrate teachers' content knowledge structure, gains and acquisition, depending on the context (Dickerson, Dawkins & Annetta, 2007; Greene et al.,

2013; Hay, 2007; Hough, O'Rode, Terman, Weissglass, 2007; Ijeh, 2012; Kaya, 2008; Zak & Munson, 2008). For example, Kaya (2008), in a study on pre-service teachers in an undergraduate chemistry laboratory course, indicated that the use of concept mapping was a suitable assessment of knowledge gain, structure, and integration. Furthermore, in their exploratory study of elementary teachers' conceptual understanding of basic ecological concepts using concept maps, Zak and Munson (2008) asserted that a teacher's concept map can be characterized and analysed to assess the map structure, content accuracy, and depth of conceptual knowledge held within a subject area.

Very recently, Greene et al. (2013) used concept maps "to capture teacher content knowledge of the science concepts that were explored during the research sessions … intended to capture not only the breath, depth, and interrelated structure of participants' content knowledge, but also any changes in knowledge over time" (Greene et al., 2013:290-291). Based on their findings, they concluded that their study provided more evidence for the use of concept maps in determining changes in teacher conceptual knowledge as the maps were able to represent not only increases in the extent of content knowledge, but also changes in the complexity of that knowledge.

Concept maps may be viewed not only as effective for assessing teacher content knowledge, but also as evaluation instruments that are respectful of the teachers as professionals, and do not interfere with trust between researchers and teachers (Greene et al., 2013; Hough et al., 2007).

In the present study, the ideas from various studies (Gess-Newsome & Lederman, 1993; Greene et al., 2013; Ijeh, 2012; Usak, 2009) were utilized in the development and analysis of a concept mapping exercise for the participating teachers. The concept mapping exercise was used to assess teachers' content knowledge of genetics in school biology by listing and arranging genetics concepts in a logical sequence according to the way in which the teachers would present them in their classroom practice and presenting them in diagram format to show any connections or relationship.

2.5.1.1 Development of PCK: content knowledge

How do teachers develop the content knowledge component of PCK? What does the literature say? The development of teacher PCK has been described as a complex process that is not linear (Justi & Van Driel, 2005). The literature suggests that teachers gain content knowledge through pre- and in-service teacher education courses, classroom teaching experiences and curriculum documents (Arzi & White, 2008; Gess-Newsome & Lederman, 1993; Grossman (in Miller, 2007); Ijeh, 2012; Kind, 2009a; Lederman, Gess-Newsome & Latz, 1994; Schneider & Plasman, 2011). For example, in their 17-year longitudinal study, Arzi and White (2008) found that the school curriculum was the most powerful determinant of secondary science teachers' subject matter knowledge and served as both organizer and knowledge source. Other sources of teacher content knowledge, such as the Internet, textbooks, revision guides, school colleagues and other trainee teachers, were reported by Kind (2009a) in her study of the development of pre-service science teachers' subject matter knowledge. Gess-Newsome and Lederman (1993), in their study of subject matter structures for pre-service teachers, found that subject matter knowledge increased over time and through reflection.

In his study on how competent mathematics teachers developed their PCK in school statistics teaching, Ijeh (2012) used semi-structured interviews to investigate the teachers' educational background that enabled them to develop their topic-specific content knowledge and PCK. The interview questions sought information about the courses they did in tertiary education, their classroom teaching experience of planning and teaching lessons, and continuing professional development activities such as content-based and in-school workshops.

In the present study, a semi-structured interview schedule adapted from Ijeh (2012) was used to collect data about how the participating teacher's PCK was assumed to have developed.

In summary, the review of the literature in this section has revealed that teacher content knowledge is essential for the development of science teachers' PCK for teaching. Research on PCK exists in some biology topics, but there is a dearth of research that focuses on teachers' content knowledge and PCK in genetics teaching. The review indicated that various research instruments, such as lesson plans, content knowledge tests, questionnaires, interviews, classroom observations and concept maps, have been used to assess teachers' content knowledge. Researchers have used the instruments in combination in an attempt to

validate data. This study assessed the content knowledge of biology teachers in the teaching of genetics. For this purpose, it used multiple methods of data collection, including concept maps, lesson plans, interviews, and lesson observation. The data for the study were analysed according to the three components of PCK (content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties) as predetermined categories. CoRes were used to aid the analysis of pre-observation interview data. Within the category of content knowledge, the responses were classified as declarative, procedural and conditional content knowledge. This study used mainly interviews to examine how the participating teachers' PCK was assumed to have developed.

2.5.2 Teachers' PCK and pedagogical knowledge: instructional strategies

Pedagogical knowledge has been described as the 'science of teaching, instruction and training' (Ozden, 2008:634) or simply what teachers should know about teaching (Penso, 2002). It is one of the mediating factors between teachers' subject matter knowledge and classroom practice (Abd-El-Khalick, 2006). It includes knowing the content to be taught and the specific demands of that content, such as instructional strategies (Ball et al., 2008; Loughran et al., 2004, 2012). Knowledge of instructional strategies encompasses knowing how to sequence the learning outcomes, plan the lesson and facilitate discussion and group work (Ijeh, 2012). Limited knowledge of instructional strategies can negatively impact science instruction (Juttner et al., 2013).

The literature suggests that science teachers do not always have knowledge of the desired instructional strategies for teaching specific science topics (De Jong, Ahtee, Goodwin, Hatzinikita & Koulaidis, 1999; Friedrichsen, Abell, Pareja, Brown, Lankford & Volkmann, 2009; Henze et al., 2008). One reason for this lack of knowledge about instructional strategies could be insufficient content knowledge. It is said that teacher knowledge of instructional strategies is dependent on their subject matter knowledge (Magnusson et al., 2001). Kapyla et al. (2009) found that secondary student teachers who were biology majors had fewer misconceptions and inaccuracies and chose more hands-on activities and fieldwork for their lessons in the biology topic of photosynthesis and plant growth than primary student teachers. Consistent with this finding, Rollnick et al. (2008) found that high-school chemistry teachers teaching within the area of their specialisation had inadequate subject matter knowledge of the mole concept and lacked knowledge of appropriate instructional strategies for teaching the concept. Other factors may affect the teachers' choices and decisions about

instructional strategies. A review of research on science teachers' PCK (Ekis, 2012) revealed that factors influencing teachers' choice of teaching methods were the time available for lesson preparation and teaching, resources in the schools, concern about classroom management, beliefs about use of activities, and personal experiences of learning that topic in the past. The present study investigated the participating teachers' knowledge of instructional strategies in genetics teaching and the reasons for their choice of strategies.

How is teacher knowledge of instructional strategies best assessed? Kapyla et al. (2009) and Ozden (2008) used lesson plans and interviews to assess pre-service teachers' knowledge of teaching activities in the context of the topic of photosynthesis and plant growth, and phases of matter, respectively. During the interviews the pre-service teachers were asked to talk about their lesson plans in an attempt to determine their PCK in terms of teaching methods and activities. The methodology used in these studies was limited, in that it did not include observing how the teachers used that knowledge in classroom practice. Other studies (Park & Chen, 2012; Rollnick et al., 2008) have avoided this shortcoming by conducting classroom observation. Park and Chen (2012), for instance, argued that PCK appears at three stages of teaching: planning, during teaching (interactive), and after teaching during reflection (post-active); and therefore requires a methodology that captures it in these various phases. For this purpose, Park and Chen (2012) used a wider variety of methods to assess teacher knowledge of instructional strategies and representations as one component of PCK of four high-school biology teachers for the topics of photosynthesis and heredity.

In Park and Chen (2012) various data sources were lesson observation, semi-structured interviews, lesson plans, instructional materials and learners' work samples. Three different semi-structured interviews were carried out to understand what participants know and the reason for their instructional actions: background interview, pre-lesson interview, and post-lesson interview. The first interview was about the participants' demographics: their teaching background, orientations to science, and knowledge of teaching photosynthesis and heredity. The second interview dealt with teachers' planning of the lesson to be observed such as the objectives of the lesson, what they took into consideration in planning it, and their assessment plan, among others. The third interview was conducted to evaluate each teacher's reflection on the lesson. All interviews were audio-taped and transcribed verbatim. The multiple methods employed by Park and Chen (2012) seemed appropriate for the present study to assess the participating teachers' knowledge of instructional strategies at the different phases

of teaching. In the present study, the participating teachers were observed for six double-period lessons while teaching genetics, with the focus on the same genetics concepts.

In science teaching, Magnusson et al. (2001) made a clear distinction between subject- and topic-specific instructional strategies. They contend that knowledge of subject specific strategies involves general approaches to or overall schemes for enacting science instruction. Topic-specific instructional strategies refer to teachers' knowledge of specific strategies that are useful for helping learners grasp particular science concepts. This study was concerned with biology teachers' knowledge of topic specific instructional strategies with regard to the teaching of genetics.

Topic-specific instructional strategies can be classified in two sets: representations and activities (Magnusson et al., 2001). According to Magnusson et al. (2001) topic-specific representations entail science teachers' knowledge of ways to represent particular concepts or principles in order to promote learning. Indeed, in science teaching and learning, representations can include illustrations, examples, models and analogies. There could be multiple representations and analogies to represent a concept, and each representation could have conceptual advantages and disadvantages over the others (Coll, France & Taylor, 2005; Venville & Treagust, 1997). An effective teacher therefore should decide whether and when a particular representation would be useful to enhance the comprehension of learners for a specific topic and in a particular teaching situation (Juttner et al., 2013). Teacher knowledge of representations includes a teacher's ability to design representations to facilitate learning of specific concepts or relationships (Magnusson et al., 2001).

Teacher knowledge of topic-specific activities involves knowledge of the activities which can be used to aid learners grasp concepts or relationships (Magnusson et al., 2001). Examples of activities include problem solving, demonstrations, simulations, investigations and experiments. Teacher knowledge of topic-specific activities also entails knowledge of the conceptual power of a particular activity (Magnusson et al., 2001). Teachers should know the extent to which any particular activity denotes important information about a concept or relationship.

It can be gleaned from the previous discussion that in order to teach effectively, science teachers need to develop a repertoire of instructional strategies such as appropriate models, analogies, illustrations and examples, as well as demonstrations and experiments. These demands are true of biology teachers in particular (Juttner et al., 2013). A number of studies

on what constitutes instructional strategies argued that models, analogies and experiments are major instructional strategies specific to science (Clement, 2000; Coll et al., 2005; Hammann, Phan, Ehmer & Grimm, 2008; Magnusson et al., 2001; Treagust & Harrison, 2000; Venville & Treagust, 1997).

For example, Clement (2000) posited that the use of experiments and models in science teaching can assist learners in learning complex and abstract biological pathways and processes at molecular level. Hammann et al. (2008) suggested that experimentation can facilitate learner motor abilities and scientific competencies. Venville and Treagust (1997) said that in biology, analogies can aid learners to develop new knowledge by connecting it with existing knowledge structures and help them to visualize abstract or unobservable phenomenon and motivate them. But they cautioned that the use of analogies can lead to learners' misconceptions as a result of learners transferring aspects of the analogical concept to the scientific concept that are not meant to be transferred. Consequently, Coll et al. (2005) emphasized that when using models and analogies, teachers should take care to indicate similarities and differences between the model or analogy and targeted scientific concept. Research on genetics (Banet & Ayuso, 2003; Chinnici et al., 2006; Knippels et al., 2005; Law & Lee, 2004; Lewis & Kattmann, 2004; Williams et al., 2012) has shown that the use of familiar examples and visual representations such as pictures and models enhances learners' comprehension of genetics concepts.

This study investigated teachers' topic-specific instructional strategies (representations and activities) pertinent to genetics teaching and learning as displayed by the teachers. It employed lesson plans, interviews, lesson observation, reflective notes and document analysis to assess the participating teachers' knowledge of topic specific instructional strategies. The interviews and lesson observations served as primary data sources and the others were secondary data used for triangulation.

2.5.2.1 Development of PCK: pedagogical knowledge

Developing knowledge of instructional strategies may be dependent on subject matter knowledge (Kapyla et al., 2009; Magnusson et al., 2001; Rollnick et al., 2008). While Magnusson et al. (2001) generally agreed with this view, they argued that teachers' possession of subject matter knowledge is no guarantee that they would be able to transform this knowledge into representations that will enhance learners' comprehension of targeted scientific topics or concepts. Nor does it mean that teachers will automatically be proficient at deciding the appropriateness of particular representations. These authors suggested that classroom teaching experience enhances the development of teacher knowledge of instructional strategies. They stated a teacher who has taught a particular subject for a long time is more likely to have knowledge of instructional strategies than for a novice to have such knowledge. Once again, they cautioned that being an experienced teacher does not guarantee that the teacher will know conceptually powerful activities.

Several investigators (e.g. Brown et al., 2013; De Jong, 2010; Drechsler & Van Driel, 2008; Henze et al., 2008; Ijeh, 2012; Ijeh & Onwu, 2013) have assessed how pre- and in-service teachers developed their PCK of instructional strategies. While some studies (e.g. Brown et al., 2013; De Jong, 2010; Henze et al., 2008) have focused on the teachers' developing PCK over time, others (e.g. Drechsler & Van Driel, 2008; Ijeh, 2012; Ijeh & Onwu, 2013) have investigated how teachers developed the PCK they already possessed. This study examined how the existing participating teachers' PCK was assumed to have developed.

In his exploration of the development of PCK of 12 pre-service chemistry teachers, De Jong (2010) suggested that teachers' classroom teaching experiences had a strong impact on the development of their PCK of knowledge of teaching activities aimed at promoting learners' understanding of models. Classroom teaching experience has been reported by other researchers (De Jong et al., 2002; Drechsler & Van Driel, 2008; Henze et al., 2008; Van Driel & De Jong, 1999, 2001) as a crucial factor in the development of PCK. De Jong (2010) stated that in addition to classroom teaching experience, colleagues at school can function as an important source of teacher knowledge of teaching activities. Consistently, other studies (Burn, Childs & McNicholl, 2007; Drechsler & Van Driel, 2008; Kind, 2009a; Lowery, 2002) found that school colleagues can promote one another's development of PCK in various ways, such as collaborating with them and sharing ideas about the teaching of specific concepts. The factors, suggested by the literature as contributing to teachers' PCK

development were used in the development of items for the interview schedule used to assess how the participating teachers' PCK developed.

Drechsler and Van Driel (2008), Ijeh (2012) and Ijeh and Onwu (2013) used interviews to assess how experienced teachers developed their PCK. Drechsler and Van Driel (2008) investigated experienced chemistry teachers' PCK of teaching acids and bases, a topic which research had shown to be difficult for learners to understand, and how the PCK developed over time. It focused on teachers' knowledge of teaching strategies and of learners' difficulties with regard to acids and bases. During interviews, teachers were asked to explain how and why they changed their teaching methods year after year. The teachers stated various reasons including: reflection on learners' difficulties; collegial discussions; research; reflection on teaching; textbooks; stimulation; the media; and simpler experiments. The approach used by Drechsler and Van Driel (2008) of studying the development of teachers' existing PCK in a topic known to be difficult in the subject area was adopted in the present study. In this study, interviews were used to assess how the participating teachers developed their knowledge of instructional strategies for genetics teaching. Items for the semi-structured interview schedule were derived from the reviewed literature, particularly De Jong (2010), Drechsler and Van Driel (2008) and Ijeh (2012).

In summary, the review of the literature on teacher knowledge of instructional strategies has indicated that instructional strategies in biology (and genetics) teaching include topic-specific representations and activities. It has also shown that various techniques, such as lesson plans, interviews, questionnaires, observations and reflective notes, have been used to assess teachers' knowledge of instructional strategies and how this knowledge develops. A number of factors may contribute to the development of a teacher's knowledge of instructional strategies.

2.5.3 Teachers' PCK and knowledge of learners' preconceptions and learning difficulties

Research in science education has established that learners come to the classroom with their own ideas of science concepts (preconceptions) from their own everyday life experiences, observations and media (Juttner & Neuhaus, 2012; Morrison & Lederman, 2003; Treagust & Duit, 2008). The learners' preconceptions are usually incongruent with teachers' and scientists' views (Juttner & Neuhaus, 2012; Treagust & Duit, 2008). The mismatch between

learners' preconceptions and agreed scientific views may cause learning difficulties and derail learning (Gullberg et al., 2008) as it is argued that "if the differences between scientific and everyday ways of reasoning are great, then the topic in question appears difficult to learn and to teach" (Abell & Lederman, 2007:49).

According to Shulman (1986), teacher knowledge of learners' preconceptions and learning difficulties regarding a topic forms part of the teacher's PCK for that particular topic. This assertion suggests that it is crucial for teachers in the classroom to have knowledge about their learners' preconceptions of the scientific concepts to be taught in order to teach effectively and in ways that enhance learner comprehension and achievement (Gullberg et al., 2008; Juttner & Neuhaus, 2012; Morrison & Lederman, 2003; Penso, 2002).

Teachers' knowledge of learners' preconceptions helps them to interpret learners' actions and ideas, plan effective instruction, and create a discourse that stimulates learners to develop acceptable views about scientific concepts (Gullberg et al., 2008; Halim & Meerah, 2002). Teachers who are knowledgeable of learners' preconceptions and learning difficulties see the diagnosis of learners' preconceptions as the essential first step in the process of effective teaching (Morrison & Lederman, 2003). Identification of learners' preconceptions and learning difficulties is important in order to adapt teaching methods and forms of representation to the needs and characteristics of the learners (Penso, 2002).

However, research (De Jong, 2010; De Jong & Van Driel, 2004; Halim & Meerah, 2002; Ijeh, 2012; Juttner & Neuhaus, 2012; Kapyla et al., 2009; Morrison & Lederman, 2003; Ozden, 2008; Penso, 2002) suggests that many science and mathematics teachers lack knowledge of learners' preconceptions and learning difficulties in the topics they are required to teach. For example, Morrison and Lederman (2003) found that experienced science teachers lacked knowledge of learners' preconceptions, as none of them used any type of instrument such as pre-testing, interviewing, concept mapping or using writing prompts to identify learners' preconceptions. They all did not mention in their lesson plans attempts to identify learners' preconceptions about science concepts. The teachers were aware that it was important to find out what learners know, but did not have a repertoire of strategies to use for the diagnosis of learners' ideas. Recently, in the South African context, Ijeh (2012) found consistent findings. All four mathematics teachers who participated in his study lacked knowledge of learners' preconceptions in statistics teaching, despite their many years of

teaching. The current study examined teacher knowledge of learners' preconceptions and learning difficulties, if any, which the participating biology teachers, who are experienced and regarded as successful in their teaching, demonstrate in genetics teaching.

Numerous studies (e.g. De Jong & Van Driel, 2001; Gullberg et al., 2008; Halim & Meerah, 2002; Kapyla et al., 2009; Morrison & Lederman, 2003; Penso, 2002) have assessed science teachers' knowledge of learners' preconceptions and learning difficulties. While some studies (e.g. Halim & Meerah, 2002) have used single and convergent/inferential techniques to assess this aspect of PCK, others have used multiple-method evaluation (Kapyla et al., 2009; Morrison & Lederman, 2003). Morrison and Lederman (2003) examined the teaching strategies employed by four experienced exemplary secondary science teachers to diagnose learners' preconceptions. They used multiple sources of data including in-depth lesson observation; pre-and post-lesson interviews, analysis of teachers' lesson plans; and analysis of learners' written work. The pre-lesson interviews were about the teachers' teaching strategies. Lesson observations gave information on how the teachers taught science, the strategies they used, and their interactions with learners in the classroom. Post-lesson interviews provided information about the participants' thoughts and reflections on their own teaching. The teachers' planning was analysed and their learners' work reviewed to determine the emphasis the teachers placed on understanding their learners' preconceptions in the classroom. This involved examining the teachers' lesson plans for indication of the assessment of learners' ideas before or during the lesson and activities to address preconceptions. Morrison and Lederman (2003) employed a detailed multiple method to assess the teachers' knowledge of learners' preconceptions. This method as described was used for the present study.

Penso (2002) used teaching diaries to examine how 40 pre-service biology teachers identified and described the causes of learners' learning difficulties. In these diaries, the teachers were asked to evaluate the lessons they taught, focus on identifying learning difficulties and suggest their possible sources. They were supposed to identify which of the concepts or topics they taught during the lesson were difficult for the learners. They had to note what the learners said, clarifications the learners had asked for, their requests for more explanations, and their answers to tasks. While Penso (2002)'s study focused on only one method of data collection without any triangulation, the use of a reflective journal seemed appropriate in the

present study in order to triangulate data. In the current study, the participating teachers were asked to keep reflective journals using Penso (2002)'s guidelines.

Some studies (Magnusson et al., 2001; Penso, 2002) suggest possible sources of the learning difficulties that learners experience when learning scientific concepts. Penso (2002) grouped the sources in four categories: the learners' cognitive and affective characteristics; aspects of the teaching activity; aspects of the lesson content; and aspects of the lesson. The learners' cognitive and affective characteristics have to do with lack of prior knowledge to enable them to learn scientific content in a meaningful way, preconceptions acquired as a result of experience, as well as lack of motivation and concentration. Scientific concepts for which learners have misconceptions could be difficult to learn because misconceptions are typically favoured over scientific views (Magnusson et al., 2001). Aspects of the teaching activity involve 'content overload' and poor sequence and the presentation of the content. Aspects of the lesson content have to do with the level of its difficulty or complexity and abstraction (Magnusson et al., 2001). Lastly, aspects of the lesson include the lesson atmosphere such as discipline problems and organization.

In the current study, the participating teachers were asked through questionnaires, interviews and reflective journals to state the learning difficulties they anticipated their learners to have; the difficulties learners experienced during lessons; possible sources of those difficulties; and how the teachers dealt with difficulties.

2.5.3.1 Development of PCK: knowledge of learners' preconceptions and learning difficulties

Teacher knowledge of learners' preconceptions and learning difficulties is said to be dependent on subject matter knowledge (Magnusson et al., 2001) and is also influenced by classroom teaching experiences (De Jong, 2010; De Jong et al., 2002; Henze et al., 2008). Henze et al. (2008) used semi-structured interviews to assess the developing PCK of nine experienced science teachers (three physics, three chemistry and three biology majors) in their first few years of teaching a new science syllabus in the Dutch secondary education system. The interviews were conducted in three subsequent academic years. During the interviews, in order to determine teachers' knowledge about learners' learning difficulties and preconceptions, participants were asked to explain whether their learners needed any specific

previous knowledge in the context of the topic or chapter under consideration. The change in the teachers' knowledge of learners' previous knowledge was used as a reflection of growth in knowledge about learners. One limitation of this study was the sole use of interviews without triangulation, which may not be sufficient to capture PCK and how it develops, considering its complex nature (Abell, 2007; Miller, 2007). However, as with other related studies (e.g. Ijeh, 2012), this study used interviews to determine how the four participating teachers gained knowledge of learners' preconceptions and learning difficulties.

In summary, the literature reviewed in this section revealed that learners enter the classroom with certain ideas about scientific concepts, which are frequently not consistent with the scientific views they are expected to hold. For effective teaching and learning to take place, teachers are expected to know learners' ideas about the concepts they teach as well as learning difficulties learners are likely to experience and to use that knowledge to help learners develop appropriate conceptions. The review also indicated that various methods of data collection have been used to assess teacher knowledge of learners' preconceptions and learning difficulties, some of which were considered appropriate and relevant for this study.

2.6 Chapter summary

In conclusion, in this chapter, learners' learning difficulties with the biology topic, genetics, and the various conceptualizations of PCK in science teaching were highlighted. PCK, for the purpose of this study, was conceptualized in line with Shulman's (1986, 1987) definition as consisting of teachers' content knowledge, pedagogical knowledge (knowledge of instructional strategies) and knowledge of learners' preconceptions and learning difficulties. A critical review of the literature was done accordingly, with a view to identifying and synthesizing the theories and concepts that informed the methodology and analysis of results used in the study.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the research methodology that was used to explore participating teachers' pedagogical content knowledge (PCK) in genetics teaching and how it was supposed to have developed. It includes the research method and design; the development and validation of data collection instruments; ethical considerations; and the pilot study.

3.2 Research method and design

The study used a qualitative research approach within an interpretive paradigm (Merriam, 2009) to explore the research questions. A qualitative research approach was chosen because the interest of the study was in providing in-depth information and rich descriptions of the participating teachers' existing PCK profiles in the context of teaching school genetics. According to Merriam (2009), the purpose of research from an interpretive perspective is to describe, understand and interpret the phenomenon under investigation. In this paradigm, reality is multiple, context bound, and as seen by participants in the study (Creswell, 2007; Merriam, 2009; Mertens, 2010). For example, Creswell (2007:18) contends that researchers should "conduct their studies in the "field", where the participants live and work" in order to get as close as possible to the participants. Such interactions are seen as important contexts for understanding what the participants are saying and doing. To this end, data collection which is personal and interactive using qualitative methods such as observations, interviews, and documents reviews is predominant in this worldview (Mertens, 2010).

The study adopted a descriptive research design (McMillan & Schumacher, 2010), using the case study method (Merriam, 2009). A descriptive study asks the question 'What is?' or 'What was?' and describes the current or past status of something (McMillan & Schumacher (2010). It is assumed that the teachers have developed their PCK, and the interest lay in the way in which this was developed over time.

A case study is an in-depth exploration of a bounded system, which could be an activity, event, process, or individual, based on extensive data collection (Creswell, 2008). The case

study method allowed the study to be conducted in a natural context, and within a specific time and boundaries (Creswell, 2008). It also provided for the teachers' PCK to be investigated using multiple methods of data collection.

Case study research has some methodological limitations. It is usually criticized for its lack of generalizability or transferability of findings because it focuses on one or a few cases (Merriam, 2009; Rule & John, 2011). In addition, with multiple-case research, researchers tend to look for similarities and ignore differences (Rule & John, 2011). Despite the inherent shortcomings, science education researchers (Appleton, 2008; Brown et al., 2013; Lowery, 2002; Rollnick et al., 2008) continue to use the case study method fruitfully in most studies on teachers' PCK, owing to its strengths, such as providing a rich and detailed description of the case in a natural setting (Merriam, 2009). For this reason, the case study method was considered suitable for this study and was used to gather data in order to gain better insight into the PCK of successful biology teachers and the way in which the PCK may have been developed. Similarities and differences in the teachers' PCK and its development were examined.

Essentially, the research involved a multiple-case study (Creswell, 2007, 2008; McMillan & Schumacher, 2010; Merriam, 2009), consisting of four cases in which the phenomenon of individual teacher's PCK and its development were studied. The individual teacher's PCK, and how it was assumed to have developed, constituted the unit of analysis of this study.

3.3 Study population and sample

3.3.1 Study population

The population of this study comprised Grade 11 biology teachers in schools that offered pure biology at high-school level (Grades 11–12) in Swaziland from 2007 to 2010. A total of 174 of the 265 high schools offered biology in 2010.

3.3.2 Study sample

An elimination process based on certain criteria: learners' performance in biology public examinations; and recommendations by school principals and subject specialists at the Ministry of Education and Training was used to select the four teachers who participated in the main study. The purposive sampling technique (Creswell, 2007, 2008) was used to select four biology teachers considered successful to participate in the study. The selection criterion was that these teachers should have consistently produced at least 70% credit passes (Grade C

and above) by learners in the high school biology public examinations over four or more years, namely in 2007–2010. The use of learner performance as the selection criterion is in line with Ornstein's (2003:21) assertion that expert teachers are "usually identified through administrator nominations, student achievement scores, or teacher awards". Therefore, the use of learner performance in this study may be justified.

The four successful teachers were identified as follows. First, statistics in high school biology public examination results from the Examination Council of Swaziland (ECOS) for the four years (2007–2010) were obtained through the council's website to be used to identify best performing schools. Second, schools that had obtained at least 70% credit passes in four years were identified. This exercise yielded 10 out of 147 schools in 2007; 7 out of 156 schools in 2008; 16 out of 169 schools in 2009; and 14 out of 174 schools in 2010. Third, schools were selected that had consistently produced a minimum of 70% credit passes throughout the four years. This resulted in only five schools from three of the four regions of the country. Of these five schools, four were selected because they were comparable, and for logistical reasons. They were located within convenient distances that would allow the researcher to observe the lessons more than once for each teacher. Permission to carry out the study in the selected schools was sought and obtained from regional education officers (Appendix G) and the school principals (Appendix H). The next step after identifying the schools was to interview school principals and subject specialists in the Ministry of Education and Training to ascertain the willing participating teachers. Four Grades 11–12 biology teachers, one from each of the four schools, were selected, based on recommendations by science specialists and school principals, as well as their willingness to participate in the study. In schools where more than one teacher was teaching biology at this level, the teacher who consistently produced 70% credit passes in the specified period was selected and confirmed by the school head. A similar sampling method has been used by other researchers (Friedrichsen & Dana, 2005; Ijeh, 2012; Loughran et al., 2006; Morrison & Lederman, 2003).

Table 3.1 below displays the schools' percentage credit passes (70% and above) in biology public examinations in 2007–2010 for the four selected teachers in the main study. The sample teachers are referred to by pseudonyms as Lucy, Lily, Leon and Lillian.

Table 3.1: Participating teachers and their school's performance in biology public examinations

Examination year	2007 IGCSE biology exam	2008 IGCSE biology exam	2009 SGCSE biology exam	2010 SGCSE biology exam
Lucy's school (School A)	86 %	75%	100%	75%
Lily's school (School B)	95%	86%	100%	83%
Leon's school (School C)	75%	83%	70%	71%
Lillian's school (School D)	89%	100%	86%	88%

Source: ECOS statistics on IGCSE/SGCSE biology examinations 2007-2010

3.4 Data collection instruments

Multiple sources of evidence were used to investigate the four teachers' PCK and its development.

Table 3.2 provides a summary of the research instruments used to collect data for answering the two research questions.

Table 3.2: Research instruments and research questions being addressed

Research question	Research instruments
What content knowledge of genetics do biology teachers who are considered successful have and demonstrate during classroom practice?	Teacher concept map of genetics topic
	Teacher genetics topic lesson plans
	Teacher pre-lesson interview schedule on their lesson plans about genetics topics
	Lesson observation schedule on their classroom practice on genetics teaching
What instructional strategies do these teachers use in teaching genetics?	Teacher lesson plan about genetics topics
	Teacher pre-lesson interview schedule on their genetics topic lesson plans
	Lesson observation schedule on classroom practice
	Post-teaching teacher questionnaire on observed genetics lessons
	Document analysis – teacher reflective journals and learners' work samples
What knowledge of learners' preconceptions and learning difficulties,	Teacher pre-lesson interview schedules about their genetics topic lesson plans

if any, do these teachers have and demonstrate during classroom practice?	Teacher lesson plan on genetics topics
	Lesson observation schedule on classroom practice
	Post-teaching teacher questionnaire on observed genetics lessons
	Teacher post-lesson interview about usual areas of learners' difficulty
	Document analysis - Teacher reflective journals and learners' work samples
How do these teachers develop pedagogical content knowledge in genetics teaching?	Teacher post-lesson interview schedule about teachers' educational background
	Document analysis - Teacher reflective journals, learners' work samples and curriculum documents

The lesson observation and interview schedules were the main research instruments for data collection and the others, namely concept mapping, lesson plans, questionnaire, and document analysis (reflective journals, learners' work samples and curriculum documents), were used for triangulation.

The sequence in which data were collected is presented in Table 3.3.

Table 3.3: Research sequence for data collection

Research stage	Research activity
Stage one	**Introduction of the study to the participants** An individual information session was conducted with each participant. The research purpose and process were discussed with each individual participant. Then the data collection method was explained (ref. consent letter, Appendix I). Consent letters were given to each participant. It was explained that consent was voluntary
Stage two	**Concept mapping exercise** Teachers were asked individually to draw concept maps to show key terms or concepts and the relationship among them for the topic genetics. They were provided with guiding questions (Appendix A)
Stage three	**Pre-lesson interview and Lesson observation** Semi-structured pre-lesson one-on-one interviews were conducted with each participant. The teachers were interviewed about their lesson plans before each observed lesson with the aim of determining their knowledge of the genetics content

	knowledge to be taught; instructional strategies to teach specific genetics concepts and learners' preconceptions and learning difficulties with regard to those concepts; and how they planned to teach the lessons. They were observed teaching the lessons using a semi-structured observation schedule to determine their genetics content knowledge, knowledge of instructional strategies, and learners' preconceptions and learning difficulties, if any
Stage four	**Teacher post-lesson questionnaire and reflective journal** Teachers were asked to complete a semi-structured post-teaching questionnaire after each observed lesson, which enquired about the instructional strategies they employed during the lesson and how they took learners' preconceptions and learning difficulties into account. They were also asked to keep reflective journals during the data collection period to record their successes and failures in and possible improvements to their genetics lessons
Stage five	**Post-lesson interview** At the end of the observation period, a brief individual interview was conducted to seek clarification or thoughts about observed classroom events noted by the observer that would illuminate the what and how questions about teacher PCK. The teachers were shown stills from the video to reflect on. Then a post-lesson interview schedule was used to interview individual teachers about their educational background to determine how their PCK was presumed to have developed
Stage six	**Document analysis** Learners' work samples, for example exercise books and worksheets, were reviewed with the aim of determining the instructional strategies and consideration of learners' preconceptions and learning difficulties, if any. Copies of teachers' lesson plans and reflective notes were collected for analysis to determine their PCK and how it developed. Curriculum documents (biology syllabus and SGCSE consultative document) and textbooks were examined to assess how the teachers developed their PCK in genetics teaching

3.4.1 Development of research instruments

Each of the data collection instruments and its development and scoring procedure are described in this section.

3.4.1.1 Concept mapping for teachers

The purpose of the concept mapping exercise was to assess the participating teachers' content knowledge of the school genetics. In this study, concept mapping was used as a supplement to the pre-lesson interview and lesson observation schedules, which were the main instruments used to evaluate the teachers' content knowledge in school genetics teaching. The exercise required the participants, first, to list topics or concepts they considered key in the school genetics curriculum for Grades 11–12; second, to arrange the concepts in the sequence in which they would teach them to Grade 11 learners; and last, to represent them in a diagram format showing any connections among them. The teachers were provided with these guideline questions (Appendix A):

1. What topics or concepts do you consider to be key in the topic of genetics (Inheritance)? List them.
2. Arrange the key concepts in a linear format showing the sequence in which you would teach them to Grade 11 learners. That is, start with the topic you would teach first and end with the one you would teach last.
3. If you were to present the listed topics or concepts in diagram format showing any relationship among them what would it look like? Draw your diagram of the key genetics concepts. Use arrows to show any connection between concepts.

It was assumed that the teachers' facility to list the concepts, arrange them in a logical manner, and show the relationships among them provided an indication that they had adequate knowledge of the genetics topics in the school biology curriculum and how they should be organized for effective teaching.

This open-ended or free-form approach (Baxter & Lederman, 2001; Greene et al., 2013) gave the teachers freedom to select any topics or concepts that best represented their subject matter of genetics and allowed them autonomy to represent the relationship among these topics in any way that best represented their understandings. It was hoped that such an approach would provide a more valid representation of the teachers' views on subject matter than other approaches in which participants were given key topics or concepts to map (Baxter & Lederman, 2001).

Concept maps have been used in several studies (e.g. Greene et al., 2013; Kaya, 2008; Ijeh, 2012) to assess science and mathematics teachers' content knowledge.

Scoring of concept mapping

A quantitative method (Greene et al., 2013) was used to score the teachers' concept maps. The researcher developed a rubric to indicate how to assess the genetics' concept maps drawn by the participating teachers. The rubric allocated marks, first, to the number of correct key concepts (nodes) that were listed; and second, to the number of concepts that were correctly arranged (links). The rubric deducted marks for incorrect arrangement of concepts (Appendix P).

The Swaziland General Certificate of Secondary Education (SGCSE) biology syllabus for Grades 11–12 was used as a basis for assessing teachers' concept maps in terms of the list of key topics or concepts, sequence and the linkage or relationship among the topics. It was used to compile a list of contents of genetics in school biology. The topics or concepts under the topic of Inheritance (as titled in the curriculum document) are: chromosomes (genes, allele, haploid nuclei, diploid nuclei, inheritance of sex in humans), mitosis, meiosis, monohybrid inheritance (genotype, phenotype, homozygous, heterozygous, dominant, recessive, monohybrid crosses), variation (mutation), selection, and genetic engineering (Examination Council of Swaziland, 2009:21–22). The rubric allocated one mark for each correct concept listed. The subtotal for this question was 20 marks.

For the second question on sequencing the topics, the teachers were expected to arrange the listed topics in such a way that the previous topic formed the basis for the next one, in other words in hierarchical form. The rubric allocated marks to the number of topics that were correctly arranged in hierarchical manner. This question was allocated 10 marks. An example of the sequence derived from the SGCSE biology syllabus is as shown below.

Inheritance → Chromosomes → Genes → Allele

→ Mitosis → Meiosis → Monohybrid inheritance →

Variation → Selection → Genetic engineering

For the third question, the focus was on the relationships among the genetics concepts, particularly those of interest in this study, which are chromosome, gene, mitosis and meiosis, as well as among these and the other concepts in the topic listed in the biology syllabus. The rubric allocated one mark for indicating each of these connections: chromosome–gene; chromosome–mitosis; chromosome–meiosis; gene–mitosis; gene–meiosis; gene–monohybrid inheritance; meiosis–monohybrid inheritance; chromosome (gene)–variation; gene–selection; gene–genetic engineering. The mark allocation for this question was 10 marks.

The concept mapping exercise scored a total of 40 marks, that is, 20 marks for question 1), 10 marks for 2) and 10 marks for 3). Percentages of teachers' scores were calculated and used as determinants for their genetics content knowledge. A teacher who scored a minimum of 32 marks (80%) would be considered as having the knowledge of the curriculum content that would inform his or her insight into the topic.

3.4.1.2 Pre-lesson interview schedule

A semi-structured pre-lesson interview schedule (Appendix B) was used to gain insight into biology teachers' content knowledge, knowledge of instructional strategies, and knowledge of learners' preconceptions and learning difficulties. Although interviews are sometimes criticized for possibly being deceptive in that participants may give the information and perspective they want the researcher to hear (Creswell, 2008; McMillan & Schumacher, 2010), several investigators (Drechsler & Van Driel, 2008; Henze et al., 2008; Ijeh, 2012; Ijeh & Onwu, 2013; Loughran et al., 2006; Park & Chen, 2012; Rollnick et al., 2008) have continued to use interviews in PCK research. Semi-structured interviews have the advantage of allowing the researcher to obtain detailed responses from the participants through probing (Creswell, 2008).

The interview schedule used in this study was developed by the researcher through adapting questions from other researchers (Kapyla et al., 2009; Ozden, 2008; Rollnick et al., 2008). To this end, questions were developed to solicit, first, the teacher's demographic information (years of teaching experience, academic qualifications, and major subjects), which was used to develop a general profile for each participant; and, second, the teacher's planning of the lesson to be observed, such as the specific content to be taught, the objectives of the lesson, what the teacher took into account in planning the lesson, the instructional strategies he or she

planned to use in teaching the genetics topics and reasons for his or her choice of teaching approach.

The interview questions were categorized according to the components of PCK being assessed in the study. This approach of categorization has been used by other researchers (Ijeh, 2012; Kapyla et al., 2009; Rollnick et al., 2008) in the areas of science and mathematics education. Table 3.4 shows the distribution of the questions among the PCK components.

Table 3.4: Item specification for pre-lesson interview schedule

PCK component	Demographic information	Three PCK components (content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties)
Item number on schedule	1–4	5

The first four questions on the schedule elicited teachers' demographic information and the last required them to describe their lesson plans. The teachers were asked:

- For how long have you been teaching?
- For how long have you been teaching biology?
- What are your academic qualifications?
- What are your major subjects?
- Would you tell me about your lesson plan in detail and describe how you will carry out the lesson.

Within the categories of PCK, specific prompts in the CoRes listed by Loughran et al. (2012:17-18) were used to analyse the teachers' descriptions of their lesson plans:

- What is (are) the concept or big idea to be taught in this lesson?
- What do you intend the students to know about this idea?
- Why is it important for students to know this?
- What else do you know about the concept, which you do not intend your students to know yet?
- What teaching procedures are you going to use to teach this concept and what are your particular reasons for using these to engage with this concept?
- What difficulties/limitations are connected with teaching this idea?

The tacit nature of PCK, which usually makes it difficult for teachers to explicate, could somewhat limit the effectiveness of interviews in assessing PCK (Kapyla et al., 2009). It is necessary that interviews should be combined with other methods, such as lesson observation. Lesson observations often reveal the association between teachers' thinking and classroom practice (Kapyla et al., 2009).

3.4.1.3 Lesson observation schedule

A semi-structured lesson observation schedule was used to assess the participating teachers' content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties. Lesson observation has been used for similar purposes in other studies (e.g. Brown et al., 2013; Ijeh, 2012; Ijeh & Onwu, 2013; Rollnick et al., 2008).

In this study, the schedule was developed based on the standard requirements for normal classroom practice by the Ministry of Education and Training (Ministry of Education and Training, 1978:3). The ministry's requirements are that 'daily preparation is to be recorded in a book, the preparation book of all teachers must always be up to date, and the following minimum information should be recorded in the preparation book, which must be kept neatly and systematically: the date of the lesson, the period, and the name of the class; the topic or activity to be dealt with; the books and materials to be used; the work to be done by the teacher; and the work to be done by the pupils' (MOET, 1978:3).

The schedule focused on the genetics content that was taught, explanations and teaching approaches, as well as activities. Attention was paid to the prior knowledge teachers have or had of their learners' preconceptions, if any, of the lesson topic, and the ways they used in classroom teaching to solicit or identify learners' preconceptions and learning difficulties. What the learners said, the clarifications they asked for, their requests for more explanations, and their answers to their tasks were noted.

The observation guidelines were lesson objectives, content presented and how it is presented, learners' preconceptions, learners' difficulties, teaching strategies and activities, presentation of lesson, learner's involvement, and evaluation/conclusion of lesson (Appendix C).

The data from the observation schedule were categorized into the three PCK components, as defined, of genetics content knowledge, pedagogical knowledge, and knowledge of learners' preconceptions and learning difficulties. Specifically, content knowledge was assessed through the content taught, pedagogical knowledge through the lesson objectives, and instructional strategies used, and knowledge of learners' preconceptions and learning difficulties through lesson plan and teacher probing activities and learners' responses or feedback.

3.4.1.4 Post-teaching teacher questionnaire

A semi-structured post-teaching teacher questionnaire was used to collect data to assess teachers' knowledge of instructional strategies and learners' preconceptions and learning difficulties in genetics teaching as part of their PCK. In addition to background information about the lesson (lesson date, topic, duration and objectives), the questionnaire consisted of ten open-ended questions derived mainly from De Jong, Ahtee, Godwin, Hartzinikita and Koulaidis (1999) and Kapyla et al. (2009). The questions were grouped according to the PCK elements investigated in this study as displayed in Table 3.5.

Table 3.5: Item specification for questionnaire

PCK component	Knowledge of instructional strategies	Knowledge of learners' preconceptions	Knowledge of learners' learning difficulties
Item number on schedule	1, 2, 10	3–4	5–9

Questions 1, 2 and 10 concerned the teachers' pedagogical knowledge and sought information on the teacher's reasons for choosing the teaching strategies used in the lessons and the rationale behind the planned teaching approach. They read as follows:

- What teaching methods and activities did you use during the lesson?
- What were your reasons for using those teaching methods and teaching activities?
- What changes would you make the next time you teach the same concept or content?

Items 3 and 4 on the questionnaire asked the teachers about preconceptions of genetics concepts that they expected their learners to have and how they found out about those preconceptions. The questions were:

- What preconceptions did you expect your learners to have about the topic/concept(s)?
- How did you find out the learners' preconceptions?

Questions 5–9 enquired about the learning difficulties the teachers expected their learners to experience during the lessons and the difficulties that the learners actually experienced during the observed lessons. The teachers were asked to explain how they found out learners' learning difficulties, what they thought made those areas difficult for learners, and how they addressed such difficulties, if at all. The precise questions were:

- What learners' learning difficulties did you anticipate in planning your lesson?
- What did learners find difficult to understand during the lesson?
- How did you discover or find out learners' learning difficulties?
- What do you think made those areas difficult for learners to understand?
- How did you address learners' learning difficulties, if at all, during the lesson?

The complete teacher questionnaire is available as Appendix D.

3.4.1.5 Post-lesson interview schedule

The semi-structured post-lesson interview schedule (Appendix E) sought information on how the participating teachers developed their PCK, namely genetics content knowledge, knowledge of instructional strategies, and knowledge of learners' preconceptions and learning difficulties in the context of teaching genetics. In the development of this schedule, findings of some researchers and practitioners in the field (e.g. Burn et al., 2007; Grossman, 1990 as cited by Miller, 2007; Henze et al., 2008; Ijeh, 2012; Van Driel et al., 2002), were used to construct questions based on personal and external factors likely to influence the development of PCK. Questions about the courses that the teachers had studied during university education, sources of knowledge in teaching genetics, teaching experience, continuing professional development and collaboration with official departmental peers were supposed to give insights into the way(s) in which their PCK is assumed to have developed.

The questions were grouped according to the PCK components of the study as shown in Table 3.6. Various researchers (Ijeh, 2012; Rollnick et al., 2008) in the areas of science and mathematics education have used this approach of grouping questions.

Table 3.6: Item specification for post-lesson interview schedule

PCK component	Content knowledge	Instructional strategies	Learning difficulties	Professional development
Item number on schedule	1, 2, 10	2, 3, 6, 9	4 – 5	7 – 8

The first question dealt with the teachers' formal education and how the courses they had done at university helped them in teaching school genetics to ascertain whether content and methods courses contributed to the development of the teachers' content knowledge and knowledge of instructional strategies. The second question was about the influence, if any, of the years of teaching experience. The third and sixth questions sought information about the teachers' views about the effectiveness of their genetics lessons and the instructional strategies they use to help learners who experience problems. Questions 4 and 5 concerned teacher base knowledge of learning difficulties usually experienced by learners in learning the topic of genetics.

The influence of in-service training workshops on PCK was assessed by items 7 and 8 of the schedule and read as follows:

- Have you ever been to a biology workshop on teacher development? If yes, what was the content, and duration of the workshop? Who were the facilitators? As a biology teacher, how did you benefit from the workshop? Would you recommend that similar workshops be held for teachers?
- Have you ever been to a workshop, specifically on genetics? As a biology teacher, how did you benefit from the workshop? Would you recommend that similar workshops be held for teachers?

The last two items on the schedule requested information about whether the teachers collaborated with peers and how such collaborations affected their teaching of genetics (item 9) as well as other sources of information the teachers used in genetics teaching (item 10). The questions were:

- Do you collaborate with other teachers in your department about teaching? If yes, how has that helped you in your teaching?
- What other sources of information do you use?

3.4.1.6 Teacher reflective journals

The teacher's reflective journal sought information on his or her knowledge of learners' learning difficulties and reasons for changes in instructional strategies, if any. Questions (Appendix F) derived from previous studies on teacher professional development and continuing professional development in the South African setting and outside (Onwu & Mogari, 2004; Penso, 2002) were used and adapted as teacher guidelines for completing the journal. The participating teachers were expected to reflect on their lessons using the guidelines provided. They had to think about successes, difficulties and failures in presenting their genetics lessons over a period, how they resolved knotty issues, and how they thought they could improve the lesson the next time they taught it. The teachers were also required to reflect on classroom organization regarding individual learner activity and group work (cooperative, competitive or individualized learning); individual and group level of participation and confidence shown during lessons; learner completion of task time, level of performance and enjoyment. The guiding questions were grouped into the PCK components of the study as displayed in Table 3.7.

Table 3.7: Item specification for reflective journal guidelines

PCK component	Knowledge of instructional strategies	Knowledge of learning difficulties
Item number on schedule	1–3, 7–12	4– 6

The guiding questions 1–3 and 7–12 concerned the effectiveness of the instructional strategies the participating teachers used to teach the genetics lessons. For example, they were asked:

- Was your lesson effective? How do you know?
- Do you think the students learned what you intended them to learn in the lesson?
- What changes would you make the next time you teach the same content/concept?
- Did your learners enjoy the lesson? What were the indicators?

Questions 4–6 required the teachers to think about any difficulties their learners experienced during lessons, to state those difficulties, and to describe what they thought their sources were, and how they resolved them during the lessons. The precise questions were:

- What did learners find difficult to understand during the lesson?
- What do you think made those areas difficult for learners to understand?
- How did you address the learners' difficulties during the lesson?

3.4.1.7 Document analysis

The purpose of conducting a document analysis was to triangulate data from interviews, lesson observations and questionnaire. Various documents that could contribute to the profiling of teachers' PCK were identified for analysis. The documents included the Swaziland General Certificate of Secondary Education curriculum documents, which were the consultative documents (MOET, 2005), biology syllabus (ECOS, 2009), biology textbooks, handouts such as instructional support materials that the teachers provided to learners, and learners' written work samples. These documents were analysed to determine the teacher's compliance with curricular recommendations for teaching genetics at high school level.

Reviewing curriculum documents gave an indication of whether the participants were following policy recommendations for teaching and learning in terms of their teaching approaches and assessment procedures (Ministry of Education and Training, 1978).

The four selected teachers wrote individual lesson plans for each lesson, as is required of teachers in schools by the Ministry of Education and Training policy (Ministry of Education and Training, 1978). In this study, therefore, each of them had to write lesson plans for the selected genetics concepts to be taught. The teachers' lesson plans were analysed to find out the content to be taught, the instructional strategies and activities that teachers used in teaching the concepts, their knowledge, if any, of learners' preconceptions and learning difficulties.

3.4.1.8 Video-recording

Video-recording was used to record the participating teachers' observed lessons on genetics topics. It was mainly meant to triangulate the data collected from the lesson observations. The video transcripts were used to gain some insight into the participants' content knowledge, and how that knowledge was used in classroom practice, as well as the instructional strategies the teachers demonstrated in teaching genetics topics. Video clips were used during post-lesson

interviews to promote discussion and reflection about the participant's teaching. These discussions corroborated the researcher's interpretations of what had transpired during the observed lessons.

3.4.2 Validation of research instruments

After the research instruments had been developed by the researcher, they were given to three biology experts, one in the Ministry of Education and Training and two university lecturers, to test their content validity before they were used in the pilot study. Both lecturers hold DSc degrees in science education with biology as their area of specialisation. One lecturer has an MSc degree in biology while the other majored in biology in her BSc degree. They have been teaching at university level for more than ten years. In addition, they are experienced researchers and have published articles in refereed journals. The Ministry of Education and Training officer holds a master's degree in science education and has taught school biology for many years. Currently, she is a science inspector responsible for monitoring and evaluating the teaching of science in Swaziland schools and the organization and facilitation of in-service workshops for improving content and pedagogical content knowledge of science teachers. She has been in this position for several years and has published. To demonstrate content validity, the instrument should show that it measures – properly and comprehensively – what it purports to measure (Cohen, Manion & Morrison, 2007). The subsequent sections discuss the validation of each of the research instruments used in this study.

3.4.2.1 Validation and reliability of concept mapping exercise

Three biology experts, one from the Ministry of Education and Training and two university lecturers, were given a set of criteria to content-validate the concept mapping exercise and its rubric developed by the researcher (ref. 3.4.1.1). The experts had, first, to establish whether the concept mapping exercise would allow biology teachers to list key topics and terms in the Grades 11–12 curriculum, sequence them in a coherent manner, such that one topic formed the foundation of the next, and draw a diagram to show relationships among the topics. Second, they were required to verify the answers by determining whether the rubric was correct for answering the concept mapping exercise (Appendix P). Lastly, they were asked to check the clarity of the questions, and to identify factual and grammatical mistakes. The reviewers' responses showed that the questions would allow biology teachers to list and

sequence genetics topics and terms in school biology in line with the SGCSE curriculum (ECOS, 2009). There was overall 100% agreement in their responses, indicating that the concept mapping exercise contained adequate information for assessing teachers' curriculum knowledge of the genetics topics at this school level and the ways in which they should be taught in a logical and sequential order. Also, all the specialists agreed that the rubric was appropriate for evaluating the concept mapping exercise.

The reliability of the concept map was determined as follows. The concept mapping exercise and memorandum were given to three school biology teachers who did not participate in the study and who were physically found outside the study site to avoid contamination. The biology teachers' responses were consistent with the expected answers (memorandum) of the concept mapping exercise. In other words, the responses of the biology teachers were consistent with the idea of listing the key genetics topics and terms for high-school level (Grades 11–12) and the way in which they should be taught in logical hierarchical and sequential order. The uniformity in the teachers' responses showed that the concept mapping exercise is reliable enough for assessing the teachers' knowledge of genetics in the school biology curriculum (Morse, Barrett, Mayan, Olson, & Spiers, 2002). Their comments about the clarity of questions were used to review the concept mapping exercise and memorandum before they were used for the main study.

3.4.2.2 Validation and reliability of teacher pre-lesson interview schedule

The developed pre-lesson interview schedule (ref. 3.4.1.2) was given to the three biology experts to content-validate using the provided set of criteria. The specialists were requested to comment on the clarity of the interview items and their (items) capacity to assess the biology teachers' demographic information that was necessary to create their general profiles, content knowledge, knowledge of instructional strategies, and knowledge of learners' preconceptions and learning difficulties (Appendix L). In addition, they were asked to note grammatical errors. The reviewers' responses indicated agreement that the schedule contained the necessary information for assessing teachers' demographic information, content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties. Their slight comments about grammar were used to improve the items before the schedule was used in the pilot study.

To ascertain the reliability of the interview schedule, it was used with some school biology teachers who were not participating or involved in the main study. The interest was in determining the extent to which the schedule was likely to yield consistent responses from them (Cohen et al., 2007; Morse et al., 2002) in terms of assessing the biology teachers' content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties in genetics teaching (Appendix L). The responses of the teachers were similar and consistent in terms of the items selected for the interview schedule. The reliability of the instrument was thus generally assured (Morse et al., 2002) and their comments about clarity of questions were used to revise the schedule.

3.4.2.3 Validation of lesson plan and lesson observation schedule

A specific set of criteria was given to the three biology experts to validate the developed lesson plan and lesson observation schedule (ref. 3.4.1.3). The criteria required the reviewers to establish whether the lesson plan and observation schedule contained sufficient information to evaluate normal classroom practice in line with the SGCSE curriculum (Appendix M). The validation confirmed that the schedule was in line with the requirements of the Ministry of Education and Training and the SGCSE curriculum and contained the required information to assess normal classroom practice.

3.4.2.4 Validation of teacher questionnaire

The three biology experts were requested to validate the developed teacher questionnaire (ref. 3.4.1.4) by determining whether the questionnaire covered sufficiently what teachers are supposed to do in demonstrating components of their PCK in genetics teaching using a set of criteria. The criteria required the reviewers to determine whether the questionnaire would assess what teachers did during the observed lessons, namely the teaching approach and instructional strategies they used and the reasons for their selection; their knowledge of learners' anticipated preconceptions and learning difficulties, and how they went about acquiring that knowledge and sought to address these aspects: and the changes, if any, the teachers would make the next time they taught the same concept/content (Appendix N). In addition, the reviewers were requested to establish the clarity and accuracy of the items. Their responses indicated that the questionnaire consisted of items that would elicit information concerning the instructional strategies that biology teachers employ during classroom practice, as well as how they try to deal or had dealt with learners' preconceptions and learning difficulties. The comments and suggestions from the specialists on the ambiguity of

items and repetition were used to revise the questionnaire before it was used in the pilot study (Appendix D). This appraisal resulted in some questions being re-worded or deleted from the questionnaire.

3.4.2.5 Validation and reliability of post-lesson interview schedule

The purpose of the semi-structured post-lesson interview schedule (Appendix E) was to assess the educational background that may have enabled the participating biology teachers to develop their assumed topic-specific PCK in genetics teaching. The schedule developed by the researcher (ref. 3.4.1.5) was validated by the three biology experts using the given criteria (Appendix L). The validation criteria required the experts to ascertain whether the interview schedule contained appropriate information to determine teachers' biology educational background for developing PCK as defined in genetics teaching. The reviewers' responses indicated unanimous agreement that the protocol contained the necessary information for assessing how the participating biology teachers developed their PCK in genetics teaching. Their comments on the clarity of items and grammar were used to review interview items. For instance, questions that were not well-phrased were improved before the schedule was used in the pilot study.

To determine the reliability of the post-lesson interview schedule, it was used with three school biology teachers who were not involved in the study. The aim was to establish the degree to which the schedule was likely to yield consistent responses from the teachers (Morse et al., 2002) with regard to assessing their educational background that might have enabled them to develop their topic-specific PCK in genetics teaching. The teachers' answers were consistent in terms of the interview schedule's items. Thus the instrument's reliability was generally assured. The teachers' comments were used to revise the protocol.

3.4.2.6 Validation of reflective journal guidelines

A set of criteria was given to the three biology experts to content-validate the reflective notes guidelines developed by the researcher (ref. 3.4.1.6). The experts were requested to establish whether the written reflective notes guidelines could be used to gather data about whether the lesson was effective or not, what made it easy or difficult, and how it can be improved (Appendix O). Their responses agreed that the guidelines consisted of enough questions to

guide a biology teacher to write such notes. Their comments were used to review the written reflective notes guidelines before it was used for the pilot study (Appendix F).

3.5 Pilot study

A pilot study was conducted to determine the reliability indices and validity of the instruments including the practicability of administering the research instruments (Cohen, Manion & Morrison, 2007) within the constraints of a school setting.

3.5.1 Purpose of the pilot study

Specifically, the purposes of the pilot study (Cohen et al., 2007) were:

- To test the validity and reliability of the research instruments
- To assess the logistics feasibility of administering the research instruments and improve on the procedure for the main study, if necessary
- To gain feedback on the design and methodology for administering the main study
- To establish the approximate duration to administer the research instruments
- To test the clarity and comprehensibility of the instruments' items and instructions given to participants

3.5.2 Participants used in the pilot study

Three willing biology teachers at high-school level who were not part of the sample for the main study participated in the pilot study. The teachers were chosen because of their school performance in biology public examinations for the school leaving certificate for at least two years. They volunteered to participate in the pilot study. All teachers hold a Bachelor of Science degree with biology and chemistry as their major subjects. They have taught biology for more than five years, with 15, 9 and 8 years' teaching experience. They have been teaching the biology curriculum since the inception of the IGCSE curriculum in 2006. Their school has obtained consistent credit pass rates of at least 70% in biology for at least two years.

3.5.3 Administration of the pilot study

Permission to conduct the study was obtained from the Regional Education Office (Appendix G) and school principals (Appendix H). The teachers signed letters of consent (Appendix I), which informed them about the purpose of the study, their expected role, their right to

participate or withdraw from the research process voluntarily, as well as the ways in which confidentiality would be assured. The research instruments, namely concept mapping, pre- and post-lesson interview schedules, lesson plan schedule, lesson observation schedule, questionnaire, and teachers' reflective note guidelines, were administered to the participants during the pilot study after they had been validated by the three biology experts, as described in section 3.4.2. The teachers were requested to record the time it took them to answer the questions, and to comment on the clarity of questions and grammatical errors.

The concept mapping exercise was administered to the pilot teachers before they taught the topic of genetics to high-school learners. Each teacher was provided with information about concept maps, as well as the procedure on how to create concept maps, and instructions for creating his or her own genetics concept map. The concept maps were collected for analysis. The teachers prepared lesson plans based on selected genetics concepts – chromosomes, genes, and cell division (mitosis and meiosis) – for high-school learners. The teachers were not restricted on what sources to consult during lesson preparation, and no particular lesson plan format was suggested to them. They planned the lessons according to the time allocated for biology in their school timetables. Copies of the lesson plans were collected for analysis at the end of the observation sessions. The pre-lesson interview schedule was used with the pilot teachers to conduct one-on-one interviews before they taught the lessons that were observed, and to assess what content they intended to teach and how they planned to teach it. The interviews were audio-recorded to provide a complete record of the conversations. All sessions ended with the researcher thanking participants and assuring them of confidentiality of data and findings. The teachers were observed teaching their genetics lessons. Classroom observations provided first-hand information about what the teachers knew and how they taught genetics in their classrooms. They also provided an opportunity to record information as it occurred in the classroom, and to study the behaviour of the participating teachers to determine their PCK in genetics teaching (Creswell, 2008). The researcher assumed a non-participant observer role. All the observed lessons were video-recorded from start to finish, providing comprehensive information of what took place. Video-taping offered a semi-permanent record that was played back repeatedly, allowing for analysis at a greater level of detail and reliability (Berg, 2001; Breakwell, Hammond & Fife-Schaw, 2000; Flick, 2009).

The teachers completed a post-teaching questionnaire for each lesson observed. This questionnaire was completed after the lessons so that it did not cue the teacher of learners'

preconceptions and learning difficulties. After the observed lessons, brief discussions with the teachers sought clarification on what had transpired during the lessons, where necessary. Formal individual teacher post-lesson interviews were conducted to determine how the teachers developed their PCK using the schedule described in section 3.4.1.4. The teachers wrote reflective notes, which essentially evaluated the lessons they had taught on genetics using the guidelines provided (ref. 3.4.1.6; Appendix F). The reflective notes were later collected and analysed.

3.5.4 Results of the pilot study

The results from the pilot study were used to revise the questions or items of the instruments in order to improve them. They were also used to establish the approximate duration of each instrument. Duration of each instrument was determined by obtaining an average of the length of times taken by the three pilot teachers. The administration of the instruments was also used to check for possible logistics problems before the main study was conducted. Practical problems of getting time to interview teachers immediately after their observed lessons necessitated arrangement of suitable time at the end of lesson observation period.

3.5.4.1 Concept mapping

The concept mapping exercise was administered to the three pilot school biology teachers who were not part of the main study sample. The teachers' responses showed consistencies with the prepared rubric of the concept mapping exercise. In other words, the responses of the biology teachers were consistent with the idea of listing the biology topics, sequencing them in the way in which they would be taught, and drawing a diagram. The consistency in the responses of the teachers indicated that the concept mapping exercise was reliable enough for assessing teachers' knowledge of genetics in the school biology curriculum (Usak, 2009). The teachers' comments with regard to clarity of questions were used to further improve the concept mapping exercise and rubric, before they were used for the main study. Using the rubric developed to evaluate the concept maps drawn by the pilot teachers, the three teachers scored 70%, 75% and 75%.

3.5.4.2 Pre- and post-lesson interview schedules

The pre- and post-lesson interview schedules were used with the three pilot school biology teachers. The interest was in determining the extent to which the pre-lesson interview schedule was likely to yield consistent responses in terms of assessing the biology teachers'

content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties and the post-lesson interview schedule about the educational background of the teachers that may have enabled them to develop their topic-specific PCK in genetics teaching. The responses of the pilot teachers were in agreement in terms of the items selected for the interview schedules. The reliability of the instruments was thus generally assured (Morse et al., 2002). The teachers' comments were used to further review the schedules before they were used for the main study. The pre-lesson interview required an average of 30 minutes, while the post-lesson interview took 45 minutes on average. These durations were used to guide the main study.

3.6 The main study

3.6.1 Participants of the main study

The four selected high-school biology teachers in two regions of Swaziland participated in the main study.

3.6.2 Administration of main study

The main study was administered using the same procedure as the pilot study. The validated and piloted research instruments were administered to the participants: concept mapping, pre-lesson interview schedule, lesson plan and lesson observation schedule, questionnaire, post-lesson interview schedule, reflective notes guidelines and document analysis. A total of six double-period lessons for each participant were observed by the researcher on arranged dates in four weeks. The number of lesson observations was limited by several factors:

(1) The study focused on particular genetics concepts: chromosomes, genes, mitosis and meiosis because they were seen to be crucial since they are the ones learners find difficult to learn (ref sections 1.1 and 2.2)

(2) In Grade 11, learners do introductory genetics and therefore the content to be taught about each concept is minimal (ref. 2.2)

(3) In Swaziland, the government limits the number of lesson observations for research. Observations are seen to disrupt classes and therefore the classes could not be disturbed for longer.

(4) The lesson observations were accompanied by in-depth interviews and other sources of evidence such as analysis of lesson plans, questionnaire and reflective journal

(5) Observing teachers for four weeks is considered sufficient for a case study in the South African context (e.g. Ijeh, 2012; Rollnick et al., 2008). For example, Rollnick et al. (2008) in their case study of science teachers' PCK of the mole and stoichiometry did at least two lesson observations for each of the two teachers who participated in their case study.

(6) Park and Chen (2012) presented two of their observed lessons in their study of biology teachers' PCK in teaching photosynthesis and heredity.

For each of the four lesson observations, the teachers wrote a lesson plan, they were interviewed prior to the lesson, and they completed a post-teaching questionnaire. The teachers kept reflective journals throughout the data collection period (four weeks). At the end of the four-week period, the teachers were interviewed once to assess how they might have developed their existing PCK in genetics teaching.

3.7 Procedure for analysing data

The collected data from the listed instruments as described in this section were analysed. These steps were carried out:

- The data were identified by pseudonyms and organized according to the participating teachers for easy access during analysis and writing up of the findings.
- The audio-recorded pre- and post-lesson interviews and videotaped lesson observations were transcribed verbatim by the researcher to obtain accurate and comprehensive records of the conversations.
- The teachers' responses to questionnaires, reflective notes, and notes from reviews of documents were typed by the researcher.
- The data were read several times and recordings listened to repeatedly to get a sense of what the participants said.
- Data were coded into predetermined categories of content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties to obtain each teacher's PCK profile and way the PCK was assumed to have developed. This step involved reading and comparing teachers' responses to questions about each

of the aspects of PCK (categories) from each of the various research instruments for triangulation.

- The teachers' PCK profiles were compared to identify similarities, common patterns and differences.

The data analysis is presented in sections 4.3 to 4.8.

3.8 Validity and reliability of the study

The present study incorporated several techniques in order to meet the standard of trustworthiness, the validity for naturalistic inquiry (Creswell, 2008). The validity and reliability of the study were assured mainly through triangulation. Different methods of data collection, including interviews, observation and a questionnaire, were employed to increase the credibility of the findings and consistency of results with the data (McMillan & Schumacher, 2010; Merriam, 2009). Other strategies involved recording interviews and lesson observation with an audio-recorder and videotapes in order to get accurate and relatively complete records and to describe in detail how data were collected and analysed, producing thick description, which enhanced the trustworthiness of the findings (Rule & John, 2011). The research instruments were validated by biology experts (Ref 3.4.2) and piloted (ref. 3.5) before they were used in the main study. The processes of validation and piloting further improved the validity and reliability of the study.

3.9 Ethical considerations

Before data collection commenced, the researcher applied for ethical clearance from the Ethics Committee of the University of Pretoria. Permission to conduct the study was obtained and a clearance certificate issued (Appendix Z). To gain access to the schools, permission was obtained from the Ministry of Education and Training, Regional Education Office (Appendix G) and school principals (Appendix H). Informed consent was sought from the selected teachers. Through a letter of consent (Appendix I), the purpose of the study was declared to the participants without deception. This helped to gain the support of the participants. The participants were also made aware of their rights of voluntary participation and withdrawal from the study at any stage. The letter informed the participants about the approximate time and expectations for data collection and the plans for using the results

(Creswell, 2008). The letter sought participants' consent for audio-recording interviews and videotaping lessons.

Pseudonyms were used to identify the schools and participants, and label audio-recordings, video-recordings, field notes and transcriptions, as well as in the process of analysing and reporting data. This was done to ensure confidentiality and non-traceability to people outside the research. At the end of data collection, the researcher thanked the teachers for participating in the study and assured them of the confidentiality of the responses. It was necessary to seek consent from the learners and their parents because, although the learners were not interviewed, they were regarded as participants during classroom observations, especially since lessons were videotaped. Permission for observing and video-recording lessons was obtained from learners (Appendix J) and their parents (Appendix K). The learners and their parents signed consent forms.

The participants were informed that the video pictures would not be published. The videotapes helped the researcher only in cross-checking the transcriptions and reflecting on the teachers' performance during data analysis. The participants of the study benefited in that they had an opportunity to reflect on their lessons in terms of knowledge of learners' preconceptions, learning difficulties, and pedagogical skills and practices using video shots. The reflections might have enabled the teachers to improve their teaching knowledge and modify their teaching strategies in order to enhance learner performance. This ensured reciprocity in the study.

3.10 Chapter summary

In this chapter, the methodology used in this study was outlined and the procedure for developing and validating the research instruments was discussed in detail. The purpose of the pilot and its outcome were used to set the stage for the administration of the main study. The participants were described as four biology teachers who obtained 'good' results in biology public examinations within a selected period, 2007–2010. The methods of data collection, analysis and trustworthiness procedures were discussed. The next chapter presents the results of the study.

CHAPTER FOUR

DATA ANALYSIS AND RESULTS OF THE STUDY

4.1 Introduction

This chapter presents an analysis of classroom observation data, teacher questionnaires, interview schedules and related documents, together with the results of the main study. The results of the study are presented in this order, beginning with the teachers' demographic information:

- Teachers' demographic profiles
- Concept mapping
- Pre-lesson teacher interviews
- Lesson observations and video-recordings
- Post-teaching teacher questionnaire
- Post-lesson teacher interviews
- Document analysis (reflective notes, learners' notebooks and curriculum documents)

The chapter concludes with a chapter summary.

4.2 Teacher demographic profile

A total of four teachers, three women and one man, participated in this study. They are referred to by aliases as Lucy, Lily, Lillian and Leon. The demographic profiles of the four teachers are presented in Table 4.1.

Table 4.1 Teachers' demographic profiles

Teacher	Qualifications	Teaching experience in years	Number of years teaching biology	Subjects taught	Grades taught
Lucy	BSc (Biology, Geography) + PGCE	10	10	Biology, integrated science	8–12
Lily	BSc (Biology, Chemistry) + PGCE	17	17	Biology, integrated science	8–12
Leon	BSc (Biology, Geography) + concurrent Diploma in Education	22	22	Biology, integrated science, mathematics	8–12
Lillian	BSc (Biology, chemistry) + PGCE	5	3	Biology, chemistry, integrated science	8–12

Table 4.1 shows that the four teachers who participated in this study hold Bachelor of Science degrees, with biology as a major subject, and a teaching qualification, and therefore were qualified to teach biology at high school level. Their teaching experience ranged from 5 to 22 years. Because they all have been teaching for at least five years, they could be considered experienced teachers (Morrison & Lederman, 2003; Schneider & Plasman, 2011).

4.3 Concept mapping

An analysis of the teachers' concept maps (ref. 3.4.1.1; Appendix P) showed that Lucy scored 95%, Leon 90%, Lillian 90% and Lily 85%. Lucy listed all the key concepts in the SGCSE curriculum document, and arranged them logically so that prerequisite concepts formed the bases for the more complex ones. She identified the main interrelationships among the genetics concepts correctly, indicating that she possessed a coherent structure of the curriculum content for genetics teaching at that level (Appendix A). She however, did not show a connection between genes and genetic engineering, and between meiosis and monohybrid inheritance, thus two marks were deducted from her responses. Lily and Lillian did not list all the concepts in the curriculum document, so marks were deducted. For example, Lily did not include the terms 'genotype', and 'phenotype'. Again, for Leon, Lily and Lillian, marks were further deducted for not linking chromosomes and/or genes to mitosis and meiosis, suggesting perhaps a less coherent content structure. Based on their scores, all the teachers were assumed to have enough content knowledge to teach genetics at high-school level. Interestingly enough, the results of the concept map analysis showed some positive correlation between the teachers' concept map scores and their demonstrated content knowledge of the genetics topic during lesson observations, as is shown later in section 4.5.

4.4 Pre-lesson teacher interviews

During pre-lesson teacher interviews, the participating teachers were asked individually to describe their lesson plans and how they planned to conduct their genetics lessons in order to assess their subject matter content knowledge, knowledge of instructional strategies, and knowledge of learners' preconceptions and learning difficulties. The semi-structured interview schedule is available as Appendix B. The recorded interviews were transcribed verbatim by the researcher and transcripts analysed according to the three components of PCK using questions from CoRes (ref. 3.4.1.2).

Content knowledge

In the interviews, the teachers stated the genetics concepts they were going to teach and what they intended their learners to know about those concepts. Lucy, Lily and Lillian stated that they had planned first to teach the concepts of inheritance, chromosomes, genes, alleles, diploid and haploid nuclei. They intended their learners to know the definitions of these genetics terms and their differences. Thereafter, they would teach the concepts of mitosis and meiosis. With these genetics concepts, the teachers wanted their learners to know descriptions of the concepts in terms of purpose, process and product. However, they did not plan to teach the processes in much detail because the SGCSE biology syllabus states that *'details of stages are **not** required'* (Examination Council of Swaziland (ECOS), 2009:21). For example, none of the three teachers expected their learners to master the names of the stages for the processes. Lucy and Lillian added that they would omit details of the stages such as the idea of crossing over during the process of meiosis. The three teachers also intended their learners to know the differences between mitosis and meiosis. In addition, Lucy and Lily insisted on explaining the importance of these processes.

Leon, the fourth teacher, stated that he would first teach the concepts of inheritance, chromosomes, mitosis, meiosis, diploid and haploid nuclei. He intended his learners to know the definitions of chromosomes, diploid and haploid nuclei and their differences. For mitosis and meiosis, he expected learners to know general descriptions in terms of purpose and product. He also wanted his learners to know the differences between mitosis and meiosis. Leon did not intend his learners to know how the processes of cell division occur, and therefore had not planned to teach their stages. He quoted the same section of the curriculum document as the other three teachers as the reason for the omission. He stressed that he would explain why mitosis and meiosis are important in organisms. After the introductory lesson, Leon indicated that he wanted to familiarize his learners with the genetics terms, including homologous chromosomes, genes and alleles. Again with these genetics concepts he intended his learners to know the definitions and differences between related terms such as homozygous and heterozygous.

The next question on the CoRes requires the teachers to state reasons that it was important for learners to know what they planned to teach them. All four teachers said it was important for learners to know about those genetics concepts because, first, they (concepts) were included

in the biology syllabus (SGCSE curriculum document). Second, the ideas would enable learners to make sense of human development, including characteristics and conditions of inheritance. Lily and Lillian added that genetics content knowledge would provide a basis for further studies in biology.

On the question on, 'what else do you know about the concepts that you do not intend your learners to know yet?' Overall, the teachers' responses to pre-lesson interviews revealed that they knew more content than they were required to teach high school biology learners. For instance, Lily referred to knowledge of the synthesis of proteins. Lucy and Lillian said they could extend the topic by teaching crossing over of chromosomes during meiosis. Leon indicated the stages of mitosis and meiosis, and di-hybrid inheritance crosses as part of his knowledge of genetics.

Knowledge of instructional strategies

In terms of knowledge of instructional strategies, a question in the CoRes requires teachers to state teaching procedures they would use as well the reasons for their choice. Lucy indicated that, based on her experiences, she would first require the learners to read the relevant chapter in their textbooks, and have them attempt to construct physical models of the concepts to be taught, where applicable, for example models of chromosomes and genes and to use these models for peer teaching in class. Learner presentations would provide some indication of the areas in which they have misconceptions or difficulty in grasping the meaning of the genetics concepts.

Regarding their teaching approach to introducing the genetics concepts, Lucy, Lily and Leon indicated that they would use familiar contexts to arouse interest and to begin from the known and progress to the unknown. With the concept of inheritance for example they would begin by discussing characteristic features of resemblances in the family, such as complexion, height and eye colour. Lillian would begin by finding out learners' ideas about the term 'inheritance' and later discuss resemblances in the family. The next step for all four teachers would be to link inheritance and chromosomes to topics or concepts that the learners already know and have been taught, in this case the cell, and perhaps fertilization. The questioning technique would be used to review previously taught concepts, which is necessary to link to new genetics concepts.

Leon would use predominantly lecture method to teach because it is quicker in covering more topics. All four teachers stated that they would use illustrations such as diagrams to explain the relations among chromosomes, genes and alleles indicating differences. Lily and Lillian emphasized the importance of illustrations to help learners visualize abstract genetics concepts. According to Lillian, her past teaching experience showed that without the use of visual aids, it is difficult for learners to comprehend genetics concepts.

In teaching the concepts of mitosis and meiosis, Lily stated that she had given learners homework to read the relevant chapter in their textbooks and answer questions about the topics to be taught. During the lesson she would begin by reviewing the homework and addressing learners' difficulties, which she had identified when marking the homework before class. Lillian would also begin by reviewing the previous day's homework on concepts taught in the previous lesson and try to rectify learners' mistakes, which she had identified when marking the homework before class. Lucy stated that she would start her lesson by reviewing the previous lesson, using the questioning technique to assess learners' grasp of the concepts.

All four teachers stated that as part of their explanations they would use illustrations such as diagrams to help learners visualize and comprehend mitosis and meiosis. In addition, Lillian would use scientific charts. Other teaching procedures and approaches (listed by Lucy, Lily and Lillian) would include classwork and homework assignment to assess learners' comprehension of genetics concepts.

Knowledge of learners' preconceptions and learning difficulties

In the descriptions of their lesson plans, the four teachers did not mention any specific learners' ideas or preconceptions about the genetics concepts they were going to teach and how they considered them during their lesson planning. They did not show any evidence of consideration of learners' preconceptions by including activities to eliminate potential learning difficulties, which learners were likely to experience during lessons. All four teachers stated that they would use questioning to find out learners' prior knowledge about related concepts previously taught. Lucy, Lily, and Lillian would use questioning technique, classwork or homework to assess learners' comprehension of taught concepts.

In sum, an examination of the four teachers' lesson plans confirmed, first, that they would concentrate on teaching the definitions of 'chromosome', 'gene', and 'allele'; and their differences, as well as the descriptions of 'mitosis' and 'meiosis' and their differences. Second, the four participating teachers would use peer teaching, questioning technique, class and homework assignments, and illustrations including diagrams and charts to teach the genetics concepts. None of the four teachers included in their lesson plans activities aimed at identifying learners' preconceptions of the specific genetics concepts to be taught and preventing or minimizing possible learners' learning difficulties. Curriculum documents (SGCSE biology syllabus) and recommended biology textbooks were listed as the main sources of information for lesson preparation and teaching. The teachers' lesson objectives were derived mainly from the curriculum documents.

4.5 Lesson observations

The analyses of lesson observations and results are presented as four individual cases (Lucy, Lily, Leon and Lillian). In each case, an analysis of two of the observed genetics topic lessons and a summary of the teacher's observation analysis are described. The four teachers taught the same topics that were observed, namely chromosomes, genes, mitosis and meiosis. The observation schedule included examining what teachers did before the lesson, such as reviewing their lesson plans, and after the lesson, such as homework assignments. The video-recordings of the lessons taught by the four teachers were used to triangulate the written observation notes and give details of what had transpired during the lessons.

4.5.1 Case 1: Lucy

4.5.1.1 Lucy's lesson observation analysis

Two lessons of 70-minute (2 x 35) duration were observed on two separate classroom occasions, in which the concepts of chromosomes, genes, mitosis and meiosis were taught. The analysis begins with a brief description of the classroom context, followed by the teacher's classroom practice, as categorized. The teacher's voice and learners' responses are presented in italics.

Table 4.2 Lucy's lesson observation analysis

Description of lesson	Categorization or themes
Classroom context Lucy's biology class consisted of 27 learners, i.e. 15 girls and 12 boys of mixed ability. Her biology class was taught in a standard conventional school science laboratory, which was well resourced. The workbenches and stools were in good condition and arranged in rows and columns with enough space for teacher and learner movement. Every learner had a biology textbook and notebook to write on	(a) The classroom context provided a safe learning environment for both girls and boys. (b) Learners were provided with textbooks and notebooks
Lesson one topic: Inheritance, chromosomes and genes **Class**: Grade 11 **Time**: 70 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: Lucy greeted her learners and informed them that they were starting on a new topic 'Inheritance'. Earlier she had assigned them to read the chapter and make physical models of chromosomes: *I hope you have read the chapter and made your chromosome models as I assigned you*. Line 2: Lucy continued, *Before we define inheritance; tell me about your families, do you in any way look similar to your mother, father or siblings?* Learners responded by stating how they were similar to or different from their family members in terms of their physical features namely, complexion, height and ear size. After the short discussion, Lucy said *Let us define inheritance*. She asked learners individually to define inheritance. The learners responded as follows: Learner A said *'I think inheritance is the passing of certain characteristics from the parents to the offspring.'* Learner B, reading from a textbook, said *'Inheritance is the transmission of genetic information from generation to generation leading to continuity and variation of the species.'* Line 3: As a follow-up, Lucy asked learners, *What can you say about learner B's definition?* (They were supposed to have read the chapter beforehand.) Line 4: Learners gave varied responses from saying nothing to offering the suggestion that the definition *'It's too long'*. Line 5: Lucy commented that the learner's definition was all right because *actually what we want is the full definition. Now that we are dealing with genetics, I would like you to use all the terminology that is related to genetics.* Using a textbook as her source, she repeated the definition read by learner B as *the passing on or transmission of genetic information from one generation to another generation leading to continuity of, and variation within, the species*. Line 6: Lucy followed this up by asking the learners *What is the meaning of continuity?* A learner responded it means *'It goes on.'* *What goes on?,* the teacher asked. The same learner said *'The genes'*.	**Pedagogical knowledge (PK)**: As her teaching strategy, Lucy asked learners to read the chapter prior to the lesson in class and to make physical models of chromosomes, the genetics concept to be taught (line 1) **PK**: Lucy used the questioning technique in a familiar context to arouse interest and engage learners on a novel topic of inheritance and to determine individual learners' conceptions of inheritance (line 2). **Content knowledge (CK):** Lucy used a textbook to define inheritance (line 5). She did not explain the terms 'genes' 'genetic information' and 'variation within species' in the definition. She failed to provide adequate and meaningful explanation of these terms (line 6). **PK:** Lucy used the questioning technique to

The teacher responded by saying, *Yes, the genes. I was told that my child, who is dark in complexion, resembles his grandfather, which means the genetic information from the grandfather has been passed on from generation to generation. Like you also said that you do not look exactly like your mother or father, you may find that you resemble some of those great-grandparents who died long time ago. I think you now all understand the meaning of 'inheritance'?* The whole class said *'Yes'*. Lucy did not explain other terms e. g. genetic information, variation in the definition) and, as a result, provided only a formal definition of inheritance for the learners to memorize perhaps. Lucy concluded the discussion on inheritance. *So in this lesson we will look at 'Inheritance', how the genetic information is passed on from one generation to another.*	assess learners' comprehension of the term 'inheritance', which yielded a chorus response from the class (line 6)
Line 7: Lucy recalled a previously taught concept, sexual reproduction and sought to link its outcome (inheritance) to the genes. She said: *Remember in sexual reproduction there is the fusion of gametes, which are the sperm and the ovum. Can you tell me what is there in the sperm or ovum that has resulted in you being the person you are? What do you think really brought up this creature that is you?* Line 8: Learners responded to teacher's questions one at a time. Learner A: '*Parents had sexual intercourse'* Learner B: '*The genes'* Line 9: Lucy probed Learner B's response. *Where are the genes in this case?* The learner replied '*They are in the chromosomes'* *Did we see chromosomes during fertilization?* asked the teacher. The class as a whole said *'No.'* The teacher then asked one learner: *Where are the chromosomes?* The learner said, *'In the nucleus'* Line 10: Lucy then tried to link together what the learners had said so far about the nucleus and chromosomes. *We said during fertilization both the sperm and the ovum cells contain a nucleus and the two nuclei fuse to form a zygote. For now let us talk about the nucleus. We want to know the structures that are there in the nucleus that might have resulted in the formation of the whole being. In the nucleus of these cells there are chromosomes which contain genes*. Before providing any definition of chromosomes and genes, Lucy requested learners to present their constructed models.	**CK**: Lucy introduced chromosomes and genes using genetics content knowledge by reviewing previous concepts namely sexual reproduction and linking the outcome of this process to the chromosomes and genes contained in the nucleus (lines 7–10). **PK**: Questions were used to probe individual learner's grasp of previously learned concepts of sexual reproduction and cell (lines 7–9).

Learner presentation on chromosomes and genes

Line 11: With the focus now on chromosomes Lucy asked volunteers to present and describe their models of chromosomes. Figure 4.1.1 shows two of the models.

Model 1 **Model 2**

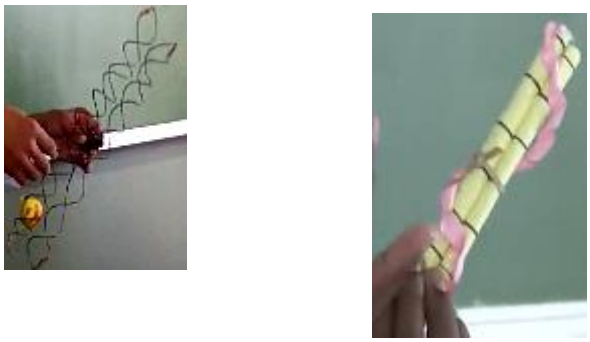


Figure 4.1.1: Learners' models of chromosomes and genes

Line 12: Model 1 was described by the learner: *'As we all know that chromosomes are always in pairs, these are my chromosomes, two of them* [the spiral wires]. *The chromosomes are held together by a centromere and that is why I used the magnet to hold the wires together. This is a gene* [pointing at darker sections of the wires] *which is DNA strand.*

The second learner described model 2: *'What I understood from my reading is that each chromosome has two chromatids that is why I did these two things (rolled yellow papers depicted in rod-like structures). My model represents one chromosome but the problem was that I had to put the DNA strand and I didn't know how so I put the pink paper around. The grey string is the centromere which holds the chromatids together. Then in my model the black marks are the genes. The genes are for different features like one would be for the ears and the other would be for eyes. But what is still confusing me is the chromatid thing. I do not know what it is and what is it for.'*

Line 13: Lucy followed up the learner's difficulty in comprehending that one chromosome can exist as two parts (replicates) called chromatids and asked other learners to describe what chromatids are. They responded as follows.

Line 14: The learner who presented the first model answered: *'Maybe I can use my artifact again. I said chromosomes always exist in pairs and so one of this strands here is a chromatid'* [not a chromosome as he said in his first presentation in line 12]. This learner confuses homologous chromosomes, which are two different chromosomes and chromatids, which are replicates of the same chromosome.

Third learner: Another tried to explain chromatids by saying *'The book says that this chromosome is made up of two parallel strands called chromatids, meaning each of the rods on your (second learner) model is a chromatid.'*

Line 15: Because she was not satisfied with the answers, Lucy told the class that they would discuss chromatids in the next lesson on cell division and requested the definition of chromosome from the class as that was the focus of the

PK: Through asking the learners to present their work (peer teaching) Lucy provided opportunities for diagnosing any difficulties the learners had in reading the chapter. It was also one way of actively engaging the learners in the learning process (lines 11–14).

Learners' preconceptions and learning difficulties (LPLD): Learners expressed their conceptions of chromosomes and genes through models and presentations (lines 11–12). Learner 2 experienced difficulty in comprehending how DNA molecule fits into the structure of a chromosome and chromatids as replicates of the same chromosome (line 12). Learner 1 could not differentiate between homologous chromosomes as two different chromosomes and chromatids as replicates of the same chromosomes (line 14).

PK: Lucy asked other learners to explain what chromatids are in an attempt to address learner's difficulty (line 13).

PK: Lucy did not immediately address learners' learning difficulty about chromatids (line 15). The teacher's instructional strategy of postponing the explanation of chromatids was perhaps designed to place the particular concept in a valid context even though the second learner

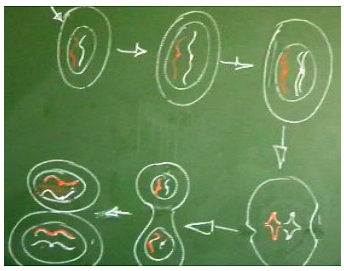
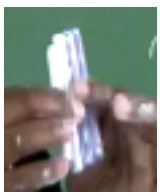
lesson.	had presented her model using the term 'chromatids', which she did not fully comprehend.
Line 16: After Lucy had thanked the three presenters, she asked the class: *From the presentations, do you think you can come up with a definition of a chromosome?* One learner defined a chromosome as *'a strand of DNA which carries genes and a protein'*, referring to the biology textbook. The teacher responded, *Okay.* One was not sure whether she agreed with the answer or it was a mere acknowledgement of an answer. However, she then defined a chromosome as *a thread-like structure of DNA, made up of genes found in the nucleus* and followed this up by asking a learner, *What does DNA stand for?* Line 17: The learner responded, *'Deoxyribonucleic acid'.*	**PK**: The questioning technique was used to encourage learners to use their own words to provide a definition of a chromosome (line 16). **CK**: Teacher content knowledge was used to define a chromosome (line 16). **PK**: She used the questioning technique to find out if learners knew what the acronym DNA, which appears in the definition of chromosome stands for (lines 16–17).
Line 18: Lucy, after providing a formal definition of chromosome, introduced the concept of homologous chromosomes. She started off by saying *Chromosomes always exist in pairs;* and then drew a diagram of a pair of chromosomes on the chalkboard (Figure 4.1.2) to illustrate this.  **Figure 4.1.2: An illustration of a pair of chromosomes** Line 19: As Lucy drew the diagram (the two rod-like structures) she said *So these will be our 'thread-like structures' which are the chromosomes. Along the lengths of the chromosomes there are genes represented by the sections as drawn.* Pointing at the different sections of each of the paired chromosomes she said, *This section will be a gene and*	**CK:** Lucy introduced homologous chromosomes by stating that *chromosomes always exist in pairs* (line 18) **CK**: Lucy used a schematic diagram drawn on the chalkboard to illustrate a pair of chromosomes and genes. However, her diagram did not quite depict a *'thread-like structure' for a* chromosome as per her description (lines 18–19). **CK:** Lucy's content knowledge was used to state or describe the relationship between chromosomes and genes using a diagram (line 19). **PK**: Lucy used an ineffective method of questioning that drew a

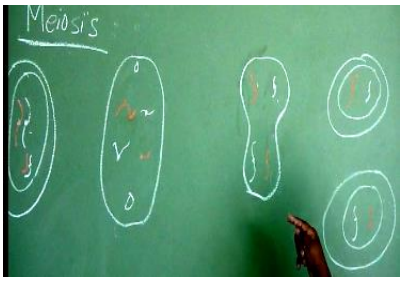
this will be another gene so they occur in pairs and so on. Line 20: As the lesson progressed, she asked the learners, *Have you heard about the term homologous?,* which drew a choral response from the class *'Yes.'* *What do you think are homologous chromosomes?* She pointed to one learner who stated, *'I think they have the same genes.'* Lucy continued, *You think they have the same genes? Yes somehow they are similar. A pair of similar chromosomes is called homologous chromosomes.* Without any further explanation of how homologous chromosomes are similar Lucy then talked about genes.	chorus answer from the class. But later she resorted to identifying individual learners to answer specific questions on homologous chromosomes (line 20). **CK:** Lucy described homologous chromosomes insufficiently at this stage by not explaining how they are similar (line 20).
Genes Line 21: Having defined homologous chromosomes as a pair of similar chromosomes, Lucy wanted to know from the learners what genes are. Directing her question at the whole class she asked, *Who can define a gene?* Line22: Various learners raised their hands. The first learner defined genes using a textbook: *'They are a series of chemical structures found on chromosomes.'* The second said: *'They are chemical structures found on chromosomes carrying the genetic information.'* The third said: *'They are chemical structures made up of DNA found on chromosomes.'* Line 23: Lucy agreed with an *Okay* and defined genes formally as *chemical structures made up of DNA found on chromosomes and control particular characteristics.* She added: *Some books would say a gene is as a section of DNA which carries genetic information about a particular characteristic or protein.* Line 24: Referring to the schematic diagram of chromosomes (Figure 4.1.2) in line 18 Lucy pointed to different sections and stated that those sections are referred to as genes and they are responsible for physical features of an organism, e.g. colour of eyes, and shape of nose Line 25: Lucy used the analogy of a recipe book to illustrate the relationship between chromosomes and genes and their functions. *If I were to use an example of a recipe book. For those of you who are doing Home Economics what is a recipe?* A learner answered, *'It is a list of ingredients for making a particular meal.'* Line 26: The teacher agreed. *We would say a recipe book contains ingredients that are necessary for making different dishes e.g. Baking cakes, cooking rice, and ligusha* [a native dish]. *Here we would say the book would be the chromosome. The whole structure of a chromosome carries the genes, the genetic information. In this case if we liken a gene to a recipe it means that the gene carries some information about how to make a particular protein like haemoglobin. Are we all together?* The class as a whole said *'Yes.'*	**PK**: Lucy again is directing her question to the whole class (not an effective way of diagnosing individual learners' difficulty or mistakes, if any) for the definition of a gene. The three learners gave answers from their textbooks (lines 21–22). **CK**: Lucy's content knowledge was used to adequately define genes giving different definitions (line 23). **CK**: Lucy used content knowledge to describe the function of genes (line 24). **CK:** Lucy used a recipe book as an analogy to describe the relationship between chromosome (recipe book) and genes (different recipes in the book) (lines 25–26). **PK:** Lucy used an ineffective method of questioning that drew chorus answer from the class to sum up her explanation (line 26).
Line 27: Lucy identified individual learners at random and	**PK**: Lucy identified

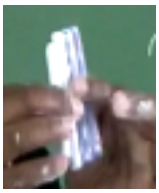
asked them review questions: *We have now defined a chromosome and a gene? Can you please now re-define them for me?* The first learner defined chromosomes as *'Thread-like structures found in the nucleus of all living things.'* The second learner said *'They* [chromosomes] *are thread-like structures which contain genes which have instructions from both parents.'* The teacher asked the class, *What is the function of the chromosome?* The class as a whole responded, *'They carry the genes.'* The teacher asked, *What is the function of the genes?* The whole class said, *'They carry the genetic information.'* Line 28: Lucy agreed to the learners' responses with an *Okay* and summarized their responses: *Chromosomes carry the genes and the genes carry the genetic information* Lucy then introduced alleles.	individual learners to define chromosome and gene. The assessment was meant to provide immediate feedback on the learners' grasp or otherwise of the concepts of chromosome and gene (line 27). As unfortunate again whole class and not individuals in some cases. **CK:** Lucy's content knowledge was used to respond to learner feedback (line 28).
Alleles Line 29: Lucy introduced the concept of alleles: *Let us now move on and talk about alleles. We want to know why we resemble our parents, grandparents or great grandparents for that matter. Or why we resemble one parent and not the other. From your chromosome models I think you can show me what alleles are. First of all can we have someone define an allele and then use his or her model to show alleles?* **Learner presentation on alleles** Line 30: One learner began by defining an allele while referring to her textbook: *'Alleles are genes occupying corresponding positions on homologous chromosomes and control the same characteristic.'* She used her model (Figure 4.1.3) of beads on a thread to try to illustrate alleles.  **Figure 4.1.3: Learner model of chromosomes illustrating alleles** Line 31: The learner continued, *'In my model I would say the beads are the genes and those that go in pairs are the alleles although they are not straight but you can see the pairs. The genes in a pair control the same characteristic.'* Line 32: After the girl had finished her presentation, Lucy asked other learners at random to define alleles. Learners gave the following responses: The first learner said *'Alleles are genes which occupy corresponding positions on homologous chromosomes and control the same characteristic',* reading from the textbook. The second learner stated *'These* [alleles] *are alternative forms of the same gene which affect a particular characteristic'* Line 33: Lucy agreed. Referring to the same schematic	**PK:** Lucy introduced the concept 'allele' by arousing learner interest and curiosity by asking why 'we resemble our parents' (family resemblance) and followed this up with a question (line 29). **PK:** Lucy used learner activity involving class demonstration to assess learner's knowledge (line 30). **Learners' preconceptions and learning difficulties:** Learner demonstration allowed Lucy to determine a learner's comprehension of alleles. The learner described alleles as pair of genes controlling same characteristic (line 31) **PK**: The questioning strategy was used to elicit individual learners' conceptions of alleles (line 32). That provided Lucy with the opportunity to learn

diagram on the chalkboard (Figure 4.1.2) Lucy described alleles: *When we talk about alleles we are still talking about genes but we are talking about genes that occupy the same position on homologous chromosomes or you can say they occupy the same locus on homologous chromosomes. Another thing about alleles is that they control the same characteristic.*  **Figure 4.1.4: Diagram illustrating alleles** Line 34: Pointing to the two first genes on the two homologous chromosomes (Figure 4.1.4), Lucy explained: *This means that this one gene corresponds to this one. These two genes occupy the same locus on the homologous chromosomes and they control the same characteristic. For instance, suggest which characteristic they can control* A learner said *'Skin colour'*. Lucy continued, *Complexion. This one may be responsible for the bright skin and the other one responsible for the dark skin. So because they are occupying the same position and they are controlling the same characteristic they are referred to as alleles. Some books refer to alleles as the alternative forms of the same gene. So I hope you now understand what chromosomes, genes and alleles are and make differences.* At the end of the double period the teacher did not have time to summarize the lesson.	more about their understanding of the meaning of alleles, even though the definitions were being read from the textbook (line 32). **CK:** Lucy's content knowledge was used to emphasize that alleles are genes, with different effects on a particular characteristic (line 33). **CK**: A diagram drawn on the chalkboard was used to show the position of alleles on homologous chromosomes to help learners visualize those (lines 33–34). **CK:** In summing up, Lucy did not state clearly the idea of alleles as variants of the same gene, probably because of lack of time, even though this could be implied in her example of genes responsible for skin complexion (line 34).
Homework Line 35: Lucy instructed learners to read up about mitosis and meiosis, which were the concepts to be discussed in the next lesson.	**PK**: Reading the topic beforehand for homework was the usual strategy used by Lucy to introduce new topics (line 35)
Lesson two topic: Cell division: Mitosis and meiosis **Class**: Grade 11 **Time**: 70 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: Lucy began her lesson by asking individual learners to define concepts learned in the previous lesson, namely inheritance, chromosomes, genes and alleles. Line 2: Learners defined inheritance, chromosomes and alleles correctly. They needed probing to define a gene adequately. For example, one of them said *'Genes are chemical structures found*	**PK**: Evenly distributed questioning of individual learners was used to review the previous lesson (line 1). **CK**: Lucy's content knowledge was used to determine learners'

along the length of a chromosome which carry the genetic information' Line 3: Lucy probed: *I think we were specific when we talked about a gene. We said a gene carries what?* The class as a whole said *'Genetic information'.* The teacher asked, *For what?,* again without directing her question at individuals. One learner blurted out: *'For the development of a particular characteristic'.* She agreed with a *Yes* and emphasized that a gene carries the genetic information about a particular characteristic. With the review of the previous lesson having been concluded, Lucy moved on to the topic of the day's lesson, mitosis and meiosis.	inadequate responses to their conceptions of genes (lines 2–3). **PK**: Probing questions addressed to the whole class were again to elicit information (line 3). **CK:** Teacher content knowledge was used to respond to learner feedback (line 3).
Mitosis and meiosis Line 4: Lucy introduced the concepts mitosis and meiosis by simply announcing that they would not cover the details of the processes as per the requirements of the syllabus for the grade level. She asked learners who volunteered to present on mitosis. **Learner presentation on mitosis** Line 5: One learner said: *'Mitosis is the division of cells. When the cell divides the chromosomes divide in stages.'* Using his textbook, the learner drew cell diagrams on the chalkboard to illustrate the process of mitosis. Line 6: He then described the process of **mitosis** thus: *'When you have a cell that has two chromosomes. The two chromosomes duplicate to form chromatids. The chromatids separate to form two new cells. The two cells have two chromosomes each like the first one'.* The teacher asked the class if the learner's description was correct. A second learner offered to correct the description. Using his textbook he stated that '*before the cell divides, the chromosomes get short and fat. They duplicate to form chromatids. The nuclear membrane disappears. Chromosomes come to the centre of the cell and spindles form. The spindles pull the chromatids apart and one group of chromatids goes to each end of the cell. The nuclear membrane re-appears around each group of chromatids. Two new cells are formed like that. And two cells are like the first one and have two chromosomes.'*	**PK**: Lucy advised learners on what to focus on based on syllabus requirements (line 4). **PK:** Learner activity in the form of peer teaching was used by Lucy to assess the extent of understanding based on homework assignment (lines 5–6). **Learners' preconceptions and learning difficulties:** The first learner described the process of mitosis by giving its overview, omitting details such as chromosomes becoming short and thicker, and the disappearance and reappearance of nuclear membrane and role of spindles, which were provided by the second learner (line 6). Overall, the learners described the process of mitosis correctly. **PK:** Lucy asked learners to correct their peer's description of the process of mitosis (line 6).
Line 7: Following the learner's presentation, Lucy asked individual learners about the importance of mitosis, *Why do we need mitosis?* Referring to their textbooks, learners gave varied responses from: *'To form new cells' 'to repair damaged cells' 'for growth'* to *'to form new cells necessary for the growth of an organism'*. She reacted with *Okay* and stated, *We need mitosis to form new cells and to repair worn out tissues. Mitosis is the cell division responsible for growth and replacing worn out*	**PK:** Lucy used a questioning technique to arouse learners' curiosity and their thinking as to why the study of mitosis is important (line 7). **CK:** Lucy used her content

tissues. With no further explanation or attempt to link mitosis to everyday life examples, Lucy described the stages of mitosis. Line 8: Lucy used a diagram drawn by a learner, Figure 4.1.5, to explain the process of mitosis.	knowledge to say why it is important to study mitosis without providing daily life examples of the process (line 7).
 **Figure 4.1.5**: **Learner's illustration of the process of mitosis**	
Referring to Figure 4.1.5 Lucy said: *Mitosis occurs in stages. In the beginning we have a cell with these two chromosomes in the nucleus. Note that this is an illustration to show how you end up with the same number of chromosomes. The number of chromosomes in the nucleus depends on the particular species you are talking about. In human beings for instance you have 46 chromosomes in a cell and in the 46 chromosomes these are the stages that are followed during mitosis.* Line 9: *This is the parent cell* [first circle]. *Actually before cell division, the chromosomes prepare themselves for cell division by replicating. To replicate is to duplicate. Let me show you how it occurs.* Line 10: Lucy used coloured chalk (white and blue) to illustrate replication of chromosomes during the process of mitosis.	**CK**: Teacher content knowledge was used to describe the process of mitosis explaining meaning of new terms e.g. replication (lines 8–11). **CK**: Lucy used coloured chalk as visual aids to illustrate replication of chromosomes during mitosis (line 10–11).
  (a) (b) **Figure 4.1.6: Pictures of coloured chalk used to illustrate chromosome replication during mitosis**	
Line 11: *So let us say in the beginning this is the parent cell* (Figure 4.1.6 picture a) *it has two chromosomes depicted by the white chalk and blue chalk. The cell prepares itself for mitosis by replication of the two chromosomes. By replication we mean duplication. When they replicate each chromosome makes two chromatids called sister chromatids and now we have two whites and two blue* (Figure 4.1.6 picture b). *The chromatids are held together by a centromere.* Line 12: Lucy then asked the class, *Why it is necessary for the*	**PK:** Lucy used an ineffective method of questioning of whole class, but later decided to point to one learner to answer (line 12) **CK:** Lucy's content knowledge was used to explain separation of

chromosomes to duplicate? One learner said *'To make chromosomes that are similar to them so that they can move to the different ends.'* Line 13: Lucy agreed with an *Okay* and continued, *Some of you may be wondering who is pushing these chromatids to move to the poles of the cell. There are fibres and the chromatids are attached to the fibres which then pull to the different poles of the cell. The nuclear membrane breaks into two nuclei. These nuclei will form two cells with the same number of chromosomes as the parent cell. So here we refer to this cell as a diploid cell.* Line 14: Lucy concluded the discussion of mitosis by asking the class, *Is that clear?* She followed up the choral response of *'Yes'* with individual questioning: *What can you say about the number of chromosomes in mitosis?* A learner answered, *'The number of chromosomes is the same.'*	chromatids, how two cells eventually form, and meaning of diploid (line 13) **PK:** Lucy used an ineffective method of questioning that drew a chorus answer from the class. But later she resorted to identifying an individual learner to answer specific questions on mitosis (line 14).
Learner presentation on meiosis Line 15: After concluding the topic of mitosis Lucy moved on to meiosis. A learner offered to present the process of meiosis to the class. Line 16: Before starting, he said: *'I struggled a bit to understand meiosis, particularly understanding how the number of chromosomes ends up being half because it is like the same process as mitosis occurs.'* Lucy intervened: *May you start by describing mitosis then so that we see where you fail to make the difference when you talk about meiosis*. The learner described the process of mitosis correctly, showing how the chromosome number is maintained. He then described the process of meiosis. Referring to his textbook occasionally, he drew cell diagrams (Figure 4.1.7) to show the stages of meiosis.  **Figure 4.1.7: Learner's illustration of the process of meiosis** Line 17: He continued. *'In the first stage of meiosis* (Figure 4.1.7) first cell diagram from left] *homologous chromosomes are close together, two long ones and two short ones. They pair up. The second stage, homologous chromosomes split, centrioles move to the poles and spindles pull the chromosomes apart. Then there is like the haploid number of chromosomes. How is it half as it happens the same way as in mitosis?'* He then asked the class, *'Is it correct? Do the resulting cells contain a haploid number of chromosomes?'* Learners gave different responses: some said *'Yes'* and others *'No.'* It could not readily be ascertained what *'yes'* or *'no'* meant. The 'yeses' might have responded by merely looking at the two final cells with	**PK:** Peer teaching was used to give learners a chance to present on meiosis, increasing learner participation (lines 15–17). **Learners' preconceptions and learning difficulties**: A learner expressed difficulty in differentiating between meiosis and mitosis and the halving of chromosomes during meiosis (line 16). **PK**: Through peer teaching learners expressed their conceptions of meiosis. Once again it revealed learners' difficulty in comprehending meiosis e.g. reduction of chromosome number (line 17).

half the number of chromosomes or thought the presenter was still to show the second division where the chromatids would separate, while the 'nos' noted that the second division where the chromatids separate was missing. Line 18: Lucy acknowledged the learner-presenter's effort, and added: *I think when you have struggled a bit it would be much easier to understand when I explain.*	
Line 19: Lucy asked the learners the significance of meiosis. *Why do we need meiosis? Why do we need another type of cell division different from mitosis? In other words what is the significance of meiosis?* Line 20: One learner answered by reading from his textbook *'Meiosis results in the formation of gametes. It is necessary that we have the haploid number of chromosomes because the gametes form the zygote. If the gametes had the full number of chromosomes, each time a zygote was formed it would have double the number of chromosomes. And that will continue doubling.'* Line 21: Lucy accepted the learner's response with a *yes* and continued, *Meiosis is the type of cell division specifically for the formation of gametes and therefore in meiosis the daughter cells should have half the number of chromosomes.* Line 22: *Let us now follow the stages to see what happens in meiosis that results in half the number of chromosomes. Is that okay?* The class agreed with a *'yes'*. Line 23: Lucy further explained the process of meiosis. *In meiosis we are forming the gametes, the sex cells. Our daughter cells shouldn't contain the same number of chromosomes as the parent cell as the learner explained. The chromosomes should be half. That is why sometime meiosis is referred to as the reduction division. Why reduction division? Because the number of chromosomes in the nucleus is reduced. We refer to such a nucleus as a haploid nucleus because it contains half the number of chromosomes as compared to the initial nucleus.* Line 24: Lucy again used coloured chalk to illustrate replication and separation of homologous chromosomes during meiosis.    (a) (b) (c) **Figure 4.1.8: Pictures of coloured chalks used to illustrate chromosome replication and separation during meiosis** Line 25: *So initially we have two chromosomes, the two white and purple chalk (Figure 4.1.8a). Before cell division, the chromosomes replicate (Figure 4.1.8b) and now we have two white and two purple. Each chromosome (white and purple)*	**PK:** Lucy used a questioning technique to arouse interest and wish to know about meiosis (line 19). **CK:** Lucy used her content knowledge to determine learner's correct response (line 20–21). **CK:** Lucy's content knowledge was used to state the purpose and explain the outcome or product of meiosis (line 21) **CK**: Teacher content knowledge of meiosis was used to explain correctly why meiosis is sometimes referred to as reduction division (line 23). **CK&PK:** Lucy used coloured chalk as visual aids to illustrate and describe the duplication and separation of homologous chromosomes during the first division in meiosis using her knowledge of the stages of the process (lines 24–25).

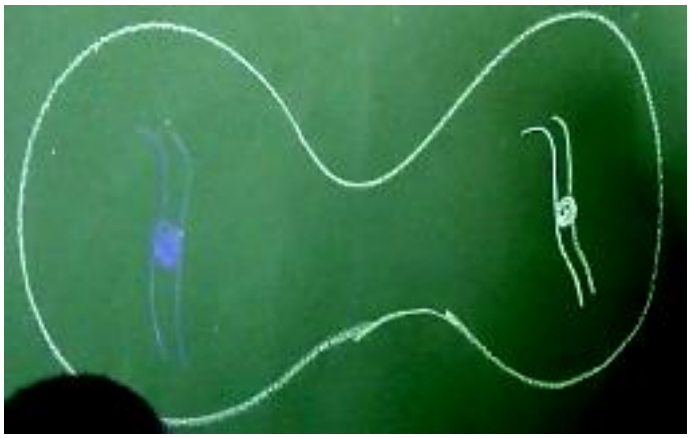
has replicated to form sister chromatids. Why replicate? Because the chromosome has to make a copy of itself so that one copy can go to the other cell. When the cell first divides in meiosis the sister chromatids will not separate (Figure 4.1.8c) but the chromosomes do. Do you understand Learner1? Lucy said, pointing to the learner who had difficulty in describing meiosis and was confused about the reduction of chromosome number (line 17). The learner responded by saying '*yes*'. Line 26: To illustrate the first division of the process of meiosis, Lucy drew a diagram (Figure 4.1.9) on the chalkboard showing the separation of a pair of homologous chromosomes using different colours of chalk to represent different chromosomes.	**CK:** Lucy used diagrams on the chalkboard to illustrate that during the first division of meiosis homologous chromosomes separate and not chromatids (line 26–27).
 **Figure 4.1.9: Diagram illustrating separation of a pair of homologous chromosomes during meiosis**	
Line 27: *So the first division in meiosis does not allow the sister chromatids to separate. So what happens is that they just move together to the poles of the cell.* Line 28: *And then from there the sister chromatids will separate. The spindles will pull the sister chromatids of each chromosome so that one chromatid moves to each pole. From there the nuclear membrane is going to divide such that now we have four cells and each of these cells contains one chromosome which is half of the two that I was having at the beginning.* She drew a diagram (Figure 4.1.10) as an illustration of the formation of the four haploid cells.	**CK:** Teacher content knowledge was used to describe the process and product of meiosis showing the separation of chromatids during the second division resulting in four cells with half the number of chromosomes (line 28). **PK:** Lucy used diagrams on the chalkboard to further illustrate that during the second division of meiosis four haploid cells are formed (line 28)

 **Figure 4.1.10: Diagram illustrating four haploid cells during meiosis** Line 29: Lucy concluded by asking the class *Do you get the difference between mitosis and meiosis?* The class responded as a whole and said *'Yes',* a response which did not tell her who knew and who didn't.	**PK**: The question was directed to whole class and not to individuals to ascertain comprehension (line 29)
Learner assessment Line 30: As a way of summarizing the lesson Lucy asked learners individually to define meiosis in their own words: *How can you define meiosis <u>in your own words</u> from what we have done so far?* Line 31: The learners gave varied responses ranging from *'Meiosis is the division of a cell so that it ends up being four parts',* which was derived from the teacher's diagram and description, to *'Meiosis is a reduction division whereby a nucleus with a diploid number of chromosomes divides to produce a nucleus with a haploid number of chromosomes to form gametes'*, i.e. a comprehensive description of the process of meiosis synthesizing what has been taught in the lesson. This definition of meiosis was a result of Lucy's intervention after the first response so that learners should not only concentrate on the product, but also focus on the process. Line 32: Lucy accepted the last response as correct. Line 33: Lucy drew diagrams on the chalkboard representing mitosis and meiosis in terms of the number of chromosomes in resulting nuclei without labelling them and asked individual learners to identify which diagram represented each process. Line 34: Learners matched the diagrams with the process correctly.	**PK:** Questioning of individual learners was used to assess how well learners had grasped meiosis (line 30). **CK:** Lucy used her content knowledge to recognize that learners were focusing on the product rather than the process of meiosis (line 31). **PK:** Probing questions were used to elicit comprehensive definition of meiosis including its purpose and product (line 31) **CK:** Lucy used her content knowledge of meiosis to respond to learners' feedback (line 32, 34). **PK:** Lucy used a questioning technique involving written work to assess learners' comprehension of mitosis and meiosis (line 33)
Line 35: Lucy reminded learners that in human beings there are 46 chromosomes in an ordinary cell and asked them how many chromosomes there would be in cells resulting from	**CK:** Lucy's content knowledge was used to connect meiosis to

meiosis? Learners together said 23. Line 36: She explained using illustrations on the chalkboard that the 46 chromosomes in the initial dividing cell are in pairs (i.e. 23 pairs of chromosomes), but the resulting haploid cells contain a single set which are not in pairs (i.e. 23 single chromosomes). She stated that the resulting haploid cells are called gametes, which are the sperm and ovum. Line 37: She again asked the class: *Why is it important that the sex cells contain half the number of chromosome?* Line 38: One learner answered that it was to make sure that during fertilization the zygote has 46 chromosomes. Line 39: Lucy agreed and emphasized that *during fertilization each gamete from male and female parents comes with half the number of chromosomes carrying the genetic information from the parents.*	fertilization (lines 35) **PK:** The whole class questioning technique was used to find out the significance of the process of meiosis (line 37). **CK:** Lucy's content knowledge was used show the passage of genetic information from parents to offspring (line 39)
Homework Line 40: Lucy gave out photocopies of homework, in which learners were asked to define a chromosome, state the number of chromosomes in various human cells e.g. skin cell, egg cell and red blood cell; name the process which provides new cells for the growth of a young mammal; and explain why it is necessary for gametes to be formed by meiosis.	**PK**: Homework assignment was used to give learners a chance to demonstrate their knowledge and understanding or lack of it about chromosomes and the processes of cell division (line 40).

4.5.1.2 Summary of Lucy's lesson observation analysis

Lucy demonstrated in her lessons that she had the required content knowledge to teach genetics topics at that grade level. She began the inheritance lesson by describing the basic hereditary structures of chromosomes, genes and alleles. She linked these concepts to the related ones of cell structure, nucleus and fertilization, which the learners had previously been taught. In this case, Lucy showed the relationships among the concepts nucleus, gametes, fertilization, chromosomes and genes. Interestingly enough, biology has a special standing when it comes to teacher's content knowledge (Abell, 2007), in the sense that "it is the only science subject that includes both substantive and syntactic structures" (Juttner et al., 2013:47). According to Juttner et al. (2013), substantive structures suggest ways in which biological concepts and principles may be organized to make them more accessible to learners, say, while syntactic structures indicate propositions or ways by which extremes of true and false conditions (i.e. truths and falsehoods) may be established in the context of teaching. Teacher's content knowledge therefore is not only 'to understand that something is so; the teacher must further understand why it is so' (Shulman 1986:9). Lucy illustrated the interrelationships among these hereditary structures using schematic diagrams and the

learners' models. Familiar examples and analogies of common objects in the learners' everyday experiences were used to enhance their comprehension of those abstract concepts (ref. 4.5.1.1 first observation lesson line 5). Specifically, Lucy used an analogy of a recipe book to illustrate the relationship and functions of chromosomes and genes in which the recipe book carrying different recipes represented a chromosome carrying different genes that control specific features (ref. 4.5.1.1 first lesson observation lines 25–26). Through the illustrations, she also showed the relationship between genes and inherited characteristics.

At times, learners' unsatisfactory responses to her probing questions – such as their incomplete definitions of a gene (ref. 4.5.1.1 second lesson observation lines 2–3) – were corrected by the teacher using her content knowledge, which is referred to here as declarative knowledge. Declarative knowledge is operationalized in this study as 'knowing that' (Krathwohl, 2002), which is teacher knowledge necessary for stating and explaining facts or theories included in the subject matter (Juttner et al., 2013).

Once Lucy had dealt with the basic structures, she linked them with the processes of mitosis and meiosis. Here she focused not only on describing the purpose, product and process of mitosis and meiosis using diagrams and coloured chalk as visual aids (ref. 4.5.1.1 second lesson observation lines 7–8, 19, 26–30) using her procedural knowledge, but also on the significance of those processes (why the processes of mitosis and meiosis). Procedural knowledge designates knowledge of how biological processes operate (Juttner et al., 2013).

In other instances, Lucy displayed another type of knowledge. For example, when learners expressed difficulty in differentiating between mitosis and meiosis (ref. 4.5.1.1. second lesson observation line 16), that is, how and why one process results in the diploid nuclei while the other produces haploid ones. Lucy explained how homologous chromosomes and chromatids separate, and emphasized the production of the gametes in meiosis, which are haploid cells, which is important to maintain chromosome number during fertilization in the formation of a zygote. This knowledge of the 'how and 'why' (Paris et al. 1983) that she demonstrated in the explanation may be construed as conditional knowledge (Paris et al. 1983). This dimension of her content knowledge has to do with understanding concepts and principles. Overall, Lucy's content knowledge could be construed as declarative, procedural and conditional content knowledge.

The main topic-specific instructional strategy used by Lucy in introducing new concepts was to ask learners to read up the topic in the textbook before the lesson and present to the class in the form of peer teaching. In the case of chromosomes, genes and alleles, learners were asked to construct physical models of chromosomes and present them to the class in a teaching format. Following the presentations and post-presentation discussions, the teacher introduced the concepts, sometimes using learners' diagrams and models to illustrate incorrect conceptions. Some researchers (Chinnici et al., 2006; Clement, 2000) have insisted that experiments and models can assist learners in learning complex and abstract biological concepts and processes. Using simple coloured chalks, Lucy was able to help her learners visualize the process of replication of chromosomes during mitosis and meiosis. Lucy also used a familiar context to introduce the topic in order to arouse interest.

Oral questioning techniques were used frequently to achieve instructional purposes. These include eliciting individual learner's genetics topic conceptions (ref. 4.5.1.1 first lesson observation lines 1–2, 16, 21–22, 32), but Lucy used predominantly whole-class directed questions, which yielded chorus responses from the learners and rarely individualized questioning techniques. Therefore her teaching strategy was deficient as far as questioning techniques are concerned.

With regard to knowledge of learners' preconceptions and learning difficulties, Lucy became aware of learners' confusion with the terminology used in genetics through individual learner presentation. For example, one of the learners wanted to know how DNA fits into the structure of a chromosome, that is, whether DNA makes up a chromosome or was a separate entity, as shown in her physical model (ref. 4.5.1.1 first lesson observation lines 11–12). Others confused the terms 'chromosomes' and 'chromatids'.

From the lessons observed, it can be construed that Lucy's PCK profile of genetics teaching constituted declarative, procedural and conditional content knowledge; the use of familiar situations, models, learner presentation, analogies, diagrams, and questioning techniques, both whole class, which were not effective, and rarely individual, which could have been more efficacious in gaining insight into her learners' conceptual understanding. Knowledge of learners' preconceptions and learners' learning difficulties was derived mostly from her

use of learner presentation and oral questioning technique during the lesson itself. There was no evidence of knowledge of learners' preconceptions and learning difficulties prior to teaching.

4.5.2 Case 2: Lily

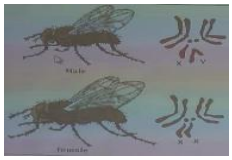
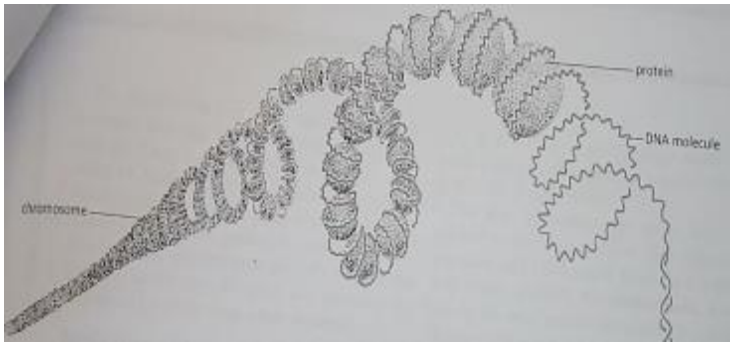
4.5.2.1 Lily's lesson observation analysis

Two 80-min lessons (2 x 40) were observed on two separate classroom occasions, in which the concepts of chromosomes, genes, mitosis and meiosis were taught. The analysis begins with a brief description of the classroom context, followed by the teacher's classroom practice, as categorized. The teacher's voice and learners' responses are presented in italics.

Table 4.3 Lily's lesson observation analysis

Description of lesson	**Categorization/themes**
Classroom context Lily's biology class was a mixed ability class of 29 learners, 18 girls and 11 boys. Biology classes were always taught in a standard conventional science laboratory, which had locks for supervised entry. Learners were seated comfortably on single stools, with shared workbenches that were arranged in rows and columns with enough space for teacher and learner movement. All learners had the biology textbook, study guides and notebooks.	(a) The conditions of the science laboratory provided a safe learning environment for both boys and girls. (b) Learners had textbooks, study guides and notebooks.
Lesson one topic: Chromosomes and genes **Class**: Grade 11 **Length**: 80 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: Lily began her lesson on chromosomes and genes by asking the class, *How many of you have siblings at home*? Most learners responded by raising their hands. Line 2: Lily asked individual learners, *Who can tell us if there is anyone that you resemble in your family*. Learners gave these responses: *'Father, brother, grandfather, great grandfather.'* Line 3: Lily carried on with her questions. *Do you look exactly like your father or your other relatives?* The class as a whole said *'No'*. Line 4: Lily then asked, *Why do you think we resemble our sisters, brothers, parents, grandparents and not any members of other families?* One learner responded, *'It is because they* [family members] *share the same blood.'* Line 5: Lily probed the learner to elaborate. *What do you mean by blood? A few weeks ago we were donating blood and told our blood groups. Do you mean they share the same blood group?*	**Pedagogical knowledge (PK)**: Lily used the questioning technique in a situation familiar to learners to arouse interest and engage learners on a new topic of inheritance (line 1–13). **Learners' preconceptions and learning difficulties:** The questioning technique allowed Lily to identify learners' misconceptions e.g. mistaking genetic information for blood (line 4). In this context, the boy responded using the Swazi culture understanding that members of the same family share the same 'blood'. **PK:** Lily used a probing question (line 5) (line 6).

Line 6: Before the learner could respond, however, Lily continued, *What exactly is it that makes us resemble only the people we are biologically linked with and not any other person?* One learner answered from her textbook. *'It is because of genes.'* Line 7: Lily agreed with an *Okay* and said she was talking about genes. *Who has ever heard of genes?* Most learners raised their hands. She clarified that *I am not talking about the jeans you wear.* Line 8: Lily then asked: *What happens to these genes? How do they cause resemblance?* Learners kept quiet. Line 9: Lily prompted. *What do you think happens?* One learner said *'They are passed on.'* She reacted positively with a *Yes*. Line 10: Using the example of the learner who said he resembled his great grandfather, Lily said, *He looks like his great grandfather. So what happened to the great grandfather's genes for him to look like the great grandfather?* One learner said, *'They were passed on.'* Line 11: Lily accepted the learner's answer with *Yes, they were passed on. So the genes were passed on from the great grandfather to the grandfather to the father and to him. Now the genes are in his body. What will happen to the genes in his body?* The class as a whole responded *'They will be passed on.'* Lily accepted the response by saying, *Yes he will pass them on to his children.* Line 12: Lily told learners that the new topic was 'Inheritance' and enquired, *Who can tell us what inheritance is?* Line 13: Without waiting for an answer from the learners, Lily defined inheritance by dictating for learners to write: *Inheritance refers to the transmission of genetic information from generation to generation. This leads to continuity of species and variation within the same species.*	**PK:** Lily defined inheritance without finding out learners' preconceptions (line 13). **Content Knowledge (CK)**: Lily's content knowledge was used to define inheritance (line 13).
Chromosomes Line 14: After defining inheritance formally, Lily introduced the concept 'chromosome' by asking the class, *Where exactly are these genes found in the body*? Learners kept quiet. Lily repeated the question and prompted by giving clues: *Where are they found? Are they in the blood? Are they in the cells? Where are they found?* The class as a whole said, *'In the cells.'* Line 15: Lily accepted the learners' response and asked: *Where exactly in the cell are the genes? Which part of the cell carries the genes?* One learner said *'In the nucleus'.* Line 16: Lily investigated, *What are the structures found in the nucleus which carry genes?* One learner said *'Chromosomes'*. Line 17: Lily reacted affirmatively. *Yes, chromosomes are the structures that carry the genes.*	**PK:** Again Lily used the whole class questioning strategy (lines 14–17). **PK:** The prompting technique was used to give learners clues or hints to help them answer the question (line 14). **CK:** Lily used diagrams sourced from the Internet to present chromosomes and

Line 18: As an example of chromosomes Lily used a data projector to show chromosomes from male and female fruit flies (Figure 4.2.1).  **Figure 4.2.1: Chromosomes of fruit flies** Line 19: Referring to the diagram (Figure 4.2.1) Lily said: *So these are the structures found in the nucleus of a fruit fly cell and they are called chromosomes. As you can see the chromosomes are arranged in pairs. A pair of similar chromosomes is called homologous chromosomes. We will discuss homologous chromosomes later. For now let us focus on just a chromosome.* Line 20: Lily described a chromosome. *What exactly is a chromosome?* Learners kept quiet. *Have you ever had of DNA? Nowadays it is common to hear people saying the child is not mine let's go for a DNA test. You have heard of that?* The class as a whole said 'Yes'. *What is this DNA?* Without waiting for a response, she said *DNA is the structure of a very big molecule a very long thread that is found in the nucleus. The DNA coils up to make the chromosome.* Line 21: Lily referred learners to a simplified model of chromosome structure (Figure 4.2.2) in their textbook.  **Figure 4.2.2: Simplified model of chromosome structure** (This is a '1974' model, which has been superseded by something much more complicated.) Line 22: *The chromosome is the coiled DNA molecule. The chromosomes carry the genes. Okay let us look at the genes.* Lily did not explain the term DNA. However, it was assumed that learners had previously learned about DNA.	enhance learners' comprehension (line 18). **CK:** Lily demonstrated her content knowledge of chromosomes in explaining the diagram showing connection between cell structure (nucleus) and chromosomes (line 19). **PK:** Lily described a chromosome without eliciting learners' preconceptions (line 20). The ineffective questioning technique of posing a question to the whole class did not elicit learners' preconceptions of the genetics concept. **PK:** Lily used a familiar situation of a DNA test to determine paternity of a child' to arouse interest (line 20). **CK**: Lily's content knowledge was used to describe physical relationship between chromosomes and genes (line 20). **CK:** Lily used the textbook to show learners a diagram of a DNA molecule which coils to form a chromosome (line 21). **CK:** Lily's content knowledge was used to describe the structure and function of a chromosome (line 22).
Genes Line 23: Lily asked, *What are genes? What do you think?* Learners kept quiet. Line 24: Without prompting, Lily then defined a gene giving examples. *On a chromosome there are several*	**PK:** Lily defined a gene without eliciting learners' preconceptions (line 24). **CK:** Lily used her content knowledge to describe the

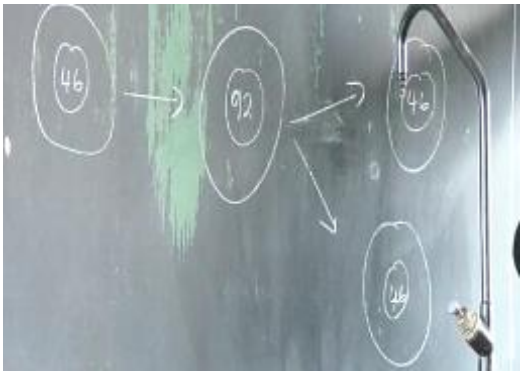
genes. A gene carries specific information about a particular characteristic in an organism. Let me give you an example. You see that I am dark in complexion that means somewhere in my chromosomes there is information about dark complexion. On the same chromosome you will find information about the eyes. There is also information about the sex. There is information about the type of hair I have. Line 25: Lily asked the class, *Am I making any sense?* The class responded as a whole and said *'Yes'*. Line 26: Lily asked the class about the location of genes. *Where do you think genes are on the chromosomes?* Learners kept quiet. Lily repeated the question, *Where are the genes found?* One learner said *'Inside'*. Line 27: Lily drew a diagram (Figure 4.2.3) on the chalkboard to illustrate the location of genes on a chromosome.  **Figure 4.2.3: Illustration of genes on a chromosome** Line 28: Lily said, *So the information is here on the chromosome* (depicted by the rod-like structure). *On this chromosome there are several genes* (depicted by the sections). She gave examples of genes controlling physical human features such as complexion, shape of nose and hair colour and located them on the diagram.	physical relationship between chromosomes and genes (line 24). **CK:** Familiar examples of features such as complexion and type of hair were used to enhance learners' comprehension of genes (lines 24). **PK:** A poor and ineffective questioning technique was used to assess learners' knowledge about genes (line 25). **CK:** Lily used a schematic diagram on the chalkboard to illustrate the relationship between chromosomes and genes and between genes and characteristics (line 27–28). **CK**: Lily demonstrated her content knowledge of chromosomes and genes in describing the diagram (line 28). **CK:** Familiar examples such as nose shape and hair colour were used to promote learners' comprehension of the function of genes (line 28).
Classwork Line 29: Lily assigned classwork in which learners were asked to state in their own words (a) *What is a chromosome?* And (b) *What is a gene?* Lily walked around the class to monitor the learners. She checked, marked and gave learners feedback about their work. Most learners experienced difficulty in defining the concepts in full, e.g. stating both structure and function of a chromosome. For example, many learners defined a chromosome as '*a structure of DNA'* or *'a thread-like structure'* and a gene as *'a part of a chromosome', 'a chemical structure'* or *'a section of DNA.'* Lily's usual comment was, *Your answer is incomplete ….*	**PK:** Written classwork was used to assess spontaneously how well individual learners had grasped the content of the lesson to provide immediate feedback (line 29). The assessment was meant to provide immediate feedback on the learners' grasp or otherwise of the concepts of chromosome and gene. **PK:** Lily monitored and analysed learners' responses to classwork on

	defining chromosomes and genes to ascertain how well the learners were responding to the questions and to detect any misconceptions (line 29). **Learners' preconceptions and learning difficulties:** Through marking of classwork Lily identified learners' inaccurate conceptions of chromosomes and genes (line 29). **CK:** Lily used her content knowledge to respond to learner feedback (line 29).
Discussion of classwork Line 30: Lily conducted a class review of the classwork exercise and decided to revisit the definitions: (a) *Let us coin the definition of a chromosome together. Most of you said a chromosome is a thread-like structure. We all agree on that. Something is missing when you are talking about chromosomes. What is that?* One learner said *'Genes'*. Lily agreed and defined a chromosome on the chalkboard for learners to copy: *A chromosome is a thread-like structure of DNA found in the nucleus which carries genes.* (b) *What is a gene?* One learner said *'Protein'* and another said *'A section of DNA'*. Lily said, *I want the full definition* and then defined a gene through dictation for learners to write: *A gene is a section of DNA which codes for the formation of a protein and controls a particular characteristic of the organism.* Line 31: Lily concluded the discussion of the classwork by asking, *Any questions?* Learners did not ask questions.	**PK**: Review of classwork was used to rectify learners' mistakes or misconceptions about chromosomes and genes (line 30). **CK:** Lily used her content knowledge of chromosomes and genes to correct learners' mistakes (line 30). **CK**: Lily's content knowledge was used to define a chromosome and gene (line 30). **PK:** Lily summed up the discussion of the classwork by posing a question to the whole class, which was ineffective (line 31).
Alleles Line 32: Lily said, *Now we are looking at information coming from two parents carried by genes controlling the same characteristic, the size of ears for example. May be the information from the father says the ears must be big and that from the mother says the ears should be small. So what will happen?* Without pausing for a response from the class she continued, *It might happen that the ears will be small like the mother's. What else can we use? Let us use complexion. The gene from one parent may be carrying the information for a dark complexion and the gene from the other parent saying the complexion should be light. In this case both genes are describing the complexion of the child but the descriptions are different. Genes that are coming from two parents describing the same characteristic but in different forms are called alleles. Alleles are different forms of the same gene. Is it*	**CK**: Through the use of familiar examples such as ear size and complexion, Lily used her content knowledge to describe alleles (line 32). **PK:** Lily described alleles without finding out learners' preconceptions (line 32). **PK**: Lily again summed up her description of alleles by asking the question *is it clear?* To which the class responded as a whole and said 'yes' (line 32).

clear? The class as a whole said *'Yes'.*	
Homework Line 33: Lily assigned learners homework to read about topics to be taught in the next lesson, namely mitosis and meiosis. She also handed out photocopies of homework in which learners were asked: *State the number of chromosomes in a human embryo and human sex cells,* given a diagram and, *Describe the purposes for the following types of cell division: (a) mitosis (b) meiosis.*	**PK:** Homework assignment of reading the topic beforehand was used to introduce the new topics of mitosis and meiosis. It served as a pre-activity on new topics, which could reveal learners' misconceptions or difficulties when reading the chapter and answering those questions (line 33).
Lesson two topic: Cell division (mitosis and meiosis) **Class:** Grade 11 **Length:** 80 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: Lily introduced the lesson on cell division by reviewing the previous day's homework, which she had marked before the lesson. She remarked: *I noticed that none of you scored the total marks.* She asked individual learners to state the answer to each question. Line 2: For example, for the second question on the purposes of mitosis and meiosis, a learner said the purpose of mitosis is to *'make cells for growth'*. The teacher said, *Yes, what else?* A second learner said it is *'cell division for repair of worn-out tissues'.* She agreed. *There is a third mark for mentioning the number of chromosomes and no one got that. What can you say about the number of chromosomes in mitosis?* Learners kept quiet. *Look at the diagram, you have the embryo developing into an adult through the process of mitosis, what can you say about the number of chromosomes?* The whole class said, *'They are the same'* and the teacher accepted that response with a *Yes.* Line 3: With regard to the purpose of meiosis, Lily said *there are a few people who got one tick for this question, give me that one point.* One learner answered and said meiosis is *'for the formation of gametes'*. Teacher said *yes. What happens to the number of chromosomes during meiosis?* Another learner said 'it is halved'. Teacher said *yes, the purpose of mitosis is to produce cells which are identical to the parent cell for growth and replacement of worn-out cells and meiosis is for the production of gametes.* With the review of homework concluded, Lily introduced the day's lesson topics.	**PK:** Lily used a teaching strategy assigning homework and marking it before class, which enabled her to identify learners' difficulties (lines 1–2) **PK**: Review of homework was used to rectify learners' mistakes in answering homework questions (lines 1–2). **CK:** Lily's content knowledge was used to respond to learner feedback (lines 2–3). **Knowledge of learners' preconceptions and learning difficulties:** Marking or correcting homework allowed Lily to identify learners' conceptions of mitosis and meiosis (line 2). **CK:** Lily used her content knowledge to state the importance of mitosis and meiosis (line 3)
Cell division (mitosis and meiosis) Mitosis Line 4: After the review of homework, Lily announced the topics mitosis and meiosis: *Now let us look at mitosis and meiosis. In which part of the body does mitosis occur? Which cells in our body undergo mitosis?* Learners kept quiet. Lily then prompted: *What did the hand-out say?* One	**PK:** The questioning and prompting techniques were used to find out the site for mitosis (line 4). **PK:** Lily described mitosis without finding out learners' preconceptions (line 5).

learner said *'Somatic cells'*. Line 5: Lily agreed and described mitosis on the chalkboard for learners to copy. *Mitosis occurs in body cells which are called somatic cells. It results in daughter cells which carry the same number of chromosomes as the parent cell. For an example, humans have 46 chromosomes so when mitosis occurs new cells must also have 46 chromosomes.* Line 6: Lily asked the class: *Let us say I cut myself on my finger when chopping onion at home; new cells must form. How many chromosomes should the new cells have?* The whole class said *'46'*.	**CK:** Lily used her content knowledge to describe the product of mitosis (line 5). **CK:** Lily's content knowledge was used to respond to learner feedback (line 5). **CK:** A familiar example replacement of cut human body cells was used to illustrate the importance of mitosis and enhance learners' comprehension (line 6).
Line 7: Lily then described how the process of mitosis occurs. *Before the cell divides the chromosomes must duplicate. Each one of them must duplicate itself. To duplicate is to make something identical. If I give you this paper and ask you to duplicate it, it should come out looking exactly like this one. There is a word used for duplication of chromosomes in a cell that is replication. When I say DNA I mean the chromosomes in the nucleus they must replicate.* Line 8: *So in a human cell which has 46 chromosomes after duplication it must have how many?* The class as a whole said *'92'*. Line 9: Lily described replication on the chalkboard for learners to copy: *A human cell has 46 chromosomes. Before the cell divides each chromosome makes a copy of itself. They replicate. In humans there are 92 chromosomes in a nucleus of a cell that is about to divide.*	**CK:** An analogy of paper photocopying was used to illustrate duplication of chromosomes during mitosis (line 7), but the teacher did not explain the analogy to enhance learners' comprehension. CK: Lily stated clearly that duplication occurs in all chromosomes in a dividing cell showing the relationship between chromosomes and mitosis (line 7). **CK**: Lily's content knowledge was used to explain the term duplication correctly (line 7). **PK:** The questioning technique was used to assess learners' comprehension of duplicate (line 8). **CK:** Lily describe duplication of chromosomes resulting in a human cell with 92 chromosomes instead of 46 chromosomes each consisting of two chromatids. Not using the term 'chromatids' might make learners unable to differentiate between a chromosome and chromatid (lines 8–9)
Stages of mitosis Line 10: Referring to a diagram on a handout that she had given learners to read as homework, Lily described the stages of mitosis, writing brief notes about each stage on the chalkboard for learners to copy. She said: *The actual process of mitosis occurs in stages. Avoid using the names of the stages given in the handout because they are not*	**PK**: Lily described the stages of mitosis without involving learners (lines 10–11) **PK**: A diagram on a handout was used to illustrate the stages of mitosis (line 10).

required by the syllabus. Just use stages 1–4. Line 11: *After duplication of chromosomes has occurred, the cell is ready to divide (refer to interphase stage on the handout).* Stage 1 (refer to late prophase on the handout): *The chromosomes become short and fat, so they can be seen with a light microscope.* Stage 2 (refer to metaphase on the handout): *The nuclear membrane has disappeared. All chromosomes are arranged at the centre of the spindle to ensure that when they separate they do so in an orderly manner.* Stage 3 (refer to anaphase on the handout): *The chromosomes now separate. They go to opposite ends. One set of the chromosomes, half, is pulled by the spindles to one end and the other half goes to the other end.* Stage 4 (refer to telophase on the handout): *Re-appearance or formation of a nuclear membrane around each set of chromosomes and the cell eventually divides into two cells. In humans each new cell formed has 46 chromosomes.* After describing the stages of the process of mitosis Lily gave learners classwork.	**PK:** Lily advised learners on what to focus on based on the requirements of the syllabus (line 10). **CK:** Lily used her content knowledge to describe how the process of mitosis occurs (line 11). **CK:** A familiar example 'human being' was used to enhance learners' comprehension (line 11 stage 4).
Classwork Line 12: Lily assigned learners classwork in which they were required to work in pairs to *identify stages 1, 3, and 4 from six photographs taken at various stages through the process of mitosis in a plant cell* that were not in any particular order and to *describe two important changes that chromosomes must undergo before cell division can take place.* Line 13: Lily walked around the class to monitor the learners and mark their work. Most learners were able to identify the stages. For the few learners who had difficulty, Lily insisted they read the notes to help them identify the stages.	**PK:** Written classwork was used to assess spontaneously how well learners had grasped the process of mitosis (line 12). The assessment was meant to provide immediate feedback on the learners' grasp or otherwise of the concept of mitosis. **PK:** Lily monitored and analysed learners' responses to classwork on mitosis to ascertain how well the learners were responding to the questions and give them feedback on their responses (line 13).
Class discussion of classwork Line 14: Lily remarked: *Okay even though some of you had difficulty at the beginning but almost all of you now got the stages right* and then asked the class: *which diagrams are showing stages 1, 3 and 4?* The class as a whole *'f, d, and b'*. *Okay let us move on,* Lily said.	**PK:** Revision of classwork was used to rectify learners' mistakes (line 14).
Meiosis Line 15: Lily introduced meiosis by saying: *Now we are moving on to another type of cell division, which is meiosis.* Line 16: Lily described meiosis on the chalkboard for learners to copy: *Meiosis occurs in sex organs called gonads which are organs producing gametes or sex cells,*	**PK**: Lily introduced meiosis without finding out learners' preconceptions (lines 15, 16). **CK**: Lily described meiosis by

the sperm and egg cells containing half the number of chromosomes. In humans it occurs in testis and ovaries. The mother cells that produce the gametes have the same number of chromosomes as other somatic cells which is 46 in humans.	stating facts (line 16).
Meiosis 1 Line 17: Lily then described the stages of meiosis. *Like in mitosis the chromosomes must replicate. In humans the mother cell carries 92 chromosomes after replication. The cell is now ready to divide. Meiosis occurs in two phases, meiosis 1 and meiosis 2. During meiosis 1 two cells are produced. In the cells chromosomes are halved. The daughter cell carries 46 chromosomes in humans.*  **Figure 4.2.4: Illustration of meiosis 1** Line 18: *If you look at this diagram* (Figure 4.2.4), *you can see that there is first replication of chromosomes. The chromosomes separate to form two cells, which have half the number of chromosomes.* **Meiosis 2** Line 19: Lily explained that in meiosis 2, each of the two cells resulting from meiosis 1 (with 46 chromosomes) *undergo four stages similar to those of mitosis* and used Figure 4.2.5 to summarize meiosis 2.  **Figure 4.2.5: Illustration of meiosis 2** Line 20: Lily asked the class, *So all in all, how many cells*	**CK:** Lily again did not use the term chromatids in her explanation of replication of chromatids (line 17). **CK:** Lily's content knowledge was used to describe the first division of meiosis without indicating that homologous chromosomes and not chromatids separate at this stage (line 17). **CK**: A diagram on the chalkboard was used to represent meiosis 1 (line 17). **CK**: Lily used her content knowledge of meiosis to describe the process inaccurately (line 18). **CK:** A diagram drawn on the chalkboard was used to illustrate how meiosis results in haploid nuclei (line 19). **PK**: The questioning technique was used to assess learners' comprehension of meiosis (line 20).

have been formed? Two or four cells? The class as a whole said '*Four'*.	
Homework Line 21: Lily gave learners homework to *draw a table to compare mitosis and meiosis*.	**PK:** Homework assignment was the usual strategy used by Lily to assess learners' grasp of the concepts mitosis and meiosis (line 21).

4.5.2.2 Summary of Lily's lesson observation analysis

Lily demonstrated during the observed lessons that she had the necessary content knowledge to teach aspects of the genetics concepts at high-school level. She taught the genetics concepts, starting with the basic hereditary structures of chromosomes, genes and alleles. She provided factual information about the structure and function of chromosomes, genes and alleles, using her declarative content knowledge (ref. 4.5.2.1 first lesson observation lines 30, 32). She also described the relations among these concepts, indicating the differences by stating the facts. Lily used diagrams sourced from the Internet or drawn on the chalkboard to help learners visualize the structure of chromosomes and the relationship between chromosomes and genes (ref. 4.5.2.1 first lesson observation lines 18, 27). Familiar examples of physical features or phenotypic traits controlled by genes, such as complexion and nose shape, were used to enhance learners' comprehension of genes (ref. 4.5.2.1 first lesson observation lines 24, 28).

After dealing with the basic structures, Lily taught the concepts of mitosis and meiosis. She began by establishing why these processes were important (ref. 4.5.2.1 second lesson observation line 3) which might make learners find a reason to learn about them. She described how the processes occur, using her content knowledge of the stages, which is termed procedural knowledge in this study. An analogy of paper photocopying was used to explain the replication of chromosomes during mitosis and meiosis. However, Lily did not explain in what way the analogy was similar to the replication of chromosomes. To illustrate the process of meiosis, Lily drew diagrams on the chalkboard. Overall, Lily's content knowledge consists of three dimensions: declarative, procedural and conditional content knowledge.

Sometimes learners' unsatisfactory responses to classwork and homework questions – such as their incomplete definitions of a chromosome and a gene (ref. 4.5.2.1 first lesson observation lines 29–30) – were corrected by the teacher using her content knowledge, which is referred to here as declarative knowledge. Other inaccurate responses such as stages of mitosis (ref. 4.5.2.1 second lesson observation lines 12–14) were corrected by the teacher using procedural knowledge.

Concerning pedagogical knowledge, Lily began her inheritance lesson by using the questioning technique to discuss the familiar situation of family resemblance, which might enhance the lesson's relevance and arouse learners' interest. Familiar situations such as DNA testing to determine the paternity of a child (ref. 4.5.2.1 first lesson observation line 20) and replacement of severed human body cells (ref. 4.5.2.1 second lesson observation line 6) were also used in her descriptions of chromosomes and the importance of mitosis.

Other instructional strategies employed by Lily included written classwork and homework to assess how well learners had understood the lessons (ref. 4.5.2.1 first lesson observation line 29; second lesson observation lines, 14, 24). During classwork, learners worked individually or in pairs. Working in pairs promoted learner-to-learner interactions.

With regard to knowledge of learners' preconceptions and learning difficulties, Lily became aware of learners' inaccurate conceptions and learning difficulties such as incomplete definitions of chromosomes and genes through marking their responses to classwork (ref. 4.5.2.1 first lesson observation line 29; second lesson observation line 12-13). She assigned learners to read the relevant chapter in their textbook for homework and to answer questions about the concepts to be taught prior to the lesson on mitosis and meiosis. Marking homework prior to the lesson gave her opportunities to identify learners' misconceptions and difficulties, which she used as starting-off points in teaching the new concepts. Lily attempted to address learners' difficulties through engaging with individual learners during monitoring classwork and collective class discussions during review of classwork and homework.

Lily's PCK of genetics teaching can be construed as consisting of declarative, procedural and conditional content knowledge, and the use of familiar situations and examples, and

diagrams. Her knowledge of learning difficulties was derived during the teaching of the lessons from analysing and correcting learners' classwork and homework.

4.5.3 Case 3: Leon

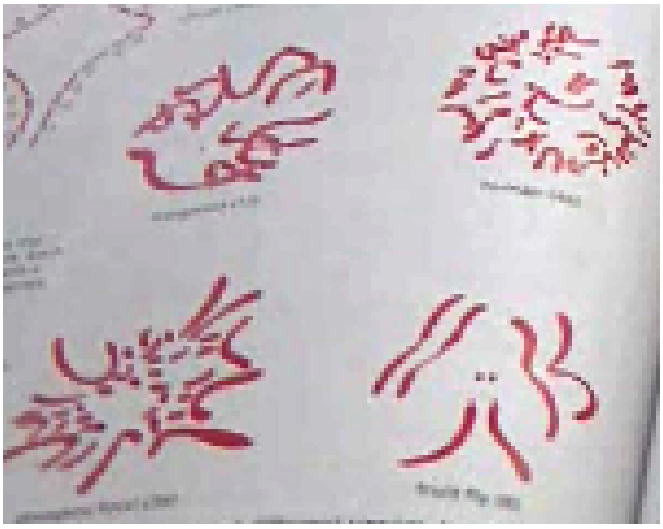
4.5.3.1 Leon's lesson observation analysis

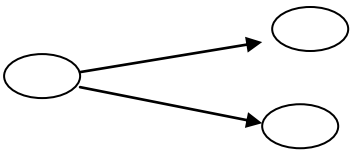
Two lessons of 60-min duration (2x30) were observed on two separate classroom occasions, in which the concepts of chromosomes, genes, mitosis and meiosis were taught. The analysis begins with a brief description of the classroom context, followed by the teacher's classroom practice, as categorized. The teacher's voice and learners' responses are presented in italics.

Table 4.4: Leon's lesson observation analysis

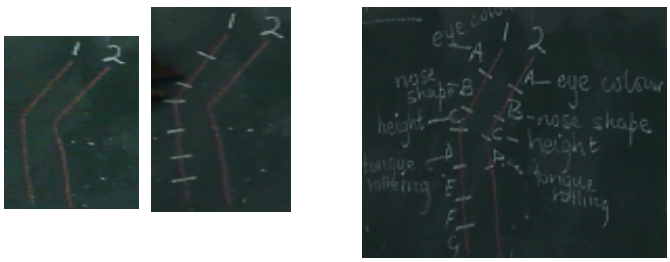
Description of lesson	**Categorization/themes**
Classroom context Leon taught in an urban girls' school. His biology class consisted of 25 learners. Biology classes were always taught in a well-ventilated standard conventional science laboratory with running water. Even though some lights were faulty, there was enough light in the room. The laboratory had locks and burglar bars for supervised entry. Learners were spaced out and seated comfortably on individual stools, sharing workbenches. The workbenches were arranged in rows and columns with plenty of space for teacher movement between rows and columns. All learners had biology textbooks and notebooks to write in.	**Comments** The classroom environment provided a safe learning environment for girls. Learners had textbooks and notebooks.
Lesson one topic: Inheritance, chromosomes and cell division **Class**: Grade 11 **Length**: 60 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: Leon began his lesson by announcing the lesson's topic to the class while he spelled it out on the chalkboard 'inheritance'. He continued, *First of all let's start with some facts. All of us here as individuals have features similar to our parents. Isn't it? People always tell you so and so looks like their father or so and so looks like the mother. You have heard of such?* Line 2: Learners responded as a class with a *'Yes'* Line 3: Leon continued: *Each and every offspring of every organism does resemble the features that are found in its parents. So that is why you have features that are similar to your father and you have features that are similar to your mother. So we could say that all offspring have features from the parent. That is one fact.* Line 4: Leon continued: *In your family you have brothers and sisters. Isn't it?* Line 5: The class as a whole said *'Yes'*. Line 6: Leon went on. *Although your brothers or sisters and you have got features similar to those of your parents, would*	**Pedagogical knowledge (PK)**: As his teaching strategy, Leon used the questioning technique in a familiar context to arouse interest and engage learners on a new topic of inheritance (lines 1–9). However, his questioning technique was whole-class directed, eliciting chorus responses from learners, which is ineffective.

you say you look exactly like them? Line 7: The whole class answered *'No'*. Line 8: Leon went on. *It means although you are coming from the same mother and same father you have inherited different features from your parents. And then offspring from same parents may also differ. If I may ask do you look exactly like your mother? Do you look exactly like your father?* Line 9: The whole class responded *'No'*.	
Inheritance Line 10: Leon defined inheritance: *What is this inheritance?* Without waiting for a response from his class he said: *Inheritance is the transmission or passing on of features from your parents to you. In other words the things that you look like e.g. small ears.* **Example of inheritance** Line 11: Leon provided a familiar example from Swazi culture of a girl impregnated out of wedlock. *In Swazi culture when a man impregnates a young girl out of wedlock what is the procedure that has to be followed?* One girl answered spontaneously, *'Kubikwa sisu'* [The impregnated girl is accompanied by an elder woman to report the pregnancy to the man's family]. The teacher explained that during that visit, the man's family would not easily accept the pregnancy but normally responds by saying *'Siyobona ngemtfwana'* [The family can only accept it when they have seen the baby]. *So when the baby is born the girl has to take the baby to the man's family. On that day the family calls elders to come and observe the features of the baby if they do in any way resemble the family. After that the family members give a verdict whether the child belongs to the family or not.*	**PK:** Leon used the questioning technique in an attempt to find out learners' ideas about 'inheritance' but his technique was whole class with no wait-time for learners to respond. Thus, it was ineffective in eliciting learners' ideas about the concept (line 10). **Content knowledge (CK)**: Leon's content knowledge was used to define inheritance (line 10). **CK:** Leon used a familiar example perhaps to show how the concept of inheritance is applied in Swazi culture (line 11). **PK:** Leon used the mother-tongue language to promote learners' comprehension of inheritance (line 11).
Chromosomes Line 12: After the example, Leon introduced the concept of chromosome by reminding learners about fertilization. He said, *For us to understand how features are transmitted from parents to offspring let's start where life starts. Where does life start? Wacalaphi wena?* [Where did you start?] Without waiting for a response from his class he continued, *It basically starts with fertilization whereby a male gamete from your male parent fuses with the gamete from your female parent in the form of an ovum forming one cell which is referred to as a zygote. Every person started as one cell, a zygote.* Line 13: Leon continued. *Now if life starts as one cell and everything that happens in the cell is controlled by the nucleus then what is it that is there in the nucleus causes this cell to develop into a human being that is you?* Without waiting for an answer he went on, *So in the cells of organisms are certain structures that are known as chromosomes. Chromosomes are not visible under the ordinary microscope only at certain*	**PK:** Leon introduced chromosomes using genetics content knowledge by reviewing previous concepts, namely fertilization and cell (lines 12, 13). **PK:** Again Leon used questions directed at the whole class with no wait-time for learners to respond (lines 12–13). **CK:** Leon's content knowledge was used to review the different genetics concepts of nucleus and cells, which led to the correct description

times. They actually look like tiny threads within the cell and are made up of DNA. It is in these chromosomes where you find the instructions if I may put it like that, the factors, the plan or the information as to what a person will look like.	and explanation of chromosomes (line 13). **CK:** Leon described the structure and function of chromosomes by stating facts (line 13).
Examples of chromosomes Line 14: Leon referred learners to diagrams of chromosomes from different species of animals in their textbooks.  **Figure 4.3.1: Chromosomes of different animal species** Line 15: Leon asked learners to state the chromosome number for each animal. Together with the teacher they stated how many chromosomes each animal has in a cell: e.g. kangaroo (12), human being (46), domestic fowl (36) and fruit fly (8). Line 16: Leon explained chromosome number. *Now there is something about these chromosomes in that each species has a specific number of chromosomes in its cells. You will notice that the chromosome number of each specific organism is an even number. This number of chromosomes is referred to as the diploid number of chromosomes denoted as 2n. So the number of chromosomes for me and you is 46.*	**CK:** Leon used examples of chromosomes in the form of diagrams from the learners' textbooks to illustrate chromosomes and enhance comprehension (lines 14–15). **CK:** Leon's content knowledge was used to explain chromosome number and diploid (line16).
Cell division (mitosis and meiosis) Line 17: Leon introduced cell division by reminding learners of how organisms grow. *Now we have already seen how life starts as one cell and what is it in this one cell that eventually results in the features that are shown by the offspring after it is born. Now after life starts as one cell how does it then proceed from one cell to the whole organism?* Without waiting for a response from the learners, as he was wont to do, he continued, *As a human being you start as one cell the cell divides into two cells, two cells divide into four cells. The cells continue dividing and start forming tissues, organs eventually resulting in a human being who after nine months comes out as an*	**PK:** Leon introduced the types of cell division without once again trying to elicit learners' preconceptions of cell division (line 17). He used his poor questioning technique repeatedly. **CK:** Leon's content knowledge was used to describe the growth of a cell into an organism (line 17).

individual. The cell does so by what we refer to as cell division. There are two types of cell division which are mitosis and meiosis. I want us to look at these two types of cell division. Let's start with mitosis. Mitosis Line 18: Leon said, *Mitosis is the type of cell division that is used by all ordinary cells. We refer to such cells as somatic cells. All somatic cells are diploid numbered. For example in human beings if you take any cell from the skin it will have how many chromosomes? 46* [learners together with teacher]. *If you take any cell from the tip of your toe it will have 46* [teacher] *you take it from the liver? It will have 46 chromosomes* [teacher]. Line 19: Leon likened mitosis to photocopying. *Now mitosis is like photocopying in that what is produced during mitosis is genetically similar or same as parent cell.* Line 20: Leon drew a circle on the chalkboard representing a cell and drew two others using arrows to show that they were from the first cell. He labelled the first cell the parent cell and the two resulting cells as daughter cells.  Parent cell daughter cells **Figure 4.3.2: Illustration of the process of mitosis** Line 21: *The daughter cells have the same number of chromosomes as the parent cell which is 46 in a human being. As a result, during mitosis what is produced is an exact duplicate of the previous parent cell which is why I was saying that mitosis is similar to photocopying.*	**PK:** Leon described the process of mitosis without finding out learners' preconceptions of mitosis (lines 18). **CK**: Leon used his content knowledge to state the site of mitosis (line 18). **CK**: Leon used an analogy of the process of photocopying to illustrate the process of mitosis (lines 19, 21). But he did not explain the shared and unshared attributes between the analogy and targeted concept. **CK:** Leon used a diagram drawn on the chalkboard to illustrate the product of mitosis being two cells identical to the original cell (line 20). **CK**: Leon's content knowledge was used to describe correctly the number of chromosomes in parent and daughter cells (line 21).
Example of mitosis Line 22: Leon explained how identical twins are formed as an example of mitosis. *Some people get identical twins. How does it happen?* Without waiting for a response from the class he continued, *This is how it happens the first division from the zygote is a very delicate one. Normally when the zygote cell divides the cells remain attach to each other so that as the division continues they form a ball of cells. Sometimes during this first division of the zygote the two cells that are produced completely separate. When that happens each cell develops into a new individual. That is how then we get what we call identical twins.*	**CK**: A familiar example of identical twins was used to help learners comprehend mitosis (line 22).
Meiosis Line 23: Leon then described meiosis: *The second type of cell*	**PK**: Leon described

division, which is called meiosis, is only used under special circumstances, which are during the formation of gametes. By gamete, remember we are referring to for an example the sperm or ovum. Now the major difference between the two types of cell division is whereas mitosis is the exact duplication of cells where both the parent and daughter cells have the diploid number of chromosomes, in the case of meiosis the chromosome number is halved. So when the gametes are formed the gametes will have half the number of chromosomes. And this number of chromosomes that is found in gametes is referred to as the haploid number. The haploid number is denoted with 'n' because diploid is '2n'. Line 24: Leon then described the significance of meiosis. *Now why is meiosis necessary? Why is it necessary that the chromosome number is halved during meiosis?* He asked, directing the question to an individual learner. Line 25: The learner kept quiet and Leon went on without reacting to the learner's silence. *We have said that the uniqueness of each species lies in the number of chromosomes they have. Human beings are unique due to the fact that in their cells they have 46 chromosomes. A change in this number results in something different as you are going to see later on in this unit. A mistake can happen during cell division where by a person ends up having 47 chromosomes. Such a person suffers the condition known as Down Syndrome.* Line 26: Leon assigned learners to read about Down Syndrome. Line 27: *So we can say meiosis is necessary in order to maintain our chromosome number. Each gamete will have 23 chromosomes in the case of human beings so that when fertilization takes place the sperm will contribute 23 and the ovum 23 as well. This will result in 46 chromosomes and it is the 46 chromosomes that make it a human being. Am I clear there?* Line 28: The class as whole responded *'Yes'.* Line 29: Leon ended the lesson by telling learners next time they would look more into the terms used in genetics.	meiosis without finding out learners' preconceptions (line 23). **CK**: Leon's content knowledge was used to describe the purpose of meiosis (line 23) **CK**: Leon used his content knowledge to describe how mitosis was different from meiosis (line 23). **PK:** The questioning technique was used to direct a question about the significance of meiosis to a learner (line 24). **CK:** Leon used his content knowledge to explain why meiosis is important (lines 25–27). **PK**: Leon summed up his explanation posing a question to the whole class eliciting a chorus response (lines 27–28) which did not help him know who knew and who didn't.
Lesson two topic: Chromosomes and genes **Class:** Grade 11 **Time:** 60 minutes	
Observation	**Categorization/themes**
Lesson introduction Line 1: Leon began his lesson on chromosomes and genes by reviewing the previous lesson on chromosomes and cell division.	**PK:** Leon introduced the lesson by providing a summary of the previous lesson (line 1).
Line 2: Leon introduced the new topic, *Before we look at how features are transmitted from parents to offspring let us familiarize ourselves with some of the genetics terms.* Beginning with a description of homologous chromosomes, he said, *Now chromosomes in a cell exist in pairs. In the case of human beings the diploid number of chromosomes is 46 and there are 23 pairs of chromosomes. Now each chromosome in*	**PK**: Leon introduced the term homologous chromosomes without finding out learners' preconceptions (line 2). **CK**: Teacher content knowledge was used to

each pair is similar to the other in shape, in size, and most importantly the genes that are found in those particular chromosomes. Such a pair of chromosomes is called homologous chromosomes. 'Homo' when used as a prefix anywhere in biology means 'same'. Line 3: Leon referred learners to a diagram in the textbook. *A diagram in your book shows chromosomes from four animals including human being. The one I want us to concentrate on is the fruit fly* (Figure 4.3. 3) *because in the fruit fly the chromosomes have been arranged in their respective pairs.*  **Figure 4.3.3: Chromosomes of a fruit fly** Line 4: *If we look carefully at the chromosomes of the fruit fly you will notice that there are 4 pairs of chromosomes. And you will see that in each pair one of the chromosomes looks like the other in its shape and size. We describe these pairs of chromosomes as homologous chromosomes.* Leon continued and described genes.	describe pairing of chromosomes using a familiar example (line 2). **CK**: Using a diagram in the learner's textbook Leon demonstrated his content knowledge of chromosomes in describing homologous chromosomes and explaining the prefix 'homo' (lines 3–4).
Genes Line 5: Leon then described genes. *In the chromosome you have what we refer to as genes. What is a gene?* Without waiting for a response from the class he went on, *A gene is a part of a chromosome and because chromosomes are made up of DNA it means that the gene is also made up of DNA. In each chromosome you may find many genes but one thing important about a gene is that a gene always controls one feature. Since chromosomes exist as homologous pairs genes also exist in pairs. Pair of genes control one trait.* Line 6: Leon drew diagrams on the chalkboard to illustrate genes on homologous chromosomes. *Let me say I take two chromosomes, 1 and 2* (Diagram a)  (a) (b) (c) **Figure 4.3.4: Diagrams showing genes on chromosomes** Line 7: *And let us say I take chromosome 1 and I break it down (*Diagram b). *Since a gene is part of a chromosome each of*	**PK**: Leon used the expository strategy to describe a gene without finding out learners' preconceptions (line 5). **CK**: Leon's content knowledge was used to correctly describe a gene by declaring facts (line 5). **CK:** Leon used diagrams drawn on the chalkboard to represent genes on homologous chromosomes and enhance learners' comprehension (line 6). **CK**: Familiar examples such as eye colour and nose shape were used to enhance learners' comprehension of genes (line 7). **PK:** Through questioning Leon used a familiar example to perhaps arouse interest (line 7).

these lengths or genes of the chromosome will control one feature. Let us think of some features that are found on human beings. Say in this position A is the gene controlling eye-colour (Diagram c) *and at position B there is a gene controlling nose shape. Can you think of any other feature which could be controlled by a gene at C? 'Height',* a learner responded voluntarily. *And there we have other genes at positions D–G. In reality you will find a chromosome with thousands of genes each controlling one particular feature. I am just using this as an example.* Line 8: *If we say the gene at position A of chromosome 1 controls eye colour of that particular organism in the same position of chromosome 2 you will also find a gene that controls eye colour because chromosomes 1 and 2 are homologous to each other. In position B there will be a gene controlling the nose shape and in Position C you will find the gene that controls height. So on and so forth throughout the length of that chromosome.* He located and labelled the same genes on chromosome 2.	**CK:** Leon demonstrated his content knowledge of genes as he explained the diagrams (lines 7–8).
Alleles Line 9: Leon stated that at times the two genes found on the same position on homologous chromosomes *control the same character but cause two opposite expressions of the feature they control*. He made learners do some activities demonstrating the effects of genes. Line 10: The first activity was tongue rolling. Leon said, *Let us take this example of tongue rolling. Some people can roll their tongue and others cannot. Let us take a quick survey and find out how many of us in this room are able to roll their tongue. When rolling your tongue do something like this* [he demonstrated tongue rolling by rolling his]. He allowed learners to try to roll their tongue one at a time, while he tallied those who could and those who could not on the chalkboard. The survey results showed that 21 learners could roll their tongues and 4 could not. After the survey he went back to diagram (c) on the chalkboard and located the genes for tongue rolling at position D of chromosomes 1 and 2. He then explained, *The results imply that there is a gene that enables some individuals to be able to roll their tongue. There is also a gene that makes other people not to be able to roll their tongue.* Line 11: Leon conducted two more activities in a similar way to the first one. The second activity was on 'clasping hands' where some people would naturally put the right thumb on top, while others would put the left thumb on top. The third activity was folding arms, where some people would put the right arm on top, while others put the left one on top.	**CK**: Leon used common examples such as tongue rolling, clasping hands and folding arms to illustrate genes causing different expressions of the same feature (lines 10–12). **PK:** The demonstration strategy was used to show learners how to carry out activities on alleles (lines 10, 11). All learners participated in the activities. **PK:** The learners were given instructions by the teacher to follow in carrying out each activity (line 10). Learners did the activities to confirm or prove known information.
Line 12: Leon used the three examples of tongue rolling, clasping hands and folding arms to describe the term 'allele'. He stated: *The examples prove that features are being controlled by genes, which exist in pairs. So there is a word*	**PK**: Leon used the expository method to describe alleles without finding out learners'

that we use in genetics. The word allele. Alleles are a pair of genes, which control one feature but cause different expressions of the feature. In the ability to roll the tongue some can and others cannot which means there is a gene that causes people to roll their tongues and another gene which makes others unable. Leon ended the lesson by telling them next time they would learn about other genetics terms such as heterozygous, genotype and phenotype.	preconceptions (line 12). **CK**: Leon demonstrated his content knowledge of genes by correctly describing alleles giving an example (line 12).

4.5.3.2 Summary of Leon's lesson observation analysis

During the observed lessons, Leon demonstrated that he had the necessary content knowledge to teach aspects of the genetics concepts at high-school level. He began his lesson on chromosomes, mitosis and meiosis by linking these concepts to previously taught concepts of cell and fertilization. He showed the associations between the new concepts and those previously taught. Leon taught chromosomes by stating the facts about their structure and function (ref. 4.5.3.1 first lesson observation line 13). The knowledge used for stating or declaring facts, which Leon used, is in this study designated declarative knowledge (Juttner et al., 2013). For mitosis and meiosis, Leon focused on their product and differences, which he taught using declarative knowledge. He followed the teaching of mitosis and meiosis with homologous chromosomes, genes and alleles. He stated the facts about the functions of these and described the relations among them, using mainly declarative content knowledge. Overall, Leon's content knowledge consists of declarative knowledge.

Leon used illustrations and familiar examples to help learners comprehend the genetics concepts. For instance, he utilized diagrams from the textbook to illustrate chromosomes and homologous chromosomes (ref. 4.5.3.1 first lesson observation line 14; second lesson observation line 3). He also used labelled diagrams drawn on the chalkboard to illustrate genes on homologous chromosomes (ref. 4.5.3.1 second lesson observation lines 8–9) to enhance learners' comprehension of genes. Familiar examples such as eye colour and nose shape were used to illustrate physical features controlled by genes (ref. 4.5.3.1 second lesson observation line 9) and features such as tongue rolling to illustrate the concept of alleles (ref. 4.5.3.1 second lesson observation lines 10–12). Leon also used the analogy of a photocopier to illustrate the process of mitosis (ref. 4.5.3.1 second lesson observation line 19). However, he did not explain his analogy to enhance learners' comprehension of mitosis. Treagust and Harrison (2000) emphasize that to make the analogy accessible to learners; teachers need to indicate the shared and unshared attributes between the analogy and target concept for their learners.

As his teaching approach to introduce the topic of 'Inheritance', Leon used a familiar context to arouse learners' interest and move from the known to the unknown. Leon adopted mainly a teacher-centred teaching approach in which the lecture method was used. He used the

demonstration strategy in carrying out activities about alleles (ref. 4.5.3.1 second lesson observation lines 10–12).

Leon appeared to lack knowledge of learners' preconceptions and learning difficulties. There was no evidence of knowledge of learners' preconceptions and learning difficulties prior to teaching. Nor did he elicit learners' preconceptions or identify learners' learning difficulties during the lessons observed.

From the observed lessons, it may be construed that Leon's overall PCK of teaching genetics included mainly declarative content knowledge, use of familiar situations, examples, and diagrams. There was no evidence of teacher's knowledge of learners' preconceptions and learning difficulties.

4.5.4. Case 4: Lillian

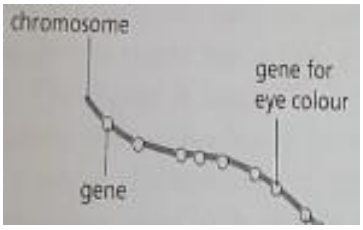
4.5.4.1 Lillian's lesson observation analysis

Two lessons of 70-min duration (2x35) were observed on two separate classroom occasions, in which the concepts of chromosomes, genes, mitosis and meiosis were taught. The analysis begins with a brief description of the classroom context, followed by the teacher's classroom practice, as categorized. The teacher's voice and learners' responses are presented in italics.

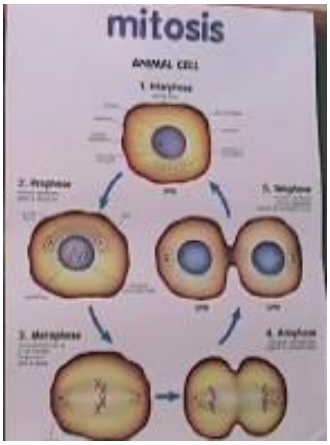
Table 4.5 Lillian's lesson observation analysis

Description of lesson	**Categorization/themes**
Classroom context Lillian's biology class was a mixed ability class of 49 learners: 31 girls and 18 boys. Her biology class was always taught in a standard conventional science laboratory, which was well ventilated and had running water and enough light. Learners sat on individual stools. They were a bit squashed as 4–6 learners of mixed gender shared a workbench. There was little space for teacher movement between columns and barely between rows. The laboratory had locks for supervised entry. All learners had biology textbooks and notebooks.	**Comments** The classroom conditions provided a safe learning environment for both boys and girls. Learners had textbooks and notebooks.
Lesson one topic: Inheritance, chromosomes and genes **Class**: Grade 11 **Time**: 70 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: Lillian began her lesson by announcing the topic. *Today our topic is inheritance. But before we move on we have to define inheritance. What do you think inheritance*	**Pedagogical Knowledge (PK):** Questioning technique was used to solicit learners' ideas about the term 'inheritance' (line 1).

is? In the absence of a response from learners she gave them an idea of inheritance. *If we say someone has inherited something, maybe at home from parents, what do we really mean by inheritance?* Line 2: Following the hint, learners responded as follows: Learner one: *'It is features or characteristics that are passed on from the parents' gametes or genes to kids or to the offspring.'* Learner two: *'It is the transmission of genetic material from one generation to another.'* Line 3: Without commenting on the learners' responses, Lillian defined inheritance on the chalkboard for learners to copy: *Inheritance is the transfer or transmission or passing on of genetic information from one generation to another leading to the continuity of life and variation within the species itself.*	**PK:** A familiar context was later used to help learners come up with the meaning of inheritance (line 1), which might arouse interest and promote the lesson's relevancy to learners. **Content Knowledge (CK)**: Lillian's content knowledge was used to correctly define the term 'inheritance' by stating the facts (line 3).
Example of inheritance Line 4: After giving the definition of inheritance, Lillian randomly asked learners to list physical features that were common in their families. *If you can reflect back at your families, you can find that there are characteristics or features which are common in your families. What are those features?* Learners responded as follows: First learner: *'Eyes'* Second learner: *'Ears'* Line 5: Lillian said *Okay* and reiterated the focus of the lesson. *In this lesson we are going to study the inheritance of the characteristics. How the genetic information is passed from one generation to another. We will start by looking at chromosomes.*	**PK**: Through questioning Lillian used familiar examples from learners' responses to enhance learners' comprehension and focus attention (line 4). Lillian failed to follow up on learners' responses (line 5).
Chromosomes and genes Line 6: Lillian continued. *Let's go back and look at the nucleus.* *During fertilization two gametes fuse to form an offspring. The gametes contain the nucleus. The nucleus contains chromosomes. The chromosomes carry the genetic information which are the genes. Is that clear?* Line 7: Lillian went on. *We will look at what a chromosome is and what are genes? You remember when we were looking at the cell structure using a light microscope. How did the nucleus appear?* The class as a whole said *'It was dark'*. The teacher said *yes* and continued. *So chromosomes in the nucleus are not easy to see unless a cell is dividing the reason being that when a cell divides chromosomes shorten and thicken. At this time they can be seen under the microscope.* Line 8: Lillian defined chromosomes and genes on the chalkboard for learners to copy. *A chromosome is a thread of DNA made up of genes found in the nucleus. Along a chromosome are a series of chemicals called genes. Within a chromosome you have several genes. A gene is a section*	**CK:** Lillian used her genetics content knowledge to review previous concepts, namely nucleus and fertilization, to link them to the new concepts of chromosomes and genes (lines 6). **PK:** Lillian used an effective questioning technique by posing an undirected question *'Is it clear?*', which demanded a chorus answer, to which learners did not respond (line 6). **PK:** Through the questioning technique Lillian connected new concept with what learners already knew (cell structure) (line 7). **CK**: Lillian used her content knowledge to connect

of DNA, which codes for the formation of a protein controlling a specific characteristic of the organism. Examples of characteristics controlled by genes can be eye colour, hair colour and tallness. Line 9: Lillian referred learners to a diagram (Figure 4.4.1) in their textbook showing the relationship between chromosomes and genes.  **Figure 4.4.1: Relationship between chromosomes and genes** Line 10: Lillian went on. *Each physical human characteristic is controlled by two genes one from each parent. Say, for instance, hair colour, one gene would come from the mother and another gene from the father. Is that clear?* Learners together said '*Yes*'.	chromosomes to the nucleus (line 7). **CK:** Lillian's content knowledge was used to define chromosome and gene by stating the facts (line 8). **CK:** Lillian used familiar examples such as eye colour and hair colour to enhance learners' comprehension of genes (line 8). **PK:** Lillian used a diagram from the textbook to help learners visualize chromosome and genes and the relationship between them (line 9). **PK:** Again, Lillian directed her question to the whole class, eliciting a chorus response from the learners (line 10), which was ineffective and did not help her learn who knows and who doesn't.
Line 11: Lillian continued. *Chromosomes exist in pairs and chromosomes which belong to a pair we call them homologous chromosomes. They look alike that is they are homo.* Line 12: Lillian copied the diagram from the textbook (Figure 4.4.1) on the chalkboard and added another similar chromosome to show a pair of homologous chromosomes. On the two chromosomes, she located genes for eye colour, height and hair colour as examples. Genes for the same characteristic e.g. eye colour were located on corresponding positions of the two chromosomes. Line 13: Referring to the diagram Lillian continued: *You find that on a pair of homologous chromosomes, you have genes which are found in the same position. If two genes are located on the same position it means they are controlling the same characteristic. The two genes may have different effects on that characteristic. We call them the alternative forms of the same gene. So then the alternative forms of the same gene we refer to them as alleles.* Line 14: Lillian gave examples of alternative forms of the same gene. *For example, you find that some people are short, others are tall, which means tallness is controlled by*	**PK**: Lillian introduced homologous chromosomes without finding out learners' preconceptions (line 11). **CK**: Lillian's content knowledge was used to define homologous chromosomes by providing facts (line 11). **CK:** Lillian used diagrams drawn on the chalkboard to illustrate the relationship between homologous chromosomes and genes (line 12). **CK:** Lillian demonstrated her content knowledge in explaining the diagrams showing the relationship among chromosomes, genes and alleles (line 13) **CK**: Lillian used her content knowledge to describe alleles (lines 13–14). **CK:** Familiar examples of different forms or variants of the same gene were used to help learners comprehend alleles

a gene for being tall or a gene being short. For eye colour, some people have blue eyes, others have brown eyes. What can you say about the hair colour? Individual learners gave different hair colours; *'Black, brown, grey and white'*. *Okay, this means there is a gene for black hair, a gene for brown hair, and so on.*	(line 14). **PK:** Through questioning Lillian used examples of hair colour from learners to enhance comprehension (line 14).
Line 15**:** A learner spontaneously asked a question '*Does it mean that the different sizes of rats are controlled by genes?*' Lillian responded: *There could be many factors, but the genes play a role in the size of the rat.* Another learner said *'I think the environment and the nutrients the rats have can make them different.'* Teacher said, *Yes, we will discuss that later*.	**CK**: Lillian's content knowledge was used to respond to learner feedback (line 15).
Homework Line 16: Lillian gave learners photocopies of homework in which they were asked to label parts of a sperm cell, and define the concepts chromosome and gene. She also instructed them: *Read about what we have looked at, chromosomes and genes. Also tomorrow we will look at mitosis and meiosis, so read pages … in your books.*	**PK**: Lillian used homework assignment as a strategy to assess learners' comprehension of taught concepts of chromosomes and genes. She also used the strategy of reading the topic beforehand to introduce mitosis and meiosis (line 16).
Lesson two topic: Mitosis and meiosis **Class:** Grade 11 **Time**: 70 min	
Observation	**Categorization/themes**
Lesson introduction Line 1: After handing out marked photocopies of homework one at a time, Lillian began the lesson by reviewing homework. In doing so, she drew learners' attention to questions where some learners made mistakes and corrected them. For example, she said: *Some of you wrote a chromosome is a thread-like structure. But because you already know that the structure is DNA you should be specific. So define a chromosome as a thread of DNA made up of genes. You should define a gene as a section of DNA which codes for the formation of single protein, controlling a specific characteristic of the organism.*	**CK:** Lillian's content knowledge was used to identify learners' inaccurate conceptions of chromosome and gene as well as to respond to learner feedback (line 1). **Learners' preconceptions and learning difficulties**: Marking homework gave Lillian an opportunity to identify learners' inaccurate conceptions e.g. 'a chromosome is a thread-like structure' (line 1). **PK:** Review of homework was used as a strategy to try to address learners' mistakes (line 1).

Mitosis Line 2: After the review of homework, Lillian reminded learners: *Last time we discussed chromosomes, genes and alleles.* Line 3: She announced the day's topics. *Today we are going to look at cell division. How does the cell divide? Cells can divide in two ways by mitosis or meiosis. We will look at what happens in chromosomes during mitosis and meiosis. Let's start with mitosis.*	**PK:** Lillian linked previous concept 'chromosomes' to processes of cell division (lines 2–3). **CK**: Lillian used her content knowledge to name types of cell division and connect new concepts to chromosomes a previously learned concept (line 3).
Line 4: Lillian defined mitosis as *a method or a process that involves the replication or duplication of chromosomes resulting in identical daughter nuclei or daughter cells.* Line 5: She put a chart on the chalkboard (Figure 4.4.2) showing the process of mitosis in an animal cell.  **Figure 4.4.2: Mitosis in an animal cell** Line 6: She told learners: *As you can see on the chart mitosis occurs in stages. We have interphase, prophase, metaphase, anaphase, and telophase; but it is not important to memorize the names of the stages because it is not required by the syllabus.*	**CK**: Lillian's content knowledge was used to define mitosis (line 4). **CK**: Lillian used a chart (Figure 4.4.2) to illustrate the process of mitosis and help learners visualize it (line 5). **PK**: Lillian advised learners about what to focus on based on the biology syllabus requirements (line 6).
Line 7: Some learners complained that they could not see clearly from the chart. Lillian occasionally made enlarged sketches from the chart on the chalkboard. She described the stages of mitosis without using the specific names for them: Stage 1 *In the first stage we have a nucleus and inside the nucleus are the chromosomes. At this stage the chromosomes are long and thin.* Stage 2 *Before a cell divides, chromosomes shorten and become thicker so that one can see them under the light*	**CK:** Lillian's content knowledge was used to describe the stages of mitosis based on the chart (line 7). She used her content knowledge of the stages to describe how the process of mitosis occurs. **CK:** Lillian also used diagrams indicating teacher acceptance of learners' views about teaching (line 7).

microscope. This means 'abamafisha abesidudla' [vernacular used to mean short and fat]. Stage 3 *At this stage a chromosome appears as two chromatids. When that occurs the nuclear membrane begins to disappear. And likewise the spindles form between the two poles of the cell.* Stage 4 *The chromatids start to divide at the centromere. When the chromatids separate, one chromatid will move to one pole and the other chromatid moves to the other end. Is that clear? So then in this way we have duplication of what? Multiplication of what? Of the cells. Is that clear?* Learners did not respond. Stage 5 *When cell division is completed, it gives rise to new cells, each containing the same number of chromosomes as the parent cell. The number of chromosomes is maintained the parent cell is diploid and daughter cells are diploid. When cell division is complete you have two daughter cells which are formed. Cells which are involved in the mitotic division we call them somatic cells. Is that clear?* The class as a whole said *'Yes'*.	**PK**: Code switching was used to describe change in chromosomes to enhance comprehension of the process (line 7 stage 2) **PK**: Lillian posed a question to the whole class '*Is it clear?*' (line 7 stage 4). She used that technique consistently. **PK**: Lillian again summed up a question directed to the whole class eliciting a chorus answer (line 7 stage 5)
Line 8: Lillian stated the site and importance of mitosis in both plants and animals. *Mitosis occurs in plants and animals. It takes place in parts of the organism which produce new cells for growth or replacement of worn-out cells. In animals it usually occurs in the bone marrow where there is a production of new blood cells and in the skin. In plants it occurs in the root tips. Roots are the sites of cell division and cell elongation. It also occurs in the stem which results in the enlargement of the width of the stem and in the fruits which results in enlargement of fruit. It that clear?* Learners as a class responded *'Yes'*.	**PK:** Lillian stated the importance of mitosis without determining learners' ideas (line 8). **PK**: Again Lillian summed up her description of mitosis by posing a question to the whole class and learners responded in a chorus (line 8). **CK:** Lillian's content knowledge was used to state where mitosis occurs in plants and animals (line 8).
Line 9: The bell rang, marking the end of the period and Lillian told learners, *We will talk about meiosis next time.* Time might have been wasted during handing out learners' marked homework.	**PK:** Lillian could not finish her planned lesson (line 9) probably due to lack of time or time management particularly at the beginning of the lesson when handing out learners' exercise books.

4.5.4.2 Summary of Lillian's lesson observation analysis

During lesson observation, Lillian demonstrated that she had the necessary content knowledge to teach aspects of the genetics concepts at that grade level. She began by teaching the basic genetics concepts of chromosomes, genes and alleles. She used her content knowledge to connect the new concepts chromosomes and genes to related concepts taught previously, cell structure and fertilization, to help learners see the associations among them (ref. 4.5.4.1 first lesson observation line 6). She defined chromosomes, genes and alleles by stating the facts about attributes such as function, using her declarative content knowledge (Juttner et al., 2013). For the more difficult notions of the relationship among chromosomes and genes, Lillian used diagrams sourced from the textbook to help learners visualize chromosomes and genes, as well as the relationship between them. To enhance learners' comprehension of genes, she used familiar examples such as eye colour and hair colour (ref. 4.5.4.1 first lesson observation line 11).

Learners' sometimes unsatisfactory responses to homework questions – such as their incomplete definitions of a chromosome and a gene (ref. 4.5.4.1 second lesson observation lines 1) – were corrected by the teacher using her content knowledge, which is referred to here as declarative knowledge.

Lillian followed the teaching of chromosomes, genes and alleles with the processes of cell division. For mitosis, she described how the process of mitosis occurs, using her knowledge of the stages of the process, that is, how they work, which in this study may be termed procedural knowledge (Juttner et al., 2013). Lillian displayed a chart showing mitosis in an animal cell to illustrate the process in order to help learners to visualize how chromosomes replicate and separate, resulting in two daughter cells, identical to the parent cell (ref. 4.5.4.1 second lesson observation line 4). She concluded her teaching of the process of cell division by stating why the process was important for organisms (ref. 4.5.4.1 second lesson observation line 8). Overall, Lillian's content knowledge consisted of declarative, procedural and conditional content knowledge.

With regard to pedagogical knowledge, Lillian adopted mainly the didactic 'chalk and talk method'. Such a teaching strategy almost always assumes that learners come to class with *tabula rasa* minds to be filled with information as established facts. Occasionally a

questioning technique was used to seek examples from learners (ref. 4.5.4.1 first lesson observation lines 1, 4, 7, 13). Homework assignment and its review were other instructional strategies employed by Lillian.

Pertaining to knowledge of learners' preconceptions and learning difficulties, there was no evidence that Lillian considered learners' preconceptions of the genetics concepts to be taught prior to the lesson and during the lesson observations, she did not find out learners' preconceptions of chromosomes, genes and mitosis. She identified learners' learning difficulties, such as incomplete definitions of chromosome and gene, while marking homework. She tried to address learners' difficulties by reviewing homework with the class.

Overall, Lillian's PCK profile of genetics teaching consists of declarative, procedural and conditional content knowledge, the use of familiar situations, diagrams and charts. She appeared to lack knowledge of learners' preconceptions and her knowledge of learning difficulties was derived through marking learners' homework assignments.

4.6 Post-teaching teacher questionnaire

A post-teaching teacher questionnaire (Appendix D) sought information on teachers' pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties.

Pedagogical knowledge

In the questionnaire (Appendix D items 1and 2) participating teachers were asked to describe and explain with reasons the instructional strategies and classroom activities that they used in teaching the observed genetics lessons. Lucy stated that she used the questioning technique to 'assess learners' prior knowledge' and learners' comprehension of what was taught and, second, prior to the lesson she had given her learners the relevant chapter in the textbook to read as homework and to prepare physical models of chromosomes and genes. This homework assignment was meant to act as an advance organizer to help or facilitate learners' comprehension before the lesson was taught. Lucy indicated that she used the learner presentation (peer teaching) strategy to find out their misconceptions about what was to be taught. Lily and Lillian indicated that they used an approach that would help the learners to visualize chromosomes and genes because as Lily wrote: 'Genes and chromosomes are too abstract and learners need aids to visualize them' (Appendix W). To this end, she taught the

concepts using diagrams from the textbook and pictures of chromosomes projected from a data projector. Lily said she used the questioning strategy to discuss the familiar situation of 'resemblance in the family' to introduce the topic of inheritance as well as classwork and homework to assess learners' comprehension of what had been taught. Homework was also used as a pre-activity. Lily wrote that since her learners had difficulty in answering some of her questions on chromosomes and genes, prior to the lesson on mitosis and meiosis she decided to give her learners the relevant chapter in the textbook to read as homework and to answer questions on the topics. The homework exercise was meant to act as an advance organizer to expedite learners' comprehension before the lesson was taught. Leon, on the other hand, wrote that he used several instructional strategies, namely teacher questioning, chalk and talk (lecture), and teacher demonstration, because 'they are quicker regarding the available time and easier to use' (Appendix W).

The teachers' answers suggested that they employed various instructional strategies to teach genetics, namely questioning, use of illustrations, homework and classwork assignments, teacher-centred chalk and talk, and teacher demonstration. The choice was based on the advance organizer to promote meaningful learning, visualizations of microscopic genetics concepts, and to cover the syllabus content in the available time.

Knowledge of learners' preconceptions

The questionnaire (Appendix D item 3) sought the participating teachers' knowledge of their learners' preconceptions, if any, about the genetics concepts taught. Lucy wrote that she expected learners to know the differences between sexual and asexual reproduction, and that chromosomes are found in the nucleus (Appendix X). Lily said she expected learners to know about resemblance in the family, fertilization, and DNA. Lillian said she assumed learners would know the functions of the nucleus, reproduction, inheritance and somatic cells. Leon wrote that he believed learners would know about sexual reproduction in humans, the structure and function of a cell, and inheritance. All their responses indicated that they presumed learners would have previous knowledge about biology topics they were taught, namely cell structure, reproduction and fertilization, as well as ideas about inheritance. But what was required was the knowledge the learners had of the concepts to be taught before they learned them. The responses imply that the teachers have no knowledge of learners' preconceptions in genetics teaching, despite their many years of teaching the topic.

The next question was about finding out learners' preconceptions, if any, which they brought to the genetics lessons (Appendix D item 4). Leon claimed that he used the questioning technique to find out learners' prior knowledge of chromosomes, genes, mitosis and meiosis. This was inconsistent with lesson observation (ref. 4.5.3 first lesson observations line 13, 17–18, 23), in which Leon defined chromosomes, mitosis and meiosis without finding out learners' ideas about those concepts. In teaching about the gene for instance, Leon asked learners 'What is a gene?' (ref. 4.5.3. second lesson observation line 5), but there was no wait-time for learners to respond. His questioning technique was ineffective in eliciting learners' preconceptions. Lillian wrote that she found out learners' preconceptions through the questioning technique. This was also inconsistent with lesson observation (ref. 4.5.4 first lesson observations lines 7–8), in which Lillian taught about chromosomes and genes without finding out learners' preconceptions about them. Her homework assignments were about taught concepts. Lucy claimed she used probing questions to find out whether learners had preconceptions about chromosomes, genes, mitosis and meiosis. During lesson observation (ref. 4.5.1 first lesson observation lines 16, 21, 29–30), Lucy asked learners questions about chromosomes, genes and alleles, but they provided definitions of these concepts from their textbooks. Lily stated explicitly that she did not find out learners' preconceptions because they had previous knowledge from her earlier teachings. However, during lesson observation (ref. 4.5.2 first lesson observation lines 20, 23) Lily asked learners the questions 'What exactly is a chromosome? And what are genes?', which they could not answer. Her instructional strategy could not elicit learners' preconceptions.

The teachers' answers showed that none of the four teachers elicited learners' preconceptions of chromosomes, genes, mitosis and meiosis. The participating teachers might not have awareness and knowledge of learners' preconceptions.

Knowledge of learners' learning difficulties

Regarding the teachers' knowledge of learners' learning difficulties, the questionnaire (Appendix D items 5 and 6) sought answers to what learning difficulties the teachers anticipated in planning their lessons and what aspects of the lesson the learners found difficult to grasp. The teachers mentioned difficulties that had to do with the terminology of genetics and comprehending the processes of cell division. All four teachers stated that

learners have difficulty in differentiating among the genetics terms ‘chromosomes’, ‘genes’, and ‘alleles’, and thus sometimes used the terms interchangeably. Lucy and Leon commented that learners interchange the terms ‘mitosis’ and ‘meiosis’. Lucy again said learners can scarcely distinguish between homologous chromosomes and chromatids. Regarding learners’ comprehension of cell division, Lucy, Lillian and Lily wrote that learners struggle with grasping how chromatids separate during cell division and the reduction of chromosome number during meiosis. The lesson observations confirmed that some of Lucy’s learners had problems in grasping the concept of chromatids and confused the terms ‘chromatids’ and ‘homologous chromosomes’, ‘chromosome’ and ‘DNA’, as well as in comprehending the process of meiosis. During Lily’s lesson observation, some learners could not easily differentiate between chromosomes and genes, or identify the stages of the process of mitosis. Part of Lillian’s class could not define properly chromosomes and genes. For Leon, there was no evidence of knowledge about learners’ learning difficulties and the instructional strategy he employed could not help him identify these areas.

On the question as to ‘How did you discover or find out learners’ learning difficulties?’ (Appendix D item 7; Appendix X), Lucy indicated that she discovered learners’ learning difficulties with the relationship between chromosomes and genes, as well as the differences between mitosis and meiosis, through oral questioning and learner presentation (peer teaching). Lillian said she discovered learners’ difficulties in understanding chromosomes and genes through marking and correcting homework assignments. Lily identified learners’ difficulties such as providing incomplete definitions of chromosomes and genes and not comprehending the processes of mitosis and meiosis through marking classwork and homework. Leon wrote that he did not identify learners’ difficulties for the observed lessons, but he usually discovered learners’ difficulties through oral questions and written work. In sum, the teachers claimed that they acquired this knowledge through classroom teaching experiences.

The teachers were also asked ‘What do you think made those areas difficult for learners to understand?’ (Appendix D item 8; Appendix X). Lillian and Lucy asserted that genes and cell division are abstract or not readily envisaged by learners. Lily and Leon were not sure. When the teachers were prompted to indicate ‘How did you address learners’ learning difficulties, if at all, during the lesson? (Appendix D item 9), Lily said she addressed learners’ difficulties

with chromosomes, DNA and the genes, and comprehending the stages of mitosis by discussing these with individual learners while monitoring classwork. The lesson observation (ref. 4.5.2 first lesson observation lines 29–30; second lesson observation lines 2–3, 14–16) confirmed that Lily addressed learners' problematic areas through monitoring classwork, discussing aspects with individual learners, and in class reviews of classwork and homework assignments. Lucy stated that she required learners to construct physical models of chromosomes and genes so that they would understand the relationship between chromosomes, genes and alleles. She said she also used demonstrations and illustrations with coloured chalk and peer assistance to help learners understand the processes of mitosis and meiosis. Lillian wrote that in order to address learners' difficulties she explained chromosomes, genes and alleles using diagrams to show the relationships among the terms. Leon did not respond, probably because there was no evidence of him having addressed learners' difficulties during the observed lessons. Leon did not appear to have any knowledge of learners' difficulties in genetics teaching, as he did not indicate learners' areas of difficulty, why those areas would be difficult, or how those areas would be identified and addressed. The lesson observations confirmed that the teachers identified learners' areas of difficulty through monitoring and reviewing classwork, and homework assignments and peer teaching.

The last question on the questionnaire sought information on how effective the participating teachers thought the approach used to teach the lessons had been and what they would do the next time they taught the same concepts or content (Appendix D item 10; Appendix X). Leon's lesson presentations did not contain an assessment or feedback from learners. So he wrote that he would 'include written work that is then discussed to gauge learners' understanding'. Lillian, who used diagrams and charts as illustrations, and described the stages of mitosis not in detail, said 'I would organize a video about chromosomes … and explain how cell division occurs using all the phases in detail rather than omitting some.' Similarly, Lucy, who used coloured chalk and diagrams to teach the processes of cell division, wrote that she would 'explain it (cell division) in more detail using demonstrations or simulation experiments'. Lily, whose learners experienced difficulty in responding to her questions about chromosomes and genes, wrote that she would assign learners to do research about the topic or read about genetics before teaching the topic. With regard to mitosis and meiosis, Lily wrote that she would use more examples of the processes of mitosis and meiosis

in plants and animals. The teachers' responses indicated that reflecting on their teaching had prompted them to change their instructional strategies to include classwork to assess learners' comprehension of the concepts immediately, to provide detailed explanations of concepts using illustrations, including more examples to illustrate concepts, and to use simulation experiments. The teachers' reflective journals complemented the questionnaire responses, as will be discussed later in section 4.8.

4.7 Post-lesson teacher interviews

The post-lesson teacher interview was meant to ascertain how the participating teachers developed or claimed they developed their PCK in teaching genetics at high-school level. The interview schedule is available in Appendix E. During the interviews, the teachers were asked a series of questions on how various factors that the literature suggests could have contributed to the development of PCK in teaching genetics. On the question of 'How have the courses that you did at university helped you to prepare and teach your genetics lessons?' (Appendix E item 1), all four teachers (Lucy, Lily, Leon and Lillian) reported that during their Bachelor of Science programmes they had studied biology courses, which had given them content knowledge about genetics that was sufficient to teach high-school genetics topics. They also claimed to have done methods courses in their Postgraduate Certificate of Education (Lucy, Lily and Lillian) and concurrent Diploma in Education (Leon) programmes, which enabled them to use appropriate instructional strategies to adapt their superior content knowledge to the school level curriculum. They learned how best to make the topics accessible to novice science learners. They claimed the content knowledge developed through university courses enabled them to explain genetics concepts and respond to learners' questions during lessons.

The participating teachers were asked whether teaching genetics over the years had helped them to teach the topic better and to explain, if yes. All four teachers asserted that teaching genetics over the years has helped to improve their teaching (Appendix Y). They have become aware of areas of difficulty that learners experience as they are newly introduced to the topic of genetics. According to the teachers, awareness of areas of learners' difficulty made them change their teaching methods, such as using learner-learner teaching, discussion (Lucy) or exercises (Lily). Lucy now uses peer teaching to help learners to construct genetics models (ref. 4.5.1 first lesson observation lines 11–12, 30), Lillian uses illustrations such as charts to illustrate the processes of cell division (ref. 4.5.4 second lesson observation line 5)

and Lily uses written classwork exercises (ref. 4.5.2 first lesson observation line 29; second lesson observation line 12). Their years of teaching genetics seem to have contributed to developing their PCK, which does not appear to be static, because they claim they have changed teaching approaches.

The teachers were asked how they know that their current way of teaching genetics is effective. All four teachers used learners' performances in tests and examinations, as well as analysis of their work through classwork and homework assignments, and learner feedback as indicators of the effectiveness or otherwise of their teaching. Lucy explained: 'Learners' performance in external examinations has improved over the years compared to when I started' (post-lesson interview).

The teachers also talked about the learning difficulties their learners experience in studying genetics and what made those areas difficult (Appendix E items 4-5; Appendix X). Lucy cited her learners' areas of difficulty as comprehending what chromatids are and differentiating between chromatids and homologous chromosomes; distinguishing between chromosome and gene; comprehending the process of meiosis and reduction of chromosome number during this process; differentiating between mitosis and meiosis; and solving Mendelian genetics problems. Lucy thought learners' difficulties stemmed from the abstract nature of genetics concepts (most involve verbally defined concepts and learners are expected to extract meaning from those concepts, and in consequence they find such terms difficult because they are not readily imageable). In addition, learners meet most genetics concepts for the first time at this school level and lack understanding of the basic structures of heredity such as genes and alleles that is required in solving genetics problems. When learners experience difficulties in learning genetics, Lucy changes the teaching approach by giving more work for practice and asking learners to explain concepts to one another.

Lily indicated that her learners normally confuse genetics terms such as chromosome, gene and DNA, and homozygous and heterozygous, and are challenged by genetics problems in which they experience difficulty with alleles and interpreting genetic crosses results. She attributed the learners' difficulties to the abstract nature of genetics concepts. Lily said she would address learners' difficulties by repeating parts of her lessons or discussing with individual learners.

Leon claimed that learners normally have difficulty with genetics terminology and solving Mendelian genetics problems. According to Leon, this difficulty might emanate from the teacher's teaching approach and also from the mathematical nature of genetics problems, which require learners to calculate percentages and ratios. Leon said he reviews tests and examination questions with the class to curb learners' difficulties. On rare occasions, he discusses problems with individual learners.

Lillian said that learners usually confuse genetics terms, for example by using the terms 'chromosome' and 'gene' interchangeably and failing to differentiate between the two, and have difficulty in understanding the replication of chromosomes during cell division and solving genetics problems. According to Lillian, learners' difficulties derive from the fact that learners come across genetics terms for the first time because they are not learned in lower school levels. She claimed that she helps learners by changing the teaching methods and assigning further reading, giving more exercises for practice, and encouraging them to help one another as peers.

The teachers' discussion and observation show that learners usually experience difficulties with topic-specific terminology of genetics by tending to use terms such as chromosome and gene, homozygous and heterozygous, chromatids and homologous chromosomes interchangeably or failing to see the relationship or to differentiate among them; with comprehending the processes of cell division; and in solving Mendelian genetics problems. The teachers thought learners' difficulties in learning genetics derive mainly from the abstract nature of genetics, that is, the nature of the content (Penso, 2002). The teachers attempt to address learners' difficulties in different ways, including changing the teaching approach.

The participating teachers were asked whether they had attended biology teacher development workshops and how they had benefited from them as biology teachers, if at all (Appendix E items 7, 8; Appendix Y) with a view to further establishing how they might have developed their PCK. All four teachers said they had attended biology workshops organized by the in-service department of the University of Swaziland and Ministry of Education and Training and facilitated by biology educators. Three teachers said that none of the workshops they attended had been specifically on genetics, but had generally dealt with

topics that seemed difficult for learners, such as evolution, photosynthesis, and genetics. The other teacher, Leon, remembered one workshop that dealt with some genetics concepts such as variation. During the workshops, the teachers gained new insights into and increased their knowledge of teaching activities and strategies. For example, Lucy, Lily and Leon claimed that they were taught to make and use physical models of chromosomes and genes using common materials such as plasticine, beads, cards and dices. Interestingly, none of the teachers used models they had prepared during the observed lessons. Lillian learned how to use illustrations and activities such as simulation experiments, slide shows and scientific charts of mitosis and meiosis in animal or plant cells to demonstrate the structure and function of chromosomes, as well as the processes of cell division. Lillian's use of a chart showing mitosis in an animal cell was evident in teaching the process of mitosis (Ref. 4.5.4 second lesson observation line 5). The teachers also claimed that during the workshops, they obtain opportunities to discuss the teaching of certain biology topics with peers, which might have further developed their PCK.

To determine whether collaboration with departmental colleagues helped teachers to teach genetics better (Appendix E item 9; Appendix Y), Lillian said collaboration with departmental colleagues, especially one who had taught genetics for many years, helped her on how best to present topics that learners find difficult, such as the processes of mitosis and meiosis. So a source of PCK development for Lillian was an experienced colleague. Leon said that he collaborates, but most of his inexperienced colleagues have benefitted from him as far as teaching is concerned. He himself has gained from his colleagues in developing continuous assessment questions and procedures. Lucy and Lily, on the other hand, emphasized that informally they discuss teaching generally with colleagues, but not specifically genetics teaching. Other sources of PCK development for genetics teaching (Appendix Y) mentioned by the teachers were recommended textbooks, curriculum documents (SGCSE biology syllabus) and the Internet. These sources, which were mainly used during lesson preparation, provided the teachers with genetics content knowledge, simpler explanations for genetics concepts, alternative illustrations and examples.

Overall, the teachers' PCK can be construed to have developed through university biology and methods courses that allowed them to study biology content and methods of teaching. Through classroom teaching experience, lesson planning and teaching, using recommended

textbooks, curriculum documents and the Internet, they gained further PCK. In-service workshops and collaboration with in-school departmental colleagues also provided ideas about presenting genetics content.

4.8. Document analysis

4.8.1 Reflective journal

Lucy indicated that her lessons were effective because she achieved the objectives of the lessons, learners participated actively during the lessons, and learners were able to answer her questions correctly (Appendix W). Lucy reported that some of her learners enjoyed the genetics lessons, were confident, and participated in various ways during the lessons, such as making presentations, asking and answering questions. She said learners worked individually to enable her to identify their individual difficulties. Learners completed assigned tasks. She noted that some learners experienced difficulty in understanding the process of meiosis, differentiating between a chromosome and DNA and between chromatids and homologous chromosomes, and defining genes properly. Lucy reported that she had addressed the learners' difficulties through explaining concepts and asking learners who understood to explain to colleagues. Lucy also commented that the next time she taught the same genetics concepts she would use demonstrations to help learners to visualize them and would spend more time on the topic.

Lily said that not all of the lessons she taught were effective. She thought the first was not very effective because learners could not respond to some of her questions. She judged effectiveness through achieving lesson objectives, learners answering questions correctly, and giving correct examples. Lily stated that her learners exhibited different moods during her genetics lessons. While some appeared to enjoy lessons, were confident and participated, others were indifferent and could not answer questions. Some learners enjoyed realizing the lessons' application to real life, such as determining the paternity of a child. Lily said learners worked individually to allow each learner to display his or her understanding and in pairs for them to help each other. They all completed assigned classwork and homework assignments. She indicated that learners had difficulty in understanding alleles, the structure of DNA, and relating genes to characteristics. According to her, the struggles were a result of the difficulty in envisaging these structures. Lily said she addressed the difficulties by using illustrations such as diagrams to help them visualize the structures and the relationships among them, as

well as between the structures and characteristics. She said the next time she taught the concepts she would change the teaching methods without specifying how.

Leon claimed that all his lessons were effective because learners did not ask questions, they answered his questions, and he covered all the concepts he had planned to teach. Leon reported that his learners enjoyed his genetics lessons as they were in a jovial mood, participated by answering his questions and carrying out activities, and appeared confident. He said learners worked individually, but he felt that his organization was not always the best since some learners would benefit from group work. Leon stated explicitly that he might not be aware of his current learners' difficulties because he did not do any assessment, but said learners usually confuse genetics terms such as chromosome and gene, homozygous and heterozygous and genotype and phenotype, which is caused by insufficient practice in using those terms. Leon said he addressed learners' difficulties by using familiar examples during teaching. The changes he would make the next time he taught the lessons would include giving learners exercises for practice and allowing them more time to work on those exercises.

Lillian stated that her lessons were effective because she achieved her intended objectives, learners responded correctly to questions, and they participated through asking questions. Lillian stated that the level of learner participation was high during her genetics lessons, especially the first lesson, which learners seemed to enjoy, as indicated by asking questions. Lillian said learners worked individually for homework assignment to make it easy for her to identify difficulties per learner. She said learners completed assigned tasks. She noted that some learners had difficulty in differentiating between a chromosome and gene and understanding the stages of the processes of cell division such as separation of chromosomes or chromatids. According to Lillian, these snags were caused by the abstract nature of the concepts, which makes it difficult for learners to visualize them. She used diagrams to help learners visualize. Lillian said changes would include assigning reading about the topic prior to lessons, discussing in class and presenting in groups during lessons. She would also teach the process of meiosis in detail, including the crossing over of chromosomes.

In summing up, the analysis of the teachers' reflective notes confirmed the results from interviews, questionnaires and lesson observations about their instructional strategies and

learners' areas of difficulty. Working on the reflective reports, that is, analysing and reflecting on their teaching experiences of genetics, might have helped the teachers augment their PCK.

4.8.2 Learners' exercise books

The learners' exercise books or notebooks of the four participating teachers (Lucy, Lily, Leon and Lillian) contained notes about the facts, definitions and descriptions of the concepts chromosomes, genes and alleles, confirming that the teachers taught the concepts mostly using declarative content knowledge. In Lucy, Lily and Lillian's classes, learners' notebooks contained steps showing the stages of the processes of mitosis and meiosis, suggesting that these three teachers actually taught the concepts they claimed they were going to teach using procedural content knowledge. Learners' notebooks for all four teachers also exhibited diagrams related to the location of genes on chromosomes with examples of physical characteristics controlled by genes showing the relationship between genes and alleles and characteristics. The learners' documents confirmed that the three teachers (except Leon) used homework assignments to assess how well they had understood the genetics lessons. In addition, Lily used classwork for same purpose. Lucy, Lily and Lillian's marked learners' work indicated areas in which learners had difficulty, such as in providing proper definitions of chromosomes and genes, as well as in comprehending the processes of mitosis and meiosis. In Leon's class, the review of learners' notebooks confirmed that he did not give any exercises to learners in the form of classwork or homework assignments. The review of learners' written work also revealed that none of the four teachers used instruments or written work to diagnose learners' preconceptions of the genetics concepts taught.

From the above discussion, it appears that the four teachers actually taught the concepts of chromosomes, genes, alleles, mitosis and meiosis, using descriptions, examples, diagrams, classwork and homework assignments. It also confirmed that learners had some difficulties with chromosomes and genes. In other words, reviewing learners' notebooks confirmed the teachers' responses to interviews, questionnaire and what they did during lesson observation.

Curriculum documents and textbooks

Analysis of curriculum documents revealed that the SGCSE biology syllabus served as the main source of the content (concepts) to be taught, as well as definitions and descriptions of

those concepts for all four teachers. For Lucy, Lily and Lillian, it also served as a source for sequencing or organizing the teaching of those genetics concepts. The recommended biology textbooks were used mainly as a source of descriptions or explanations and illustrations such as diagrams.

4.9 Chapter summary

Chapter Four began with the demographic information of the four participating teachers, followed by the results of the main study, which were presented according to the data collection instruments. For the lesson observation, detailed analyses of the teachers' observed lessons – according to the three themes of content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties that emerged from the data – were presented, followed by summaries of the observations. In Chapter Five the main findings of the study are presented and discussed.

CHAPTER FIVE
DISCUSSION OF RESULTS

5.1 Introduction

Chapter Five is concerned with the discussion of results of the study. This discussion is presented in line with the study's main research questions of what pedagogical content knowledge (PCK) participating individual biology teachers have in genetics teaching and how they developed it. The chapter concludes with an evaluation of the study's theoretical framework over the extent to which it provides useful insight into teachers' development of PCK in genetics teaching.

5.2 Teacher PCK profile and development

This section focuses on the three components of genetics related content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties in order to discuss the summary of each participating teacher's PCK profile and development.

5.2.1 Lucy

The discussion begins with Lucy's classroom practice and how she demonstrated her PCK in genetics teaching. In her pre-lesson interview about her lesson plans (ref. 4.4; Appendix V), Lucy stated that she intended her learners to be able to provide correct definitions of the genetics terms of chromosomes, genes and alleles, as stated in the curriculum document (biology syllabus) and the differences among them. The emphasis here is on her use of declarative knowledge to transmit information. For the other genetics concepts of mitosis and meiosis, which involve how biological processes work, she planned to provide step by step descriptions of the processes of mitosis and meiosis formation the differences between them (the emphasis here is in the use of procedural knowledge), and clear explanations of why they are regarded as important concepts to be taught (conditional knowledge). Indeed her content dimension of her PCK profile could be construed as reflecting the three knowledge areas or categories of declarative, procedural and conditional knowledge (Krathwohl, 2002; Paris et al., 1983).

Lucy planned and taught her genetics lessons on inheritance that were observed, using the recommended biology textbooks and curriculum document as her main sources of information. During the lessons, she began by providing first straightforward facts about the

structure and function of the genetics concepts chromosomes, genes and alleles (ref. 4.5.1 first lesson observation lines 16, 19, 23, 34). She followed this up by explaining the relationships and differences among the various concepts, of chromosome and gene, and gene and allele, using her conceptual knowledge (cf. Krathwohl, 2002). In teaching these concepts, she used mainly declarative conceptual knowledge, which is required for stating and explaining facts or principles in this case, with inheritance that the learners are expected to learn.

Other dimensions of her content knowledge that were demonstrated included knowledge of the genetics processes of mitosis and meiosis. Lucy carefully and systematically explained the significance of the processes of mitosis and meiosis in an organism or species, notably for cell growth and replacement, and the production of gametes and maintenance of chromosome number in a species (ref. 4.5.1 second lesson observation lines 7, 19–21). This explanation was followed by a description of the stages of the processes of cell division.

The knowledge displayed by Lucy in describing the processes of mitosis and meiosis in a step-wise (stages by stages) fashion is construed as procedural knowledge. This description is in agreement with what other researchers have said about procedural knowledge, which is knowledge of the 'how' of things or biological processes (Juttner et al., 2013; Krathwohl, 2002; Paris et al., 1983; Uluoglu, 2001). By describing both the 'why' and the 'how' of the processes of mitosis and meiosis, Lucy in effect is demonstrating the presence of conditional knowledge in her PCK competence repertoire. In sum, her PCK could be viewed as consisting of declarative, procedural and conditional content knowledge in teaching the genetics concepts of inheritance.

Part of Lucy's instructional strategy is to ask learners to read the relevant chapters in their textbook as homework assignment (an advance organizer) before introducing a new topic in class. Based on their readings, they are then required to construct physical models of the relevant genetics concepts and present them in class in form of peer teaching (ref. 4.5.1 first lesson observation line 1). For instance, research suggests that learners usually confuse the genetics terms 'chromosomes' and 'genes', and 'gene' and 'allele' (Tsui & Treagust, 2004, 2007; Yilmaz et al., 2011). Lucy had asked her learners to construct physical models based on their understanding of what they had read and present them in class. Lucy later explained in her post-lesson interview (ref. 4.7) that her years of teaching genetics have shown that learners usually have difficulty in differentiating and correctly using those terms.

With her experience and awareness of the difficulties learners usually have with some genetics concepts Lucy did not always plan her genetics lessons accordingly to try to eliminate or minimize the difficulties and make the concepts accessible to more and more learners. This point is highlighted precisely because teachers' knowledge about learners' preconceptions and possible learning difficulties is important, because such can be used as a useful teaching point on the learners' behalf. In Lucy's lesson plans that were examined however, there was no indication of her prior knowledge of learners' anticipated learning difficulty or the inclusion of activities designed to address areas of potential learning difficulties or conceptual misunderstanding.

Lucy explained in her pre-lesson interview (ref. 4.4; Appendix W) and post-teaching questionnaire (ref. 4.6; Appendix W) that she used the teaching approach of learner prior reading and peer teaching as an advance organizer (cf Ausubel, 1970). First, to assure that the learners have some rudimentary idea or notion of what the lesson would be about and would be in a position to contribute during the lesson and second, for diagnostics purposes. To discover areas of difficulty and areas that are easy to understand.

Thus, Lucy's PCK profile in the context of teaching genetics must of necessity include some indication of knowledge of what the learners know and have including, the difficulties they encounter in their first exposure to the topic. The learner preconceptions, errors or mistakes if any, are then or could be used as the basis for teaching and reinforcing the correct ideas. Lucy's instructional strategy of seeking to determine learners' preconceptions and learning difficulties with learner-constructed models constitutes her topic-specific instructional strategy, which forms part of her overall PCK profile in genetics teaching.

Also in her teaching, Lucy normally used contexts that are familiar to her learners to introduce the genetics concept to be taught (ref. 4.5.1 first lesson observation line 2 The use of daily life contexts is designed to make the topic more accessible relevant and motivating to learners. Research has shown that context based teaching approach in the teaching of school genetics topics leads to significantly improved learner performance (Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Kazeni & Onwu 2013; King & Ritchie, 2013)..

Furthermore, Lucy used labelled diagrams and analogies to support her explanations and promote conceptual understanding (ref. 4.5.1 first lesson observation lines 18, 25–26, 33; second lesson observation lines 26–28). the analogy of a recipe book in which DNA is a coded recipe for making proteins and each chromosome contains many recipes or genes (ref. 4.5.1 first lesson observation lines 25–26) to explain the differences between a chromosome and a gene appeared to have gone down well with the class.). The use of analogies is viewed as a characteristic of effective pedagogical explanations (Treagust & Harrison, 2000), and exemplary teachers use this strategy when expressing complex abstract ideas (Coll et al., 2005). Lucy's PCK component of topic-specific instructional strategies may be said to consist of the use of illustrations and analogies.

Interestingly enough despite her many years of teaching genetics, when Lucy was asked to list the likely prior knowledge or preconceptions of the genetics concepts her learners were likely to have (Appendix D item 3; Appendix X), she like the rest of other participating colleagues indicated only knowledge about previously taught topics, such as fertilization and cell structure and none on genetics itself. There was no mention of genetics-related preconceptions that they thought their learners might have. The reasons for this lack of knowledge were not always clear. One could suspect that the teachers might not have understood the question because their responses suggested that they regarded preconceptions as prerequisites or background knowledge for the genetics topics to be taught. Even so Lucy failed to indicate in her lesson plans or in choice of instructional strategies that she was aware of learners' possible genetics related preconceptions. A recent doctoral work in teacher PCK in statistics teaching in school mathematics in South Africa also demonstrated the same phenomenon in which experienced mathematics teachers lack pedagogical content knowledge of learners' preconceptions in statistics teaching (Ijeh, 2012).

Lucy's teaching strategy also included the frequent use of oral questioning to assess what learners know- before, during and after the lessons that were observed (ref. 4.5.1 second lesson observation lines 30–34). She explained during the pre-lesson interviews (ref. 4.4; Appendix W) and in the questionnaire (ref. 4.6; Appendix W) that this strategy enabled her to obtain immediate feedback from learners; and to identify learners' misconceptions, and learning difficulties, if any. Sometimes, with new or unfamiliar concepts however, learners responded to teacher's classroom questions by sourcing the answers directly from their

textbooks in front of them (ref. 4.5.1 first lesson observation lines 16, 22, 32). Thus Lucy's questioning technique and approach did not always seek to elicit learners' own ideas or existing knowledge about the concept under consideration.

However, through learner presentations and peer teaching she identified concept-related learner preconceptions and errors such as failure to differentiate between homologous chromosomes and chromatids; chromosome and DNA; and the explanation for the halving of chromosome number during the process of meiosis forming gametes (ref. 4.5.1 first lesson observation lines 12, 14; second lesson observation line 16). Lucy's teacher questionnaire (Appendix D item 8; Appendix X) and post-lesson interview (ref. 4.7; Appendix X) suggest that Lucy's explanation for learner difficulty with some aspects of genetics topic has to do with the abstract nature of genetics concepts. Additionally, the completed teacher questionnaire (ref. 4.6; Appendix X), analysis of Lucy's reflective notes (ref. 4.8.1; Appendix X) and the researcher's review of learners' notebooks (ref. 4.8.2) would tend to confirm that components of her PCK in genetics teaching derive from her identification of learners' difficulties in the course of their classroom presentation and peer teaching. Oral questioning technique and homework assignments were topic specific strategies that she often and purposefully used to diagnose learner difficulty and assess learner understanding.

In summary, Lucy's PCK profile in genetics concepts teaching, in terms of the three components of PCK as defined, may be characterized as consisting of declarative, procedural and conditional content knowledge; and the use of topic-specific instructional strategies, namely, of context-based teaching approach, peer teaching; use of physical models for illustrations, and analogical teaching. The use of (i) advance organizers in the form of peer teaching, (ii) diagnostic questioning technique and homework assignments, all of these among other things of classroom management and time on task combined to define the effective pedagogical strategies Lucy used to teach genetics. What was perhaps lacking in Lucy's instructional strategy in the lessons observed was the failure to follow up in a consistent manner with probing questions designed to elicit the reasons for, and/or the sources of learners' difficulties, errors and misconceptions in the topic taught.

How did Lucy develop her PCK in genetics teaching? Lucy received her formal university education and training in biology teaching. She holds a Bachelor of Science degree with

biology as her major subject, and a Postgraduate Certificate in Education, specializing in biology and geography (ref. 4.2). Through her formal education, Lucy reported (ref. 4.7) that she had gained genetics content knowledge from her degree content courses and knowledge about teaching methods and strategies such as the use of contexts familiar to learners from her methods courses. Lucy, like all the other three teachers, claimed that the genetics content knowledge she learned during her degree was definitely of a higher level than she was expected to teach at the school level. Consequently, she had to adapt the content knowledge for classroom use and make it accessible to her learners using her pedagogical content knowledge.

Lucy has about ten years' experience of teaching biology at high-school level, Grades 11–12. Her narratives during the post-lesson interview revealed that Lucy's knowledge of teaching genetics grew over the years. She observed that her instructional strategies had changed from predominantly lecture and 'chalk and talk' to being more learner-centred and participatory. She had begun to involve learners through assigning them chapters to read in their textbook prior to genetics lessons to be taught, and to construct for example physical models of chromosomes and genes, and present and explain them in class in a format of peer teaching. This exercise served as an advance organizer. According to her, such changes helped to improve her learners' performance in biology public examinations as she said 'learners' performance in external examinations has improved over the years compared to when I started'.

Lucy attended in-service biology workshops organized by the in-service department of the University of Swaziland and the Ministry of Education and Training (ref. 4.7; Appendix Y). Lucy reported that the workshops impacted positively on her skills in selecting genetics subject matter representations. Specifically, she claimed that the workshops helped to extend her repertoire for representing genetics concepts and she was better able to distinguish between effective and ineffective representations. For example, she learned about the use of physical models and how they could be made out of readily available materials.

When asked about other sources of her PCK, Lucy mentioned that she used biology curriculum documents such as the biology syllabus and recommended textbooks as sources of information for preparing genetics lessons. According to her, the syllabus served as a

source of the content to be taught, as well as the sequence in which the genetics concepts were to be taught. Textbooks, on the other hand, were used as a source of simpler explanations, examples and diagrams.

A progressive analysis of Lucy's observed genetics lessons revealed that she, like two other teachers (Lily and Lillian), demonstrated different dimensions of content knowledge, depending on the nature of the topic or concept. Lucy became aware of learners' confusion in genetics terminology through learners' presentations or peer teaching, listening to their responses to her oral questions, and marking their homework assignments. Lucy might have further developed her knowledge of instructional strategies through reflection on her observed genetics lessons. Analysis of her questionnaire responses and written reports revealed that Lucy decided that the next time she taught the same genetics concepts she would explain cell division for example in more detail and use demonstrations or simulation experiments to help her learners visualize and better comprehend the concepts.

It is interesting that Lucy seemed to have limited knowledge of learners' preconceptions that could have been used as teaching points and did not report that she had gained or learned about such knowledge from any of the factors or sources that are said to influence PCK development. It may be safe to say that perhaps this area of knowledge of learners' conceptions and learning difficulties might not have come up or been adequately flagged during teacher professional development courses or workshops.

In summary, given the evidence in her responses and progressive analysis of her lessons these factors such as the formal education programmes that she received from her university, in-service training workshops she attended, classroom teaching experience using biology curriculum documents and recommended textbooks could have contributed to her development of PCK.

5.2.2 Lily

In Lily's observed lessons, it was noted that she planned and taught her genetics lessons on chromosomes, genes, mitosis and meiosis using the recommended biology textbooks and curriculum document as her main sources of information (ref. 4.5.2). In her teaching of chromosomes, genes and alleles (ref. 4.5.2 first lesson observation lines 20, 22, 24, 32), she gave evidence of using mainly declarative knowledge. For instance, Lily first provided definitions of these genetics concepts, then provided facts about their structure and function along the lines indicated in the biology syllabus. Lily took time to explain the relationship among the concepts of chromosome, genes, and genetic information (ref. 4.5.2 first lesson observation line 24) using her conceptual knowledge. This relationship among the genetics concepts is an area in which research suggests that learners have difficulty (Lewis et al., 2000a, 2000b). Lily paid extra attention and gave her learners time to understand her explanation about how these genetic concepts are related in human inheritance. The worthy time on task spent by both teacher and learners is likely to enhance learner understanding. This was evidenced in the correct manner many learners responded correctly to her classwork questions about chromosomes and genes (ref. 4.5.2 first lesson observation line 29).

In her lessons on mitosis and meiosis, one could observe that Lily used primarily her procedural and conditional knowledge in a systematic and logical fashion to first describe the justification for the two processes in the context of cell growth and sexual reproduction followed by a description of the stages of cell division. She described the stages in a step-by-step fashion with illustrations, beginning with a pre-activity to identify learners' prior knowledge of the purposes and products of mitosis and meiosis (ref. 4.5.2 second lesson observation line 2), followed by a description of how the processes work (ref. 4.5.2 second lesson observation lines 11, 17).

A cursory examination of learners' exercise books confirmed Lily's predominant use of procedural knowledge in line with the requirements or dictates of the lesson topic. This knowledge component is particularly relevant in teaching the processes of cell division. Juttner et al. (2013) and Shulman (1986) however have highlighted the fact that in the context of teaching new knowledge in biology, it is not sufficient for the teacher to know the 'what' (knowing it-propositional knowledge) and the 'how' (knowing how-procedural knowledge)

of things but the biology teacher ought to understand why it is so. Lily stated in her pre lesson interview that she wanted her learners to know why cell division is important, because it would help them to justify the need for the study of mitosis and meiosis (ref. 4.4; Appendix V). During the lessons, she explained that the purpose of mitosis is to produce new cells for growth and replacement of worn-out cells, and meiosis is for the production of gametes (ref. 4.5.2 second lesson observation line 3). In teaching the concepts of chromosomes, genes and cell division, Lily demonstrated the three dimensions of content knowledge, notably declarative, procedural and conditional knowledge. Thus her PCK profile in terms of subject matter knowledge could be said to consist of declarative, procedural and conditional content knowledge.

In her teaching Lily normally introduced her genetics topics with familiar everyday examples meant to engender interest and make the topic relevant to learners' daily experiences. The genetics-related human physical characteristics such as height, complexion, and eye colour of family members were used to introduce the topic of inheritance. Current studies (Eastwood et al., 2012; Kazeni & Onwu, 2013; King & Ritchie, 2013; Williams et al., 2012) suggest that the use of familiar contexts in genetics teaching significantly improves learners' performance and attitudes. Thus the use of contexts familiar to her learners forms part of Lily's content driven PCK profile in genetics teaching.

In her interview (ref. 4.7; Appendix X), Lily noted that learners usually have difficulty with the terminology of genetics and its usage. This is consistent with what research says (Kazeni & Onwu, 2013). To address aspects of the problem Lily usually used illustrations from the recommended textbooks, and occasionally from the Internet, as well as diagrams and sketches on the chalkboard to help learners visualize and comprehend some of the defined genetics concepts being taught (refs. 4.7; ref. 4.5.2 first lesson observation lines 18, 21). Carefully labelled diagrams on the chalkboard for instance were used to explain the relationship between chromosomes and genes (ref. 4.5.2 first lesson observation line 27). The works of Chattopadhyay (2005), Chinnici et al. (2006), Law and Lee (2004), Oztap et al. (2003) indicate that the use of illustrations in genetics teaching assists learners in visualizing concepts and enhancing comprehension. Having said that Lily, like her other counterparts, did not often use or include teacher-prepared teaching models and/or demonstration experiments in their lessons plans and lessons. This was somewhat problematic in the sense

that biology is an experimental science. Despite the fact that she has been exposed to the use of physical models of chromosomes and genes for teaching during her various in-service workshops (ref. 4.7), clearly the acquired knowledge and skill, if any, was not demonstrated in her classroom practice. She was clearly deficient in her genetics teaching approach specifically in the use of teaching models and teacher practical demonstration experiments or individual learner experimentation as learner-centred activity. This finding is rather unsatisfactory from the point of view of making genetics concepts less difficult and more meaningful to learners. Juttner et al. (2013) and Magnusson et al. (2001) have argued that the use of physical models and individual, group or demonstration experiments are major science –specific instructional strategies that can assist learners in learning complex and abstract biological processes located at molecular level. Pictorial models in particular assist learners in forming mental images of intended concepts, promote learner comprehension of science content, and help learners to remember conceptual knowledge dealing with scientific information (Oliveira, Rivera, Glass, Mastroianni, Wizner & Amodeo 2013).

The greater part of Lily's knowledge of learners' conceptions and learning difficulties was deduced in the course of her genetics lessons' presentation. This knowledge was obtained through her questioning technique, observation and review of classroom work and homework assignments including learner feedback (ref. 4.5.2 first lesson observation lines 29, 33; second lesson observation lines 14, 23). Lily identified learners' inability to fully define a chromosome and gene through feedback and the analysis of their responses to classwork (ref. 4.5.2 first lesson observation line 29). She, like her other teacher counterparts blamed learners' difficulties on the abstract nature of genetics concepts which was left unspecified (ref. 4.7). Her questioning technique failed to elicit learners' preconceptions of the genetics concepts to be taught (ref. 4.5.2 first lesson observation lines 20, 23–24), largely because of the weakness in her probing questioning techniques as observed. This singular lack of knowledge of learners' genetics related preconceptions and possible learning difficulties was confirmed when Lily indicated in questionnaire and written reports that she had no clue about learners' preconceptions (Appendix X).

The absence of adequate knowledge of learners' genetics related preconceptions and learning difficulties was common to all four participating teachers. It is surprising that teachers with many years of teaching experience in genetics should lack this kind of knowledge that is vital for effective classroom practice. Many researchers (e.g. Lazarowitz & Lieb, 2006; Morrison

& Lederman, 2003) have warned that for effective teaching and learning to occur, teachers should identify learners' preconceptions of concepts before teaching commences, and to use this knowledge to adapt their instructional strategies to suit learners' needs and avoid potential learning difficulties.

In summary, Lily's PCK profile may be construed as an amalgam of the various components of PCK, comprising mainly of declarative, procedural and conditional content knowledge. The use of familiar examples, illustrations and labelled diagrams constituted specific instructional strategies that Lily used to teach chromosomes, genes and cell division. By identifying learners' learning difficulties through analysing their responses to classwork and homework, Lily could be said to have become aware of learners' post teaching learning difficulties.

It is assumed, that Lily might have developed her PCK in genetics teaching as a result of experience with or exposure to various academic sources. From her narratives (ref. 4.7), Lily's PCK in genetics teaching was said to have developed through formal university education programmes and classroom experiences of teaching the topic. She holds a Bachelor of Science degree, majoring in biology. She also has a Postgraduate Certificate in Biology teaching. Through university biology content courses she gained content knowledge of genetics, and through the methods courses obtained knowledge of science teaching methods and strategies.

Lily reported that over the 17 years' biology teaching experience, her teaching of genetics improved. Her teaching methods and strategies changed as a result of professional development. She attended several workshops organized by the in-service department of the University of Swaziland and the Ministry of Education and Training. According to her, from the workshops she learned, first, about the importance of making a topic relevant to learners by using everyday life contexts, and began to introduce the topic of genetics using contexts and examples familiar to her learners. Second, she used technology to improve her lesson presentation and help learners visualise genetics concepts. Third, she stressed the importance of research or reading beyond the textbook during her lesson planning and preparation. For example, during the observed genetics lessons, Lily used a data projector to show diagrams sourced from the Internet to help learners visualize genetics concepts of chromosomes, genes,

and DNA and promote conceptual understanding. Participation in in-service biology workshops could be said to have certainly contributed to Lily's PCK development in genetics teaching.

Lily indicated that her other sources of PCK in genetics teaching include the biology syllabus, and recommended textbooks. She explained that the syllabus served both as source and organizer of the content to be taught. She consulted textbooks for explanations, examples and illustrations.

A progressive analysis of the observed genetics lessons showed that Lily had further developed her PCK in teaching genetics (ref. 4.5.2). After noting that learners could not correctly respond to most of her questions during the first lesson, she decided to assign them reading assignments of relevant chapters in their textbook together with some homework exercises prior to the second lesson. As a result of reflecting on her practice during this study Lily might have further developed her pedagogical component of PCK in genetics teaching since she stated that the next time she taught the same genetics concepts she would continue to use the strategy of learners' prior reading as an advance organizer, and also use more everyday life examples to illustrate the processes of cell division (ref. 4.6; 4.8.1).

Overall, Lily's PCK in genetics teaching was assumed to have developed through formal education, in-service workshops and classroom teaching experience using biology curriculum documents, recommended textbooks and the Internet as sources of information during lesson preparation and delivery.

5.2.3 Leon

Leon planned and taught his genetics lessons on chromosomes, mitosis, meiosis and genes using the recommended biology textbooks and curriculum document (biology syllabus) as guidelines. The evidence-based data from his pre-lesson interview (ref. 4.4; Appendix V) and lesson observation (ref. 4.5.3) clearly demonstrated the fact that Leon predominantly applied his PCK-informed declarative subject matter knowledge to teach the genetics concepts to his learners (ref. 4.5.3 first lesson observation lines 13, 16, 18, 23; second lesson observation line 5).

Leon usually began his lesson by revisiting previous work and in this particular lesson on 'Inheritance' by reviewing the related concepts of fertilization and cell, which the learners had already come across. This was followed by the teaching and learning of simple genetics concepts definitions and then explanations of the why of the process of mitosis and meiosis. Their purposes and products were briefly outlined without any attempt at describing the step by step stages of the outcomes of the processes. Leon described and explained why mitosis and meiosis are important to the organism. Thus as he explained, mitosis is the process involved in cell growth (ref. 4.5.3 first lesson observation line 17). He explained meiosis as the process responsible for the production of gametes with haploid nuclei (a cell containing half the number of chromosomes), which fuse during fertilization to form one diploid cell (a cell containing the full number of chromosomes), called the zygote (ref. 4.5.3 first lesson observation lines 23–27).

Leon's teaching approach was completely different from those of the other teachers, although they were all following the same biology syllabus. In his teaching of the processes of mitosis and meiosis, Leon merely stated facts about their purposes and products (ref. 4.5.3 first lesson observation lines 18, 23). He explained at his pre-lesson interview (ref. 4.4; Appendix V) that he did not intend his learners to know the stages of cell division, because the syllabus states that 'details of the stages are not required' (ECOS, 2009:21). Clearly Leon is one who does not believe in going beyond the recommendations of the syllabus. One would have expected that his existing PCK in genetics teaching would have enabled him to go beyond the demands of the syllabus and instead teach for conceptual understanding. As was mentioned earlier, that in biology teaching it is not enough for teachers to know what or how things are, they should know why (cf Juttner et al., 2013; Shulman, 1986) they are the way they are.

The other three participating teachers described how the processes of mitosis and meiosis work, illustrating with visual representations including sketches of each of the cells and what happens internally during those processes. This difference in interpretation regarding the classroom implementation of the biology syllabus has implications for learners which do not always benefit them. Lack of consistency and implementation of the goals of the curriculum has implications for classroom practice. Leon's PCK in terms of content knowledge component may be construed to consist mainly of declarative content knowledge.

Leon normally used daily life examples familiar to his learners in introducing the topic of inheritance and illustrating alleles (ref. 4.5.3 first lesson observation lines 1–8; second lesson observation lines 10–12). Research indicates that learners usually cannot distinguish between a gene and an allele. That is, they barely grasp the idea that a gene may have a number of alternative forms (Wood-Robinson, 2000). In an attempt to help learners comprehend the concept of allele, Leon used several examples of human traits (e.g. tongue rolling and folding of arms) that are controlled by alternative forms of the same gene, known as alleles, to demonstrate the concept of allele to his learners (ref. 4.5.3 second lesson observation lines 10–12). He stated in his pre-lesson interview that his reason for the use of familiar situations was to relate the new genetics concepts to what learners know and can observe. This approach is in accordance with the view of Knippels et al. (2005), who contend that in order to deal with the abstract and complex nature of genetics, genetics teaching should begin with what is familiar to learners. Familiar contexts promote the relevance of the topic to learners' everyday lives for conceptual understanding (Kazeni & Onwu, 2013; King & Ritchie, 2013).

Since some of the topics involve concept representations at sub-atomic or microscopic level, Leon frequently used illustrations such as labelled diagrams to help learners visualize hereditary structures of chromosomes and genes (ref. 4.5.3 first lesson observation line 14; second lesson observation lines 6). Carefully labelled diagrams were drawn on the chalkboard to illustrate factual information about homologous chromosomes and to assist learners to comprehend the relationships among the concepts of chromosome, gene, and allele (ref. 4.5.3 second lesson observation lines 3–4, 6). In other instances, he referred the learners to diagrams in their textbooks (ref. 4.5.3 first lesson observation line 14; second lesson observation line 3). An analysis of learners' notebooks confirmed Leon's frequent use

of visual aids to illustrate genetics concepts (ref. 4.8.2). Leon's use of genetics topic-related instructional strategies such as familiar contexts and examples, labelled diagrams and illustrations form part of his pedagogical component of his PCK in genetics teaching.

Leon's presumed PCK of genetics teaching failed to demonstrate in any consistent convincing and systematic manner knowledge of the use of teaching physical models, individual and teacher demonstration experiments which are viewed as major instructional strategies specific to science (Juttner et al., 2013; Magnusson et al., 2001).

Leon also failed to show or demonstrate knowledge of learners' topic–related preconceptions and learning difficulties pertaining to the genetics concepts taught. Riemeier and Gropengieber (2008) state that not integrating learners' preconceptions and possible learning difficulties in the lesson planning and teaching stage but instead, emphasizing subject matter knowledge is clearly one reason for learners experiencing difficulties. Further, teachers who are knowledgeable of learners' preconceptions and learning difficulties always consider them at the planning stage of their lessons, as a first step in the process of effective teaching (Morrison & Lederman, 2003**;** Lazarowitz & Lieb, 2006). With Leon, this was not the case (ref. 4.4; Appendix V). And besides the observed questioning technique, which was whole-class directed and without wait-time for learners to respond to questions, failed to elicit learners' preconceptions of genetics concepts (ref. 4.5.3 first lesson observation lines 10, 12–13, 24–25; second lesson observation line 5). Further evidence from the pre-lesson interview, lesson observation and the post-teaching questionnaire revealed that Leon used predominantly teacher-centred approaches such as lecture method to teach genetics concepts (ref. 4.4; 4.5.3; 4.6). Such a strategy assumes that learners come to class with minds *tabula rasa* to be filled with information by the teacher. Yilmaz et al. (2011) contend that in genetics teaching, such strategies result in rote learning rather than conceptual understanding, and should be discouraged. Responses to the post-teaching questionnaire (ref. 4.6; Appendix W) and reflective notes (ref. 4.8.1; Appendix Y) confirmed that Leon mainly employed teacher-centred structured approaches in genetics teaching.

Evidence from the teacher questionnaire also confirmed that Leon first did not have prior knowledge of learners' preconceptions of the genetics concepts to be taught (Appendix W item 3). Secondly when asked about the learners' learning difficulties that he anticipated in

planning his lessons (Appendix D item 5) Leon mentioned that the learning of the relevant terminology of genetics and comprehending the processes of cell division could prove problematic. He stated that learners usually have difficulty in differentiating the genetics terms 'chromosomes', 'genes', and 'alleles' as well as 'mitosis' and 'meiosis', and sometimes use the terms interchangeably (ref. 4.6; Appendix W). With the post-lesson interview (ref. 4.7; Appendix X), he confirmed that in addition to problems with genetics terminology, his learners also had challenges in solving Mendelian genetics problems. He opined that the difficulty had arisen perhaps as a result of the mathematical nature of genetics problems, which require learners to calculate percentages and ratios. As unfortunate, Leon's awareness of potential learning difficulties did not result in intervention teaching and learning measures on his part designed to eliminate or minimize those difficulties.

Indeed, a review of Leon's class tests and exercise books showed that some learners could not solve genetics problems because of a lack of understanding of the process of meiosis. One suspects that if Leon used his ideas about learners' possible learning difficulties and had elected to teach the stages of meiosis and mitosis some of those learning difficulties would have been avoided.

Once again, Leon, like the other participating teachers, appeared not to have knowledge of learners' preconceptions and learning difficulties in the teaching of chromosomes, genes, mitosis and meiosis. Leon may therefore be said to have displayed not a rich PCK in terms of knowledge of learners' preconceptions in genetics teaching. It is perplexing that Leon, the most experienced teacher in terms of teaching years, did not appear to give much thought to possible preconceptions including misconceptions his learners are likely to bring with them when coming across new topics. This observation provides added empirical support to Kapyla et al's (2009) statement that years of classroom exposure is no guarantee of the creation of an expert science teacher.

It is encouraging to note that in his teacher questionnaire and reflective notes, Leon commented that in teaching the same genetics content next time around he would improve on his diagnostic assessment procedures and teaching approach to take into account learners' preconceptions of the genetics topics.

In summary, Leon's subject matter knowledge component of PCK consists mainly of declarative knowledge. His topic-specific instructional strategies of the use of everyday life examples to introduce the topics of inheritance and alleles, and visual aids to aid learners visualize or form mental cognitive maps (Lazarowitz & Lieb, 2006) of theoretically defined genetics concepts formed part of his PCK. By not demonstrating knowledge of learners' preconceptions however, Leon could be said to be deficient in that component area. His questioning technique was ineffective and failed to elicit learners' preconceptions before the beginning and during the lessons observed, and there were no assessment activities such as homework and classroom assignments and projects say for determining learners' conceptual understanding.

In response to the research question of how Leon might have developed his PCK in genetics teaching, certain reasonable assumptions were made that applied to all other participants of the study. In terms of formal education, Leon received further university education in the teaching of school biology. He holds a Bachelor of Science degree with biology as his major subject and a concurrent Diploma in Education (ref. 4.2). During the post-lesson interview, Leon reported that he learned genetics content knowledge during his degree courses. He explained that the knowledge he gained at university "is deeper than what I have to teach in my lessons … it becomes easier for me to explain something that is at a lesser level of understanding." Leon's content knowledge enabled him to explain genetics concepts to his learners with some confidence. He said he learned about the instructional strategies he used to teach genetics concepts from his education courses.

Leon has 22 years' biology teaching experience, and was the most experienced of the four participating teachers. Leon also claimed his teaching of genetics has improved over the years as he changed his instructional strategies. He stated that he was introduced to context-based teaching during biology in-service workshops organized by the Ministry of Education and Training and as a result began to introduce the topic of genetics using familiar situations or contexts. In addition, he claimed to have learned about the use of physical models to help learners visualize and comprehend genetics concepts such as chromosomes and genes during workshops organized by the In-service department of the University of Swaziland. But in his observed genetics lessons he did not use any models, blaming this on lack of time.

When asked about other sources of his PCK, Leon mentioned that "it is the syllabus which gives me the guide as to which topics to teach and also (the syllabus) states some of the objectives that have to be achieved when teaching this topic. That is my primary source of information of what is to be taught. Throughout the years I have used various textbooks which I have compiled into some form of notes that I give to the learners." Leon relied on curriculum documents as sources of content to be taught.

A progressive analysis of Leon's observed genetics lessons revealed that there was no significant development of PCK except for the use of more familiar examples to teach the concept of allele, which was perceived to be difficult for learners to comprehend. Analysis of the teacher questionnaire (ref. 4.6; Appendix W) and written reports in his reflective journal (ref. 4.8.2; Appendix X) all show that, based on his reflections on the observed lessons, Leon had resolved to improve his lessons, especially on assessment. Specifically, he intended to include learners' exercises to immediately assess their understanding of the genetics concepts the next time he taught the same concepts. In doing so, he would be likely to obtain learner feedback that could be used to improve his teaching.

What was of interest in his several years of teaching experience was that Leon did not indicate in his lesson plans or demonstrate in his teaching that he had any ideas or knowledge of learners' preconceptions with regard to genetics. If he did have, he did not demonstrate this as teaching points in the lessons observed. Besides, he failed to teach the processes of mitosis and meiosis arguing that the processes or their stages are not required by the syllabus as it states that "… details of stages are **not** required" (ECOS, 2009:21). But his interpretation was somehow misconstrued in the sense that without going into the process of meiosis, for example, and its stages, it would be difficult for learners to handle other genetics concepts demanded by the syllabus such as solving Mendelian genetic problems, which require them to calculate and predict the results of monohybrid crosses involving ratios. Leon appeared to be limited by the syllabus and did not see the topic or syllabus as an integrated whole. He taught only the 'what' and to some extent the 'why' of mitosis and meiosis, without addressing the 'how'. This observation about his content knowledge and knowledge of learners' preconceptions does raise some questions about the influence, if any, of his many years of teaching experience on his PCK development. Then one is left to surmise that Leon has been teaching the same way for many years, perhaps the way he did during the first years

of his teaching. Again this observation would appear to re-emphasize Magnusson et al.'s (2001) earlier assertion that years of teaching experience only is no guarantee of PCK development. Rather, as part of their everyday practice teachers should reflect on the nature and types of successes and difficulties their learners experience or encounter as a result of their teaching as a way of enhancing the development of PCK (Drechsler & Van Driel, 2008).

In sum, Leon might have developed his limited PCK in genetics teaching from the formal teacher education programmes that he received, his classroom teaching experiences and professional development workshops.

5.2.4 Lillian

Lillian indicated at pre-lesson interviews that she envisioned her learners to be properly acquainted with the correct definitions and conceptions of chromosomes, genes and alleles, as stipulated in the biology curriculum document and their differences. She intended her learners to know how the processes of mitosis and meiosis work (ref. 4.4; Appendix V). Lillian's intentions, as evidenced in her narratives were to use her declarative and procedural subject matter content knowledge to teach genetics concepts as provided in the syllabus.

Lillian taught her various lessons on chromosomes, genes, mitosis and meiosis as laid out in the curriculum document (biology syllabus) (ECOS, 2009). She used the recommended biology textbooks and biology syllabus as her main sources of information for planning and teaching her lessons (ref. 4.5.4 first lesson observation lines 8, 9). In her teaching of chromosomes, genes and alleles, she displayed mainly declarative content knowledge (ref. 4.5.4 first lesson observation lines 8, 13). Lillian taught genetics concepts according to the learning outcomes of inheritance as stated in the biology syllabus (Examination Council of Swaziland, 2009). As observed, she followed exactly the order in which the learning outcomes were spelt out. She provided their definitions- chromosomes, genes and alleles, and stated the facts about their structure and function, as well as the relationship between them using familiar examples of human physical characteristics. Lillian exhibited other dimensions of her content knowledge, notably her procedural content knowledge to define and describe the processes of mitosis and meiosis (ref. 4.5.4 first lesson observation lines 8, 11 and 13; second lesson observation line 7). She concluded her lessons by generally explaining to the class why it was important to know about those concepts and the genetic-related processes

taught. In that sense her PCK in teaching genetics could be viewed as consisting of declarative (propositional knowledge) procedural (knowledge of processes, of knowing how) and conditional content knowledge (knowledge of why and how).

As part of her pedagogy, Lillian usually used labelled diagrams and charts drawn or placed on chalkboards to support her explanations, and to help learners visualize microscopic genetics processes and genetics concepts, for enhancing conceptual understanding (ref. 4.5.4 first lesson observation lines 9, 12; second lesson observation line 5). Scientific charts were used to help learners comprehend and visualize the stages of meiosis and mitosis (ref. 4.5.4 second lesson observation line 5). Lillian's reason for using illustrations was informed by her experience of teaching the topic. She explained at her pre-lesson interview that 'since I know that to understand the term chromosome is difficult for learners, then I have designed a strategy to use diagrams to make illustrations of chromosomes and how the genes and alleles are located on the chromosome … by using the diagrams it becomes easier for them to understand how the terms are related.' The use of charts in teaching the processes of cell division for learner accessibility (Chattopadhyay, 2005) was learned during some in-service training biology workshops organized by the Ministry of Education and Training.

Like her other counterparts Lillian, hardly used physical models, individual or teacher demonstration experiments to reinforce the theoretical concepts or processes especially the ones that lend themselves to experimental work. The reasons that the teachers did not carry out experiments in genetics teaching may include lack of equipment, lack of familiarity with appropriate equipment or lack of knowledge of appropriate practical and experimental work in genetics teaching (ref. Appendix X). Her PCK in terms of knowledge of instructional strategies may be said to have been deficient in the use of experiments and physical models. The use of physical models for illustrative purposes is likely to promote learner comprehension and recall of genetics content (Chinnici et al., 2006; Oliveira et al., 2013). It helps learners' visualize concepts and form mental maps (Lazarowitz & Lieb, 2006).

It is however interesting to note that in her teacher questionnaire and reflective notes, Lillian commented that in teaching the same genetics content next time around he would improve on her instructional strategies to include videos about chromosomes and cell division (ref. Appendix W).

Lillian seemed to have no knowledge of learners' preconceptions and learning difficulties pertaining to genetics teaching. There were no indications of those in her lesson plans and no evidence that she would use learners' existing knowledge as the basis for a teaching point. Penso (2002) maintains that practising teachers should be encouraged to consider learners' thinking and prior knowledge in lesson planning to avoid learning difficulties that learners may experience during the lesson.

In her pre-lesson interviews, however Lillian stated that she would use the questioning technique to find out learners' prior knowledge about the genetics concepts. In her observed lessons, however she used this technique to more or less review previous work on cell and fertilization. The aim was to link the previous to the new work and not to determine what prior knowledge or conceptions the learners have with regards to the topic to be taught. Thus her questioning technique did not particularly elicit learners' ideas or preconceptions of the new genetics concepts.

Lillian obtained most of her knowledge of learners' learning difficulties, including errors mistakes and misconceptions through feedback from homework assignments (ref. 4.5.4 second lesson observation line 1). Correcting learners' homework on chromosomes and genes revealed that some learners still had difficulty in defining these concepts. Some defined chromosomes as 'thread-like structures found in the cell nucleus' and did not specify that they are made up of DNA and carry genes, which the teacher expected (ref. 4.5.4 second lesson observation line 1). Interestingly enough learners' definitions of a chromosome tended to be that provided in their biology textbook, while the teacher insisted on the definition provided by the Swaziland school biology curriculum document. She presented the corrections by simply stating the expected response with no emphasis on how previous errors could be avoided. It would really be a matter of speculation that if Lillian had prior knowledge of learners' preconceptions of chromosomes and genes she could have more easily addressed possible learning difficulties before or during the lesson in a systematic and enduring way. When asked in the questionnaire about her anticipation of learners' preconceptions, she simply indicated that she had none (ref. 4.6; Appendix W Item 3).

This inadequacy of PCK in terms of insight into learners' preconceptions was common among the participating teachers. This finding calls for further investigation into the reasons

why teachers despite their many years of teaching experience of particular topics appear to lack knowledge of learners' topic–specific preconceptions and learning difficulties. This finding is similar to that of recent studies (e.g. Ijeh, 2012) in the South African context, where it was found that experienced and successful mathematics teachers lacked knowledge of learners' preconceptions in statistics teaching in their competence repertoire.

In her pre-lesson interview, post-teaching questionnaire and written reports, Lillian confirmed the use of oral questioning and homework assignments as strategies that she uses to assess how well her learners have understood the lesson and to gain insight into the learning difficulties they have with the topic. Lillian attributed learners' difficulty in grasping genetics concepts to two reasons. First, learners come across genetics terms for the first time, because they are not taught or exposed to genetics related topics at the lower school end (ref. 4.7; Appendix Y) and secondly, the terms used are somewhat abstract and not visualizable to learners (ref. 4.6; Appendix W). In an attempt to address learners' difficulties, Lillian claimed that she uses diagrams to show the relationships among the terms, changes her teaching methods, assigns to her learners further reading, gives more exercises for practice, and encourages them to help one another as peers (Appendix W item 9; ref. 4.7; Appendix Y).

In summary, Lillian's presumed PCK in teaching genetics topics is profiled in terms of her ability to use the recommended biology textbooks and the syllabus to plan her lessons. Her PCK components profile in genetics teaching consisted mainly of declarative, procedural and conditional content knowledge. Her topic-specific instructional strategies comprised the use of familiar examples, labelled diagrams and scientific charts to put across specific ideas in ways she hopes they would be accessible to learners. However she did not have knowledge of learners' preconceptions of the genetics concepts to be taught but was able to identify some learners' errors and difficulties through aspects of her questioning technique and homework assignments.

Lillian's responses to the post-lesson interview (ref. 4.7) suggest that her presumed PCK of teaching genetics concepts had developed through classroom practice and learning experiences over time. In her formal education, Lillian received further university training in biology teaching. She holds a Bachelor of Science degree with biology as her major subject and a Postgraduate Certificate in Education. Through this training, Lillian reported to have

increased her content knowledge of genetics and learned about various teaching methods and strategies (ref. 4.7).

Lillian has five years of biology teaching experience and was the least experienced participating teacher. She stated in her post-lesson interview (ref. 4.7) that teaching genetics over the years had helped her improve her teaching. She attributed most of her success to collaboration with in-school departmental colleagues who had taught genetics for many years. Lillian benefited from interactions between teachers in her school science department where expertise is shared through collaborative discussions in informal settings. For instance, collaboration with an experienced colleague helped her explain what are presumed to be difficult topics to teach such as mitosis and meiosis better.

Lillian attended in-service biology workshops organized by the in-service department of the University of Swaziland and Ministry of Education and Training that dealt with different teaching approaches and strategies. From these workshops, she gained pedagogical knowledge of the use of teaching aids or illustrations such as scientific charts and diagrams in teaching the processes of cell division.

In addition to disciplinary education, professional development and collaboration with colleagues, Lillian mentioned biology curriculum documents such as the syllabus and recommended textbooks as her other sources of PCK. She used the syllabus as a source of the content to be taught and the sequence in which it should be taught. She consulted a range of textbooks from which she sourced explanations, diagrams and examples that seemed appropriate for her learners.

A progressive analysis of her observed genetics lessons indicated that Lillian gained knowledge of learners' errors during the lessons and marking homework assignments. After reflecting on her observed genetics lessons, Lillian decided to improve her practice by assigning learners to read about the topic prior to lessons and allowing them to discuss and present in groups, using a video to show chromosomes, and describing the stages of mitosis and meiosis in greater detail (ref. 4.6; 4.7).

The finding that reflection on the taught genetics lessons led the teachers to think about how they would improve their lessons was common with all the four participating teachers. The outcome of their reflecting or critical thinking exercise would tend to confirm the suggestion that, given the enabling environment and support, PCK (or aspects of it) is not stagnant (Miller, 2007), but is liable to change. What appears to be lacking generally with the participating teachers is the failure to engage in reflective or critical thinking as evidenced in their lesson plans (ref. 4.2). Teachers should possibly be encouraged to use logbooks or journals to record their lessons, successes and failures, and how they can improve them. In this way, their PCK would invariably be seen as dynamic and not something that is static.

In summary, Lillian might have developed her PCK in genetics teaching through formal university education programmes, classroom teaching experience, collaboration with departmental colleagues and in-service training workshops.

5.3 Evaluation of the theoretical framework

This section presents an evaluation of the study's theoretical framework. It seeks to explore the extent to which the framework was useful in addressing the research questions. The study investigated teachers' PCK in terms of three components: content knowledge, pedagogical knowledge (knowledge of instructional strategies) and knowledge of learners' preconceptions and learning difficulties.

A teacher's PCK is said to be complex, constituted by what the teacher thinks, knows and does (Baxter & Lederman, 2001), necessitating the use of multiple sources of data to try to capture it. The four participating teachers' content knowledge of school genetics was examined with concept maps, teacher interviews, lesson observations and lesson plans as data collection instruments. In using these instruments, the researcher intended to determine the school genetics content knowledge, even by proxy as it were, that the participating teachers have and demonstrated in classroom practice. What could be gathered from the results of the study is that the instruments enabled the researcher to capture the teachers' PCK in terms of their content knowledge in genetics teaching. The concept map was used as a proxy to indirectly determine the teachers' knowledge of the curriculum content, but was not sufficient to measure how knowledgeable the participants were about the curriculum content (ref. 4.3). It provided knowledge of the concepts the teachers considered key in school genetics, the

logical sequence in which they ought to be taught, and the relationships among them. Instruments that measure content knowledge directly, such as multiple choice or essay type questions could have been used (Abell, 2007; Juttner et al., 2013; Miller, 2007), but these instruments do not always reveal depth of knowledge (McConnell et al., 2013). The participants may not always include the detail desired. In addition, it might prove difficult to get teachers to write tests. Therefore, concept mapping was considered a good substitute for assessing the participating teachers' content knowledge (Abell, 2007). Concept maps have been used in other recent related studies on PCK (Ijeh, 2012; Usak, 2009) for assessing teachers' curriculum and content knowledge. Thus, the concept mapping exercise was regarded as useful. The qualifications the teachers obtained from university were another alternative (Baumert et al., 2010) that could have been used to assess their content knowledge. However, reviewing or considering the qualifications only without interviewing the teachers about what they know and observing how they demonstrate their content knowledge in classroom practice might not be sufficient to assess teachers' content knowledge of a topic. More so when it is assumed that PCK is manifest at different stages of the teaching process which includes lesson planning, pre- and post-interactive classroom teaching, and post-active teaching (Hashweh, 2005).

Teacher pre-lesson interviews were used to determine the content the teachers planned to teach and how they would present it to their learners. In this study the interview schedule yielded information on the genetics concepts they planned to teach, what they wanted learners to know, the rationale for learners knowing it, and additional knowledge the teachers possessed about these genetics concepts (ref. 4.4). Interviews have been used to study science teachers' content knowledge (Kapyla et al., 2009; Ozden, 2008). Given that interviews can provide only limited insight into a teacher's PCK, because PCK is tacit and not easily explicated by teachers (Loughran et al., 2004), lesson observations were used. Tacit knowledge is personal and intuitive, and is difficult or impossible for a teacher to articulate; instead the teacher demonstrates this knowledge through actions or with created objects (McMillan & Schumacher, 2010). Therefore, if PCK is tacit, judging the teachers' genetics content knowledge without observing how they demonstrate it in the classroom may not have been sufficient to determine whether the teachers possess adequate content knowledge of the topic, as alluded to earlier. Hence, lesson observation was used to examine the teachers' content knowledge and how they demonstrate it in the context of genetics teaching. It also

provides the connection between teachers' thinking and classroom practice (Kapyla et al., 2009). A number of research studies (e.g. De Jong, 2010; De Jong et al., 2002) maintain that teachers' PCK is rooted in classroom practice, thus supporting the belief that lesson observation is a useful tool to assess teachers' PCK. Other studies (e.g. Ijeh, 2012; Rollnick et al., 2008) have used lesson observation to assess teachers' subject matter knowledge of chemistry (Rollnick, et al., 2008) and school statistics (Ijeh, 2012) topics. Through the use of lesson observation in this study, it was possible to identify the nature of the genetics content knowledge that the teachers predominantly used, namely, declarative and procedural knowledge in teaching the particular genetics concepts.

The pre-lesson interviews, lesson plans, lesson observation, teacher questionnaire, reflective notes and learners' work samples were used to assess the pedagogical knowledge (knowledge of instructional strategies) the participating teachers used in teaching school genetics. The pre-lesson interviews focused on how the teachers had planned to teach the lessons on genetics. They provided information about the lesson objectives, instructional approaches or strategies, and resources or teaching materials the teachers had planned to use in teaching the genetics topics. The questionnaire concentrated on what the teachers did when teaching the observed genetics lessons on chromosomes, genes, mitosis and meiosis, and document analysis was used for triangulating the data. The questionnaire revealed many aspects of the teachers' PCK, such as knowledge of instructional strategies and learners' learning difficulties, if any. Loughran et al. (2006, 2012) regard teachers' pedagogical knowledge as fundamental to the development of PCK. Having determined the teaching component of the teachers' PCK in genetics teaching through teacher questionnaire instrument, lesson observation and document analysis of learners' notebooks and the biology syllabus, the researcher concludes that pedagogical knowledge is a usable construct for determining the richness of the PCK necessary for teaching school genetics. Post-lesson teacher interviews elicited the teachers' educational backgrounds, such as formal university education qualifications, classroom teaching experience and attendance of in-service training workshops, which seem to have contributed to the development of their pedagogical knowledge of the topic of genetics (ref. 4.7; Appendix X).

In sum, using both content knowledge and pedagogical knowledge as components of the PCK theoretical construct for this study appeared to be helpful in identifying the three dimensions

of teachers' content knowledge: declarative, procedural and conditional knowledge that teachers use and demonstrate in teaching school genetics. The instruments developed with the framework were regarded as adequate to assess teachers' content and teaching knowledge in genetics, and the theoretical framework can thus be taken as being valid and sufficient.

The framework offered opportunities to discover whether the teachers had or did not have knowledge of learners' preconceptions and learning difficulties. Identifying and addressing learners' learning difficulties is crucial in genetics teaching (Lewis & Kattmann, 2004; Treagust & Duit, 2008). Some researchers (Gullberg et al., 2008; Morrison & Lederman, 2003; Penso, 2002) argue that a teacher who lacks the facility to identify and address learners' areas of difficulty is not likely to teach scientific concepts effectively, particularly genetics concepts (Lewis & Kattmann, 2004; Yilmaz et al., 2011). Through lesson observation, review of teacher reflective notes, face to face interviews and document analysis of learners' notebooks we were able to surmise that the teachers used oral probing questioning, classwork and homework assignments to identify learners' learning difficulties in genetics teaching. The knowledge of learners' learning difficulties can be regarded as a crucial component of the PCK theoretical framework in assessing or examining the richness of the individual teacher's PCK in the context of teaching school genetics concepts.

The lesson observation, teacher written notes, questionnaire and document analysis were critical in examining teachers' knowledge of learners' preconceptions as suggested by Penso (2002) and Morrison and Lederman (2003), but did not elicit learners' preconceptions in genetics teaching. The instruments used in this study revealed that the teachers do not have knowledge of learners' preconceptions in genetics teaching. From the lesson observations, it was not possible to determine learners' preconceptions because the teachers employed instructional strategies which did not elicit them. Instead, they elicited learners' previous knowledge related to learning the new topic. It appeared that the teachers did not have knowledge of instructional strategies that might have been necessary to determine the learners' preconceptions in genetics teaching. The possibility of using learners' preconceptions as a theoretical framework for examining teachers' knowledge of learners' preconceptions needs further study. Morrison and Lederman (2003) and Penso (2002) have emphasized that learners' preconceptions and learning difficulties should be taken into account at the planning and the delivery stages of the lesson for effective teaching to occur.

5.4 Chapter summary

The chapter was introduced by highlighting briefly the research questions and the components of PCK that were used as a theoretical framework for this study. Overall, the participating teachers demonstrated that they possess the necessary content knowledge of school genetics teaching. However, their teaching knowledge comprised mainly declarative content knowledge, which they used to put across the facts and principles about the genetics concepts, of particularly chromosomes and genes. Procedural and conditional content knowledge was used by three teachers to describe the processes of mitosis and meiosis. The topic-specific instructional strategies employed by the teachers in teaching genetics concepts involved context based teaching approach using familiar examples; the classroom pedagogy involved the use of mainly illustrations of labelled diagrams. All four teachers lacked knowledge of learners' preconceptions of genetics topics of chromosomes, genes, mitosis and meiosis. Three teachers identified learners' errors and difficulties through peer teaching, oral probing questioning technique, classwork and homework assignments.

The teachers' PCK in genetics teaching is assumed to have developed mainly through formal university education programmes and the use of recommended biology textbooks and curriculum documents as sources of information for lesson planning and teaching. The teachers also attended several in-service workshops which might have contributed to their PCK in genetics teaching. The chapter ends with an evaluation of the theoretical framework indicating its usefulness in developing data collection instruments to answer the research questions.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Chapter six provides a synopsis of the study. It draws together the research questions that guided the investigation, methodology and research findings, and presents the conclusions and educational implications of the study. The chapter concludes with thoughts on the study, and recommendations for future research.

6.2 Synopsis of the study

This study was about the pedagogical content knowledge (PCK) of four selected biology teachers that were deemed successful in the context of teaching genetics at high school in Swaziland. The purpose of this qualitative study was to explore and describe the pedagogical content knowledge and its development in genetics teaching, which, it was assumed, the four participating biology teachers already possessed. The study sought to answer four research questions:

1. What content knowledge of genetics do biology teachers who are considered successful have and demonstrate during classroom practice?
2. What instructional strategies do these teachers use in teaching genetics?
3. What knowledge of learners' preconceptions and learning difficulties, if any, do these teachers have and demonstrate during classroom practice?
4. How do these teachers develop pedagogical content knowledge in genetics teaching?

Chapter One focused on the background to the study. It introduced the reader to the research problem, and provided a backdrop for the rationale, and significance of the study in relation to teacher knowledge in the teaching of genetics, a biology topic that is considered difficult to learn (Van der Zande et al., 2012; Williams et al., 2012). Chapter Two provided an evaluative synthesis of the literature, which informed the methods of data collection and analysis, assumptions of the study, and the theoretical framework used to address the research questions. In Chapter Three, the research procedures employed in this study were outlined. A qualitative research approach via the case study method was used to explore teacher knowledge and its development. The fourth chapter reported the results of the four case studies. The PCK profile of each of the four participating teachers was described, and how

this was presumed to have developed. Chapter Five provided a discussion of the results and major research findings with a view to providing further insights into the topic under study. This sixth and last chapter provides a synopsis of the study and concludes with recommendations for teacher education and future research, including limitations of the study.

6.3 Summary of teacher PCK profiles and development

The results of the study are summarized in line with the theoretical framework.

6.3.1 Teachers' content knowledge in genetics teaching

All four teachers who participated in this study used mostly declarative content knowledge in the form of stating the facts or the 'what' (Krathwohl, 2002) to teach the definitions and explain the genetics topics of chromosomes, genes and alleles (ref. 4.5.1–4.5.4). These concepts are known to be problematic and learners find them hard to grasp and distinguish (Lewis et al., 2000b). Predominant use of declarative or propositional knowledge was supposedly influenced by the Swaziland General Certificate of Secondary Education (SGCSE) biology curriculum document, which required learners to know only definitions of these concepts. The document states that 'define the terms: chromosome as a thread of DNA, made up of genes; gene as a section of DNA, which codes for the formation of a protein, controlling a specific characteristic of the organism; allele as an alternative form of a gene' (Examination Council of Swaziland, 2009:21). In Swaziland, there is no teaching syllabus for high-school level, and teachers use an assessment or examination syllabus (Swaziland General Certificate of Secondary Education (biology)). An examination syllabus, as it might be expected, does not support the teacher in presenting content as well as a teaching syllabus would. The development of a biology teaching syllabus for high-school level needs to be considered in Swaziland.

With regard to the teaching of biological processes such as mitosis and meiosis, three of the four teachers, Lucy, Lily and Lillian, used predominantly their procedural content knowledge with supporting activities that included content knowledge about cell division and illustrations to make the stages accessible to more learners (ref. 4.5.1–4.5.4). The decision to deploy declarative content knowledge or procedural content knowledge was probably determined by the nature of the topics to be taught. In mitosis and meiosis, as stated, the

syllabus does not require the learners to know the details of the stages of the processes that occur. Lack of detail or specifics about what is expected of the teacher in teaching those processes could be confusing. For instance, Leon, the fourth teacher, interpreted the curriculum document differently, and consequently did not teach the stages of the processes of cell division (ref. 4.5.3 first lesson observation lines 17–23). One would suspect that his PCK of teaching the topics of meiosis and mitosis would consist merely of the descriptions as expressed in the document. This was evident in what he did (ref. 4.5.3) and what he responded to during the interview session (ref. 4.4).

Lucy, Lily and Lillian used their conditional content knowledge to teach the processes of cell division by explaining why these processes were important in an organism for growth and replacement of cells, and sexual reproduction, in addition to describing their stages. The other teacher, Leon, was deficient in or did not demonstrate the use of conditional content knowledge, which seeks to explain 'the how and why' (Paris et al., 1983) about biological concepts and principles (Juttner et al., 2013).

In summary, all four teachers provided some explanation of the definition of the concepts of chromosomes, genes, mitosis and meiosis, using primarily their declarative or propositional content knowledge. Three teachers were able to show the use of conditional content knowledge, which is much needed in biology (Juttner et al., 2013).

The teachers claimed that their content knowledge had been developed through formal education programmes such as university courses, classroom teaching experiences of the topic, and the use of recommended textbooks and biology curriculum guidelines for planning and teaching their genetics lessons (ref. 4.7; Appendix X).

6.3.2 Teachers' pedagogical knowledge in genetics teaching

The four participating teachers normally used daily life examples familiar to their learners to introduce their lessons on chromosomes, genes and alleles. They began their teaching by drawing learners' attention to observable features (macroscopic level) of genetics-related human characteristics before linking them to the microscopic and sub-microscopic levels of the organism. Illustrations, such as labelled diagrams sourced from recommended biology textbooks, were displayed on the chalkboard to help learners visualize the genetics concepts. Lillian used scientific charts to illustrate the stages of the processes of cell division. Leon

used familiar examples to teach the difficult concept of alleles. In addition, Lucy used analogies and learner-constructed physical models to promote learners' conceptual understanding of chromosomes and genes. In teaching biology, models and analogies are useful. They enhance learners' comprehension of science content by linking new knowledge with their existing knowledge structures. They help learners visualize abstract or unobservable phenomenon and make sense of physical reality. They may arouse learners' interest in the new content (Coll et al., 2005; Oliveira et al., 2013; Treagust & Harrison, 2000; Venville & Treagust, 1997). In sum, the four teachers can be said to have used topic-specific instructional strategies such as familiar examples, illustrations, and analogies to teach the genetics concepts and make them more accessible to their learners.

Experimental work and teacher-prepared physical models were absent from the teachers' lesson plans and the lessons that were observed. As indicated earlier (ref. 5.2), this omission is of concern because the use of learner experiments and models is viewed as a major instructional strategy specific to science, which should be encouraged (Juttner et al., 2013; Magnusson et al., 2001). The reasons that the teachers did not carry out experiments in genetics teaching were not clear. Speculation may point to lack of equipment or lack of knowledge of appropriate practical and experimental work in genetics teaching.

All four teachers stated in the teacher questionnaire and reflective notes that the next time they taught the same genetics content they would improve their lessons in various ways such as using videos (ref. 4.6; 4.8.1). Reflective thinking on practice is likely to improve teaching and therefore teachers should have a philosophy of reflection in order to improve their practice and perhaps learner achievement.

The teachers' knowledge of instructional strategies in genetics teaching is assumed to have developed through formal education programmes such as university methods courses, and classroom practice, such as planning and teaching genetics lessons using recommended textbooks. Other sources of the development of this component of PCK were attendance at in-service biology workshops and collaboration with in-school departmental colleagues.

6.3.3 Teachers' knowledge of learners' preconceptions and learning difficulties in genetics teaching

Knowledge of learners' preconceptions was lacking in all four participating teachers. Examination of the lesson plans revealed that they did not show evidence of having prior knowledge of learners' preconceptions in these topics. They should have used this knowledge in lesson planning by including activities to prevent or minimize potential learning difficulties (ref. 4.4). During the pre-lesson interviews, the teachers claimed that they would use the oral probing questioning technique to elicit learners' prior knowledge. This technique, as observed during the lessons, elicited only learners' knowledge about previously taught concepts and not their ideas about the new concepts (ref. 4.5.1–4.5.4). Teachers should consider learners' preconceptions at the planning stage of their lessons and include activities to eliminate possible difficulties so that effective teaching and learning take place (Morrison & Lederman, 2003; Penso, 2002), particularly for genetics topics (Yilmaz et al., 2011).

The participating teachers all lacked knowledge of learners' preconceptions in genetics teaching, despite their training and many years of genetics teaching experience. Besides, all of them would have attended biology in-service workshops. The finding that all of these teachers lacked insight into learners' understanding of the content raises questions about their classroom practice, notably their assessment techniques and reflective practice. This finding may be attributable first to the teachers' classroom practice. For instance, as evidenced in their lesson observations (ref. 4.5.1 – 4.5.4) and document analysis (ref. 4.8), the teachers' assessment techniques were not always intended to be diagnostic or formulated in ways to gain insight into learners' existing conceptions. Oral questioning was mostly directed to the whole class rather than individually. Recall or closed-type questions, as opposed to open-ended questions, were characteristic of all four teachers' questioning technique. Again, written assessments consisted mainly of recall questions requiring learners to regurgitate facts. 'Why' questions, which require learners to think critically and give reasons for their viewpoints, were either absent or rare in the teachers' assessment procedures. This type of questioning (why question) is essential for effective biology teaching. In biology teaching and learning, learners should learn the 'what', 'how' and 'why' of things, which is declarative, procedural and conditional knowledge (Juttner et al., 2013). Probing questioning techniques and open-ended questions would allow the teachers to develop a knowledge base of learners' preconceptions or misconceptions and difficulties. Knowledge of these helps the

teacher to plan lessons in ways that take such knowledge into account. Interestingly enough none of the teachers included knowledge of learners' preconceptions and learning difficulties in their lesson plans as teaching points to be used on learners' behalf. Generally, if the teachers' assessment procedures were effective they would be able to obtain learner feedback. Learner feedback is important information for teachers; however, it seems the easiest task to neglect by the teachers.

Second, all four teachers' lack of prior knowledge of learners' preconceptions in genetics teaching and learning, despite many years of teaching experience, may be attributable to the absence of reflective processes or reflective thinking in the teachers' competence repertoire. As indicated earlier, the teachers' lesson plans gave no evidence that they knew or had any ideas about or took into account learners' preconceptions in genetics teaching. In most cases, all four teachers indicated that they relied on biology curriculum documents and recommended textbooks as their main sources of information for teaching content and assessment (ref. 4.7). In Swaziland, teachers do not use teaching portfolios, journals or diaries to record thoughts or reflections about the successes, failures and possible improvements or adjustments in their classroom practice. Both pre- and in-service teacher education programmes in the country seem not to emphasize reflective or critical thinking skills as part the teacher preparation programmes as recommended. Current research, however, indicates that the ability to think reflectively is crucial not only for teachers' success in the classroom, but also as a lifelong skill (Leonard et al., 2009). In light of this finding, teacher reflective thinking skills ought to be a major objective or outcome of any teacher education programme.

Again, the finding reinforces Magnusson et al.'s (2001) assertion that years of teaching experience only is no guarantee for PCK development. Rather, as Drechsler and Van Driel (2008) have noted, the impact of teachers' classroom experience in PCK development is enhanced by teacher reflections on the nature and type of successes and difficulties their learners experience or encounter as a result of their teaching. Furthermore, Leonard et al. (2009) support the idea of encouraging teachers to reflect on their teaching, as teachers are likely to develop PCK by doing so. So it could be said that teachers who lack the skill and practice of reflection are at a disadvantage to develop rich PCK.

Three of the four teachers identified learners' difficulties in learning about the topic through oral questioning, learner presentation (peer teaching), and classwork or homework

assignments. These included incomplete definitions of chromosomes and genes; confusion arising from the use of the terms 'homologous chromosomes' and 'chromatids'; and not grasping the processes of mitosis and meiosis (ref. 4.5.1–4.5.4). With the definition of the terms, it was not always clear whether learners had conceptual problems or linguistic ones. For the processes of cell division, the difficulty seemed to lie first in the similarity of the terms mitosis and meiosis as well as passage of genetic information during replication of chromosomes.

The teachers became aware of learners' learning difficulties through classroom teaching experiences such as learners' responses to oral questioning, written work involving classwork and homework assignments and peer teaching (ref. 4.5.1–4.5.4; ref. 4.6; Appendix W). The teachers thought the learning difficulties arose because genetics concepts are abstract and not readily observable, and learners meet genetics terms for the first time at this school level (ref. 4.6; 4.7). The teachers tried to resolve learners' difficulties through individual and group work explanations of concepts; the whole class review of class and homework assignments, and learner peer tutoring as an additional strategy for obtaining information on what the learners know and do. Peer tutoring was probably used because one who has newly learned the concepts is always likely to teach his or her peers in a stepwise fashion paying attention more to small details which the teacher as an expert would probably overlook.

6.4 Conclusions of the study

In concluding, the study has been an attempt to explore the PCK in genetics teaching of four biology teachers and how they each developed it. The findings of the study led to the following conclusions:

- The four teachers demonstrated the necessary content knowledge to teach genetics at high-school level. The study defined content knowledge using three dimensions: declarative, procedural and conditional knowledge. All four teachers used their declarative or propositional content knowledge to provide facts, definitions and explanations of the genetics concepts and terms and processes. However, three of the four teachers used mostly procedural and conditional content knowledge in teaching the biological processes of mitosis and meiosis. In biology, the use of conditional knowledge is essential. One teacher did not demonstrate the use of procedural and

conditional knowledge in teaching the genetics processes because of his erroneous interpretation of the biology syllabus. He did not see the need to teach the stages of the processes, since the curriculum document stated that details of the stages were not required.

- In the pedagogical knowledge component of PCK, all four teachers introduced their genetics topics with everyday examples or contexts that were familiar to their learners. The use of familiar contexts is likely to arouse learners' interest in learning the genetics content, make the lesson relevant to their lives, and improve learner performance (Kazeni & Onwu, 2013; Williams et al., 2012). This use of familiar contexts and examples is followed up, where necessary, with illustrations to aid learners to visualize processes and more abstract genetics concepts (Chinnici et al., 2006). One teacher (Lucy) used other instructional strategies such as advance organizers and peer teaching that takes into account learners' pre-existing knowledge; the use of physical models, and analogies such as a recipe book to represent chromosomes and genes to promote meaningful learners (Law & Lee, 2004; Yilmaz et al., 2011). Other instructional strategies included the diagnostic use of probing questioning technique, classwork and homework assignments to assess how well learners understood the taught genetics concepts and to identify their learning difficulties.
- None of the four teachers demonstrated prior knowledge of learners' preconceptions associated with some genetics concepts and terms. This could be owing to a lack of reflective practice on the part of teachers generally in Swaziland where they hardly use logbooks/journals/ diaries to record thoughts about the successes, failures and possible improvements or adjustments in their lessons. This is evidenced in their lesson plans, where there was no indication of how they took into account any learners' preconceived ideas and likely difficulties as a possible basis for a teaching point. Learners' difficulties were generally detected through peer teaching, oral questioning and marking of written work. These difficulties were addressed in various ways, including individual or collective teacher engagement with learners.
- Based on the findings of the study, individual teachers, it is assumed, developed their PCK in genetics teaching through:
  - *Formal university education programmes*: the teachers developed their content knowledge formally through university content courses in which they had

opportunities to study the genetics content and methods courses in biology teaching, which might include genetics teaching.

- *Classroom teaching experience*: the teachers developed their pedagogical knowledge through writing and implementing lesson plans in genetics topics lessons in line with their understanding of the nature of genetics and how it should be taught. They used recommended school biology textbooks, other sources of information including curriculum documents and publications to augment their content and pedagogical knowledge in teaching the topic. Through the use of journals provided for this study, they reflected on their successes and failures during classroom practice (ref. 4.8.2). By reflecting on their lessons, the teachers might have the opportunity to further develop their PCK of the topic. The practice of reflective thinking ought to be encouraged in the pre- and in-service teacher education and training programmes.
- *In-service biology training workshops*: attendance at national biology workshops on how to teach difficult topics such as genetics provided further opportunity for teachers to learn about relevant instructional strategies.

6.5 Educational implications of the study

From the findings of this study, a number of implications for science teachers, teacher educators, curriculum developers and researchers emerged. The findings of this study show that the participating teachers lacked some richness in PCK in genetics teaching, particularly in the knowledge of learners' preconceptions and learning difficulties of the genetics concepts studied despite their many years of teaching experience. The finding that all four participating teachers lacked knowledge of learners' preconceptions in genetics teaching has implications for teacher education. Teacher education programmes in Swaziland do not seem to deal with learners' preconceptions of specific biology topics such as genetics during their courses. As already pointed out, the participating teachers had this knowledge deficit, despite their training and several years of teaching experience. De Jong (2010) earlier contended that in addition to field-based teaching experiences, teachers may benefit from studying learners' preconceptions with regard to specific topics during teacher education courses. It is therefore recommended that teacher education programmes in Swaziland incorporate in their programmes learners' preconceptions with regard to topics that are generally considered difficult to learn as a way of developing science teachers' PCK.

Additionally, it is essential for teacher education in Swaziland to strengthen the development of science teachers' assessment skills, including the design of assessment tasks. The focus should be on the use of assessment for learning, rather than assessing exclusively for grading. This kind of assessment would require teachers to diagnose learners' preconceptions of specific topics using appropriate tools.

Furthermore, education programmes should include reflective skills as part of their objectives for developing rich PCK. There are various ways through which this skill and practice of reflection could be promoted among teachers. As part of their teacher education training, first, teachers should be taught and encouraged to keep reflective journals or logbooks to track the successes, failures and necessary improvements of their lessons. Second, existing research providing examples of teachers' PCK should be discussed as a way of reflecting. For example, the rich descriptions of the classroom practices of the four participating teachers in this study provides material for a meaningful discussion of the teaching of the genetics concepts. The lesson transcriptions could be used effectively in teacher education programmes when discussing instructional practices related to chromosomes, genes, mitosis and meiosis.

This study found that the three dimensions of declarative, procedural and conditional content knowledge were all important for teaching genetics. However, three of the four participating teachers demonstrated all three knowledge dimensions in their teaching of the genetics concepts, but the other teacher used only declarative knowledge. The fourth teacher's deficit in content knowledge may be attributable to misinterpretation of the biology curriculum document. The results of the study showed that the curriculum document was the most influential determinant of the participating teachers' content knowledge and served as knowledge source and knowledge organizer. In Swaziland there are currently no teaching syllabuses for the high school level and teachers rely on examination or assessment documents for teaching. Such documents lack the detail that would guide a teacher on what and how to teach a particular topic. Owing to the lack of detail, they may be prone to many interpretations. In this study, the teachers interpreted the syllabus differently and not always in ways that benefited learners. There is need therefore for teacher professional developers to familiarize teachers with the expectations of the curriculum documents in order to avoid misinterpretations as an immediate and short-term response. As a long-term solution, curriculum developers should develop a teaching syllabus for the high-school level that

would provide more guidance on what and how to teach the subject, by not only listing the content to be taught, but also perhaps suggesting appropriate instructional strategies.

With regard to pedagogical knowledge, the teachers used certain recommended topic-specific instructional strategies such as familiar contexts and examples to introduce the topic and illustrations to aid learners to visualize concepts and enhance conceptual understanding. Kazeni and Onwu (2013) suggest that context-based teaching approaches are more effective in improving learner performance in genetics than traditional ones. The information can be employed by biology teachers to develop PCK for the continuous improvement of effective genetics classroom practice and incorporated in teacher education programmes for pre-service and in-service teachers. However, in this study the use of teacher-prepared physical models and demonstration or learner experiments recommended for genetics teaching (Chinnici et al., 2006; Williams et al., 2012) was rare or absent.

Research on PCK connects knowledge of teaching with knowledge of learning (Abell, 2007). This is an important base on which to build teaching expertise. The present study found that formal university education in biology is a prerequisite in developing teachers' knowledge of subject matter and pedagogy. Several attempts have been made to investigate how PCK is developed in science and mathematics. Pedagogical content knowledge is topic-specific, but little has been made to determine how PCK is developed by biology teachers in the context of teaching genetics. This study has therefore provided insight into how PCK is developed by successful biology teachers in the context of teaching genetics. It gave a detailed account of examples of the PCK of biology teachers in terms of improving learners' performance in genetics and for consideration by teacher trainers in designing and developing genetics teacher education programmes for both pre-service and in-service teachers.

The development of subject matter content knowledge of genetics renders it a vital element of PCK for teaching it at school level. During the teaching of genetics, the actions of the teachers were influenced to a greater extent by the richness of their PCK, thereby making content knowledge fundamental to their continuing learning of school genetics for the enhancement of their expertise in genetics and effective classroom practice.

In this study, formal university education in biology was found to be essential in developing teachers' content and pedagogical knowledge. The teachers' assumed PCK also developed through attendance of in-service workshops and collaboration with colleagues (ref. 4.7). Opportunities for teachers to share expertise with in- and out-of-school biology teachers could be created to improve the teaching of genetics and learner achievement.

6.6 The role of the researcher in non-participatory lesson observations

In qualitative and interpretive research, the role of the researcher has bearing on the research process, and the research findings and interpretations. It is important that in a study the position of the researcher vis-à-vis the participants and the entire project is interrogated in order to help the reader in interpreting the findings (Mertens, 2010). In this study, the researcher holds the position of curriculum evaluator at a curriculum development unit of the Ministry of Education and Training of Swaziland. In this position, the researcher does not work directly with schools or teachers. So teachers were unlikely to feel threatened or to think that the researcher was there for assessment.

Miller (2007) contended that PCK is a continuously changing unit, and during data collection researchers need to be aware of its sinuous nature, being careful not to influence teacher knowledge. In addition, assessment of teachers' capabilities and skills has integral limitations owing to the observer's own beliefs and inclinations (McMillan & Schumacher, 2010). During lesson observations, the researcher assumed a non-participant classroom observer role. The presence of the researcher and the researcher's interest, it could be argued, could influence the teachers' and learners' behaviour during the observed lessons (Creswell, 2008). For example, the teachers could have used teaching resources and instructional strategies they thought would impress the researcher, which they would not normally use in everyday classroom experience for various reasons. Also, the presence of the researcher could have influenced learners' behaviour and participation during lessons, positively or negatively.

While these are the possibilities that could have arisen during the lesson, the researcher tried to minimize the influence by introducing herself to the teachers and their learners during earlier negotiations on the logistics for the visits and lesson observations. This direct contact with the schools and teachers was established before formal observations began. The purpose of the visits was explained and it was confirmed that the video pictures would not be

published. The researcher assured the teachers that the observations were not meant to assess them, but to gain insights into how they teach their genetics lessons. The teachers were informed before the observations that they would have access to the data to verify the results, should they wish to do so.

6.7 Suggestions for future research

The results of this study highlight areas for further research. These areas are:

- Further research needs to investigate why experienced teachers still lack base knowledge of learners' preconceptions and learning difficulties in genetics teaching.
- This study found that declarative, procedural and conditional knowledge were all important for teaching genetics. Further research is needed to investigate how this applies to other areas of biology, particularly with respect to conditional knowledge. Do teachers go the extra mile to explain the how and why, particularly with the more demanding theoretical concepts (concepts by definition) in biology?
- The impact of teachers' knowledge of learners' preconceptions and learning difficulties as a theoretical framework for investigating teachers' PCK in genetics teaching needs to be further investigated.
- It would be interesting to study how teacher education programmes in biology teaching in Swaziland give practical expression to the objective of educational courses, designed to produce reflective teachers capable of engaging in reflective or critical thinking in classroom practice.

6.8 Limitations of the study

Inherent in the methodology used in this study are certain limitations, which might require caution in interpreting the results. The first limitation is that the criteria used to select teachers to participate in this study yielded only a small number from whom the researcher could select. The schools from which the participants were selected had to obtain a credit pass rate of at least 70% in biology public examinations in 2007 to 2010.

Second, using the case study method has a limitation, which has to do with the generalizability of research findings. Only four teachers took part in this study. The sample size was limited to making broad generalizations (Rule & John, 2011). However, having a

number of cases provided the possibility of similarity or variation in PCK assessment for biology teachers using the same curriculum documents such as the biology syllabus.

Third, assessment of teaching capabilities and skills is normally linked with inherent limitations as they are often influenced by the researcher's own inclinations. The lesson observation results of this study may not essentially be replicated. The process of interpreting teachers' practice and decisions, and placing them in specific pedagogical categories may not always be perfect. However, methodological triangulation through lesson plans, interview and questionnaire to confirm the lesson observations and the categories assigned minimized possible inaccuracies in interpretation.

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APPENDICES

Appendix A

Concept mapping exercise for biology teachers

Duration: 30 minutes

1. What topics or concepts do you consider to be key in the topic of genetics? List them.

2. Arrange the key concepts in a linear format showing the sequence in which you would teach them to Grade 11 learners. That is, start with the topic you would teach first and end with the one you would teach last.

3. If you were to present the listed topics or concepts in diagram format showing any relationship among them what would it look like? Draw your diagram of the key genetics concepts. Use arrows to show any connection between concepts.

Appendix B

Pre-lesson interview schedule for biology teachers on their lesson plans

Duration: 30 minutes

1. For how long have you been teaching?

2. For how long have you been teaching biology?

3. What are your academic qualifications?

4. What are your major subjects?

5. Would you tell me about your lesson plan and describe how you will carry out the lesson.

Appendix C

Lesson observation schedule for biology teachers on classroom practice

Date: _____

School: _____

Class: _____

Teacher: _____

Observer: _____

Role of observer: _____

Length of observation: _____

Lesson Topic: _____

Lesson objectives

_____
_____
_____
_____

Lesson introduction

_____
_____
_____

Content presented and how it is presented

_____
_____
_____
_____
_____
_____
_____

Learners' preconceptions

_____
_____
_____

Learners' difficulties

_____
_____
_____

Teaching strategies and activities

Presentation of lesson

Learner's involvement

Evaluation/conclusion of lesson

Reflections (insights, haunches)

Appendix D

Post-Teaching Questionnaire for biology teachers

The questionnaire was used to investigate what the teachers did while teaching genetics in Grade 11.

Duration: 20 minutes

Date: _____

Lesson topic: _____

Lesson duration: _____

Lesson objectives

_____
_____
_____
_____

1. What teaching methods and activities did you use during the lesson?

_____
_____
_____

2. What were your reasons for using those teaching methods and activities?

_____
_____
_____
_____
_____

3. What preconceptions did you expect your learners to have about the topic/concept (s)?

_____
_____
_____
_____

4. How did you find out the learners' preconceptions?

_____
_____
_____

5. What learners' learning difficulties did you anticipate in planning your lesson?

_____
_____
_____
_____

6. What did learners find difficult to understand during the lesson?

7. How did you discover or find out learners' learning difficulties?

8. What do you think made those areas difficult for learners to understand?

9. How did you address learners' learning difficulties, if at all, during the lesson?

10. What changes would you make the next time you teach the same concept/content?

Appendix E

Post-lesson interview schedule for biology teachers on how they developed their PCK in genetics teaching

Duration: 45 minutes

1. How have the courses that you learned at university/college helped you to prepare your lessons for teaching?

2. Has teaching genetics over the years helped you teach the topic better? If yes, how?

3. How do you know your teaching is effective?

4. What learning difficulties do your learners experience in learning about genetics?

5. What makes those areas difficult for learners to learn or understand?

6. If learners have any problems in understanding the topic based on the instructional approach, what do you do to help them to understand?

7. Have you ever been to a biology workshop on teacher development?

   a. If yes, what was the content, and duration of the workshop?

   b. Who were the facilitators (Biology educators)?

   c. As a biology teacher, how did you benefit from the workshop?

d. Would you recommend that similar workshops be held for teachers?

8. Have you ever been to a workshop, specifically on genetics? As a biology teacher, how did you benefit from the workshop? Would you recommend that similar workshops be held for teachers?

9. Do you collaborate with other teachers in your department about teaching? If yes, how has that helped you in your teaching?

10. What other sources of information do you use?

Appendix F

Teacher Reflective Journal Guidelines

These guidelines were to guide the biology teachers in writing reports during the four weeks of teaching genetics in Grade11. Any other relevant information could be added by the teacher during the course of teaching.

Duration: four weeks

Date: _____

Lesson topic: _____

Lesson duration: _____

Lesson objectives

_____
_____
_____
_____

1. Was your lesson effective? How do you know?

_____
_____
_____
_____

2. What were your successes during the lesson?

_____
_____
_____

3. Do you think the students learned what you intended them to learn in the lesson?

_____
_____

4. What did students find difficult to understand during the lesson?

_____
_____
_____
_____
_____

5. What do you think made those areas difficult for students to understand?

_____
_____
_____
_____

6. How did you address the learners' difficulties during the lesson?

7. What changes would you make the next time you teach the same content/concept?

8. Did your learners enjoy the lesson? What were the indicators?

9. Did learners work individually or in work? Was that the best way? Why?

10. What was the level of learner participation during the lesson?

11. Were learners confident during the lesson?

12. Did learners complete assigned tasks?

Appendix G

Letters of Permission from Ministry of Education and Training

MINISTRY OF EDUCATION

Telegrams: IMFUNDVO
Facsimile: (268) 505-6067
Telephone: (268) 5052248/9

Kingdom of Swaziland

P.O.Box 190
Manzini
Swaziland

REGIONAL EDUCATION OFFICE
MANZINI

15 September 2010

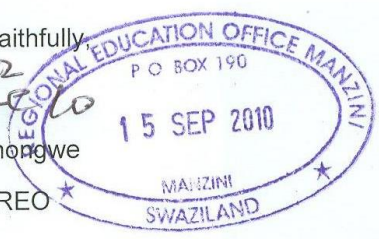
TO WHOM IT MAY CONCERN

Re: Permission to conduct research in Manzini Secondary schools

This letter serves to indicate that permission is hereby granted to the researcher; Eunice K. Mthethwa, a student at the University of Pretoria to proceed with research in respect of the study entitled "Science teachers' pedagogical content knowledge in the teaching of genetics in Swaziland".

The researcher has the responsibility to negotiate appropriate time schedules with the schools involved to conduct the research. A copy of this letter must be presented to the school principals confirming that approval has been granted for the study to be conducted.

Yours faithfully,



FOR R.S. Shongwe

Acting REO

In reply please quote
Ref: No: ……

KINGDOM OF SWAZILAND
HHOHHO REGIONAL EDUCATION OFFICE

TELEPHONE : 2404-3761/2
FAX: 2404-2955

P. O. BOX 229
MBABANE

28th June 2011

The Headteacher

……

……

Dear Sir/Madam

RE: PERMISSION TO CONDUCT A RESEARCH STUDY IN YOUR SCHOOL: EUNICE K. MTHETHWA, UNIVERSITY OF PRETORIA

This serves to confirm that the bearer of this letter, Eunice K. Mthethwa is known to the Regional Education offices as a Curriculum Evaluator at the National Curriculum Centre who has enrolled for a Doctorate degree with the University of Pretoria.

She has since approached this office seeking for permission to conduct a study in your school as a requirement for completing the programme. The Research Topic is: **Exploring Science Teachers' Pedagogic content knowledge in the Teaching of Genetics in Swaziland.**

Your office is kindly requested to allow this study and facilitate in making it feasible.

Thanking you in advance for the anticipated positive cooperation in this matter.

Yours Faithfully

for: **B.Q. DLAMINI**
REGIONAL EDUCATION OFFICER

REGIONAL EDUCATION OFFICE
PO BOX 229
2011 -06- 29
MBABANE
SWAZILAND

Appendix H

Letter to School Principals

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

28 April 2011

The School Principal

Mbabane

Swaziland

Dear Sir/Madam

Re: Permission to Conduct a Research Project in your School.

Research Project Title: Exploring Science Teachers' Pedagogical Content Knowledge in the Teaching of Genetics in Swaziland

I am a Curriculum Evaluator stationed at The National Curriculum Centre. Currently, I have enrolled for a Doctoral degree in Curriculum and Instructional Design and Development with the University of Pretoria in South Africa. As part of the programme, I am to carry out research.

I hereby request permission to conduct research in your school. The study is on the new Swaziland General Certificate of Secondary Education Science Curriculum, recently introduced in all secondary schools in the country. Its aim is to gain some insight into the teachers' Pedagogical Content Knowledge (PCK) with regard to the teaching of genetics. Genetics is one of the topics in the biology syllabus, which research says is difficult to teach and learn, hence poor learner performance. Participation of teachers in the research project will be voluntary. The good thing is that participating teachers will get an opportunity to reflect on their classroom practice based on the theoretical framework used, which include content knowledge, pedagogical knowledge and knowledge of students' conceptions and preconceptions. The findings of the study will hopefully be useful in improving pre- and in-service teacher education programmes.

The study is carried out under the Supervision of Professor G. O. M. Onwu at the University of Pretoria (Department of Mathematics, Science and Technology Education).

Should you need any clarification or have questions about the project, be free to contact me or my supervisor.

Researcher

Eunice K. Mthethwa

National Curriculum Centre

Manzini

Telephone: (00268) 25052106

Supervisor

Professor Gilbert O. M. Onwu

University of Pretoria

Faculty of Education

Science, Mathematics and Technology Education

Thanking you in advance for your anticipated cooperation in this regard.

Yours faithfully

_____

Eunice K. Mthethwa

Researcher's signature ---------- Date: ----------

Supervisor's signature ---------- Date: ----------

Appendix I

Letter of Informed Consent for Teachers

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

28 April 2011

Dear Teacher

RE: Request to Participate in a Research Project

Research Project Title: Exploring Science Teachers' Pedagogical Content Knowledge in the Teaching of Genetics in Swaziland

Kindly read the contents of this letter carefully before you decide to participate in the research project.

Purpose of the Research Study

You are kindly invited to participate in a research project aimed at gaining some insight into the teaching of genetics, a biology topic in the new Swaziland General Certificate of Secondary Education Science Curriculum, recently introduced in all secondary schools in the country.

What You Will Be Asked To Do

Participation in this research project will require you to respond to a number of research instruments including: (1) participating in a voluntary conceptual exercise on genetics based on the syllabus you are teaching, (2) drawing a concept map for the genetics concepts you teach in grade 11, (3) writing lesson plans for selected genetics concepts, (4) be interviewed about your genetics teaching and observed teaching your genetics lessons, (6) completing a post teaching questionnaire, (7) keeping a reflective journal and (8) drawing a storyline describing how your satisfaction with genetics teaching has developed over the years. These will basically seek information about your Pedagogical Content Knowledge (PCK) and how you use it to teach genetics in the classroom.

Time Required

The time duration for the different activities you will be involved in during the study varies from 10 minutes to an hour and is anticipated to take about six hours in total over a period of four weeks.

Risks and Benefits

Risks:

There is no anticipated risk or harm to you. However, you may feel a bit uneasy to have me observing your lessons, but you will soon get used to me, hopefully. The purpose of the observation and any other activity is not meant to assess you in any way and the results will not be used anywhere else outside the purpose of the study.

Benefits:

Through participating in this study, you will required to keep a log on genetics lessons, which will give you an opportunity to reflect on your classroom practice in terms of content knowledge, knowledge of student preconceptions and learning difficulties, successes and difficulties and think about how you can improve the lessons in the future. The reflections may enable you to improve your teaching knowledge and modify teaching strategies in order to enhance learner performance.

Voluntary Participation and Confidentiality

Your participation in this study is voluntary. Should you declare yourself willing to participate in the study, confidentiality is guaranteed. Your name or that of your school will not appear anywhere in the research report.

Right to Withdraw from the Study

You may decide to withdraw from the study at any stage should you wish not to continue.

Agreement: I have read, understood and considered the above, which indicate the researcher's intentions and request for my participation in the research project. I voluntarily agree to participate in the research project. I hereby show my willingness to participate in the study by signing below.

Teacher's signature ---------- **Date** ----------

Audio and Video Recording

The researcher will wish to audio-record the interviews with you and video-record the classroom observations and hereby seek your permission to do this.

Agreement: I understand that there will be audio- recording of interviews and video-taping of classroom observations, which will only be used for purposes of the research project without my name and picture appearing anywhere in the research report.

I agree to audio- recording: **Teacher's signature** ---------- **Date** ----------

I agree to video-recording: **Teacher's signature** ---------- **Date** ----------

Should you need any clarification or have questions about the research project, be free to contact me or my supervisor.

Researcher	**Supervisor**
Eunice K. Mthethwa	Professor Gilbert O. M. Onwu
National Curriculum Centre	University of Pretoria
Manzini	Faculty of Education
Telephone: (00268) 25052106	Science, Mathematics and Technology

Thanking you in advance for your anticipated cooperation in this regard.

Yours sincerely

_____

Eunice K. Mthethwa

Researcher's signature …….. Date: ……..

Supervisor's signature ---------- Date: ----------

Appendix J

Letter of Informed Consent for Learners

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

28 April 2011

Dear Learner

RE: Request to Participate in a Research Study

Research Project Title: Exploring Science Teachers' Pedagogical Content Knowledge in the teaching of Genetics in Swaziland

Kindly read the contents of this letter carefully before you decide to take part in the research study.

Purpose of the Study

You are kindly invited to partake in a research study aimed at gaining some insight into the teaching of genetics, a biology topic in the new Swaziland General Certificate of Secondary Education Science Curriculum, recently introduced in all secondary schools in the country.

What You Will Be Asked To Do

There will be no information required from you during the time of my visit and you will not be asked any questions. The researcher will only visit your class to observe your teacher teaching genetics lessons. The lessons will be video-taped. However, the focus during the observation will be on the teacher and not you. The video camera will be directed to the teacher activities and therefore your face will not appear in the recordings. Be aware that the video-tapings are meant to help the researcher reflect on the teacher's classroom practice and no pictures will be published.

Time Required

The researcher will visit your class one day a week for four weeks. The total time duration will depend on the length of your school periods.

Risks and Benefits

Risks:

There is no anticipated risk or harm to you. However, you may feel a bit uneasy to have me observing your lessons, but you will hopefully soon get used to me.

Benefits:

When the study is finished, it is hoped that we will find a better way of teaching genetics, which most people find difficult to teach and learn.

Voluntary Participation and Confidentiality

Your participation in this study is voluntary. Should you declare yourself willing to participate in the study, confidentiality is guaranteed. Your name or that of your school will not appear anywhere in the research report.

Right to Withdraw from the Study

You may decide to withdraw from the study at any stage should you wish not to continue.

Agreement: I have read and understood the above, which indicate the researcher's intentions and request for my participation in the study. I voluntarily agree to participate in the research study. I hereby show my willingness to take part in the study by signing below.

Learner's signature ---------- **Date** ----------

Video Recording

The researcher will wish to video-record the classroom observations and hereby seek your permission to do this.

Agreement: I understand that there will be video - recording of genetics lessons, which will only be used for the purpose of the study without my name and picture appearing anywhere in the research report.

I agree to video - recording: **Learner's signature** ---------- **Date** ----------

Should you need any clarification or have questions about the study, be free to contact me or my supervisor.

Researcher	**Supervisor**
Eunice K. Mthethwa	Professor Gilbert O. M. Onwu
National Curriculum Centre	University of Pretoria
Manzini	Faculty of Education
Telephone: (00268) 25052106	Science, Mathematics and Technology

Thanking you in advance for your anticipated cooperation in this regard.

Yours sincerely

_____

Eunice K. Mthethwa

Researcher's signature …….. Date: ……..

Supervisor's signature ---------- Date: ----------

Appendix K

Letter of Informed Consent for Parents

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

28 April 2011

Dear Parent

RE: Request for your Child to Participate in a Research Study

Research Project Title: Exploring Science Teachers' Pedagogical Content Knowledge in the teaching of Genetics in Swaziland

Kindly read the contents of this letter carefully before you decide for your child to take part in the research study.

Purpose of the Study

Your child is kindly invited to participate in a research project aimed at gaining some insight into the teaching of genetics, a biology topic in the new Swaziland General Certificate of Secondary Education Science Curriculum, recently introduced in all secondary schools in the country.

What Your Child Will Be Asked To Do

There will be no information required from your child during the time of my visit and he/she will not be asked any questions. I will visit his/her class to observe the teacher teaching genetics lessons. The lessons will be video-taped. Please be informed that the focus during the observations will be on the teacher. The video camera will be directed to the teacher activities and therefore your child's face will not appear in the recordings and no pictures will be published.

Time Required

I will visit your child's class one day a week for four weeks. The total time duration will depend on the length of your child's school periods.

Risks and Benefits

Risks:

There is no anticipated risk or harm to your child. However, he/she may feel a bit uneasy to have the researcher observing the lessons, but he/she will hopefully soon get used to me.

Benefits:

When the study is finished, it is hoped that we will find a better way of teaching genetics, which most people find difficult to teach and learn.

Voluntary Participation and Confidentiality

Your child's participation in this study is voluntary and confidential. Should you declare willingness for your child to participate in the study, confidentiality is guaranteed. His/her name or that of the school will not appear anywhere in the research report.

Right to Withdraw from the Study

You may decide to withdraw your child from the study at any stage should you wish him/her not to continue.

Agreement: I have read, understood and considered the above, which indicate the researcher's intentions and request for my child's participation in the research project. I voluntarily agree that my child participate in the research project. I hereby show my willingness for him/her to participate in the study by signing below.

Parent's signature ---------- **Date** ----------

Please explain the contents of the letter to your child and let him/her to sign below as an indication of his/her willingness to take part in the study.

Learner's signature ---------- **Date** ----------

Video Recording

The researcher will wish to video-record the classroom visits and hereby seek your permission to do this.

Agreement: I understand that there will be video - recording of genetics lessons, which will only be used for the purposes of the research project without my child's name and picture appearing anywhere in the research report.

I agree to video - recording: **Parent's signature** ---------- **Date** ----------

Learner's signature ---------- **Date** ----------

Should you need any clarification or have questions about the project, be free to contact me or my supervisor.

Researcher

Eunice K. Mthethwa

National Curriculum Centre

Manzini

Telephone: (00268) 25052106

Supervisor

Professor Gilbert O. M. Onwu

University of Pretoria

Faculty of Education

Science, Mathematics and Technology

Thanking you in advance for your anticipated cooperation in this regard.

Yours sincerely

_____

Eunice K. Mthethwa

Researcher's signature …….. Date: ……..

Supervisor's signature ---------- Date: ----------

Appendix L

Criteria for validating interview schedules for teachers on lesson plans and how they developed their PCK in genetics teaching

Preamble

Attached are two teacher interview schedules: pre-lesson and post-lesson interview schedules. Kindly indicate in the space provided whether the attached interview questions cover what it supposed to cover in terms of assessing the biology teachers' demographic information, educational background, content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties, which enabled them to develop their pedagogical content knowledge in the teaching of genetics.

Pre-lesson interview schedule			
	Background Information	**Options**	**Response**
	Does the schedule request for the participant' qualification(s)?	**Yes/No**	
	Does the schedule request for major subjects?	**Yes/No**	
	Does the schedule request for years of teaching experience?	**Yes/No**	
	Does the schedule request for number of years teaching biology?	**Yes/No**	
	Content knowledge	**Yes/No**	
	Does the schedule request teachers to describe their lesson plans in detail and how they would teach the lesson?	**Yes/No**	
	Can the schedule yield information on concepts to be taught in the lesson?	**Yes/No**	
	Can the schedule yield information on what the teacher intends leaners to know?	**Yes/No**	
	Can the schedule yield information on reasons why is important for learners to know the intended information?	**Yes/No**	
	Can the schedule yield information on more information the teacher know about the concepts than what he/she is going to teach?	**Yes/No**	
2	**Instructional strategies**		
	Does the schedule request teachers to describe their lesson plans in detail and how they would teach the lesson?	**Yes/No**	
	Can the schedule yield information on teaching procedures to be used and reasons for their selection?	**Yes/No**	
3	**Knowledge of learners' preconceptions and learning difficulties**	**Yes/No**	
	Does the schedule request teachers to describe their lesson plans in detail and how they would teach the lesson?	**Yes/No**	
	Can the schedule yield information on learners' preconceptions and learning difficulties?	**Yes/No**	

Comments

_____

_____

_____

NAME AND SIGNATURE OF RATTER

Post-lesson interview schedule validation		
Development of teachers' pedagogical content knowledge	**Options**	**Response**
1. Does the schedule request for how the courses studied in the university/college helped in lesson preparation?	**Yes/No**	
2. Does the schedule request how teaching genetics over the years has helped teach the topic better and how?	**Yes/No**	
3. Does the schedule request for how the teacher knows that his/her teaching is effective?	**Yes/No**	
4. Does the schedule request for learning difficulties experienced by learners?	**Yes/No**	
5. Does the schedule request for what made those areas difficult?	**Yes/No**	
6. Does the schedule request for how learners can be assisted if they experience some learning difficulties based on the instructional approach used by the teacher?	**Yes/No**	
7. If the teachers attend workshop for instance, does the schedule request to know how effective was the workshop?	**Yes/No**	
8. Does the schedule request to know of the facilitators of the workshop are biology teachers or not?	**Yes/No**	
9. Does the schedule request for the duration of the workshop?	**Yes/No**	
10. Does the schedule request for what was benefited from the workshop?	**Yes/No**	
11. Does the schedule request of the workshop participants recommend similar workshop for other teachers?	**Yes/No**	
12. Does the schedule request if the teacher attended workshops specific to genetics?	**Yes/No**	
13. Does the schedule request for what was benefited from the genetics workshop?	**Yes/No**	
14. Does the schedule request for teacher collaboration with other teachers?	**Yes/No**	
15. Does the schedule request for other sources used in teaching genetics	**Yes/No**	

Comments

_____

_____

NAME AND SIGNATURE OF RATTER

Appendix M

Criteria for validating the lesson plan and observation schedule

Preamble
Please indicate on the attached lesson plan/observation schedule with the option provided, if the schedule contains enough information for assessing a normal classroom practice in terms of lesson planning/observation and what the teacher did while teaching a particular topic.

Description	Option	Response
Planning		
Does the schedule request for lesson topic?	**Yes/No**	
Does the schedule request for lesson objectives?	**Yes/No**	
Does the schedule request for resources used during the lesson?	**Yes/No**	
Content		
Does schedule request for content taught?	**Yes/No**	
Does schedule request for how content is presented and represented?	**Yes/No**	
Instructional strategies		
Does the schedule request for teaching strategies?	**Yes/No**	
Does the schedule request for how the lesson was introduction?	**Yes/No**	
Does the schedule request for general handling of the class e.g.		
i) Classroom interaction?	**Yes/No**	
ii) Involvement of the learners?	**Yes/No**	
Does the schedule request for lesson presentation or development (progression)?	**Yes/No**	
Does the schedule request for how lesson is consolidated?	**Yes/No**	
Does the schedule request for the description of the lesson in terms of:	**Yes/No**	
i) Learners' preconceptions diagnosis?	**Yes/No**	
ii) Errors, misconceptions and difficulties?	**Yes/No**	
Does the schedule request learners' related activities?	**Yes/No**	
Does the schedule request teacher related activities?	**Yes/No**	
Does the schedule request for reflections?	**Yes/No**	

Comments

_____

_____

_____
NAME AND SIGNATURE OF RATTER

Appendix N

Criteria for validating questionnaire for teachers on PCK in genetics teaching

Preamble

The attached questionnaire aims at investigating what the teachers actually did while teaching such as strategies used, how the teacher identified learners' preconceptions and learning difficulties, how the difficulties were resolved and what the teacher plan to change the next time he/she teaches the same topic. Kindly indicate with the option provided, your opinion about using the schedule to assess what the teacher actually did while he/she was teaching genetics during the observation period.

Description	Option	Response
Instructional strategies		
Does the questionnaire request for the topic of the lesson?	**Yes/No**	
Does the questionnaires request for the duration of the lesson?	**Yes/No**	
Does the questionnaire request for the lesson objectives?	**Yes/No**	
Does the questionnaire ask for teaching methods used during the lesson?	**Yes/No**	
Does the questionnaire ask for teaching activities used during the lesson?	**Yes/No**	
Does the questionnaire ask for the reasons for the teaching methods used during the lesson?	**Yes/No**	
Does the questionnaire ask for the reasons for the teaching activities used during the lesson?	**Yes/No**	
Does the questionnaire request for how the teacher will improve the lesson next time?	**Yes/No**	
Learners' preconceptions and learning difficulties in genetics teaching		
Does the questionnaire request teachers' expectations of learners' preconceptions?	**Yes/No**	
Does the questionnaire request for how the teacher identifies the preconceptions with which learners come to the class about the topic?	**Yes/No**	
Does the questionnaire request teachers' expectations of learners' learning difficulties?	**Yes/No**	
Does the questionnaire request for information about learning difficulties that learners experienced?	**Yes/No**	
Does the questionnaire ask for how the teacher discovered learners' learning difficulties	**Yes/No**	
Does the questionnaire request for how teachers addressed learners' learning difficulties, if any?	**Yes/No**	
Does the questionnaire ask for what makes the learning of genetics difficult?	**Yes/No**	

Comments

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NAME AND SIGNATURE OF RATTER

Appendix O

Criteria for validating reflective notes guidelines for teachers on how they developed their PCK in genetics teaching

The attached is a guideline for teacher written reflective reports for a period of four weeks for teaching genetics. The guideline focuses on the effectiveness and successes of the lesson, what has made the lesson easy or difficult, where the learners' learning difficulties lie during the teaching of genetics and changes would be made to improve the lesson. Kindly indicate with the options provided, your opinion about using the guidelines to assess the effectiveness and successes of the lesson and what has made it easy or difficult.

Description	**Options**	**Response**
Does the written reflective notes guidelines request for lesson topic?	**Yes/No**	
Learners' learning difficulties		
Does the written reflective notes guidelines request for information about the learning difficulties learners experienced during the lesson?	**Yes/No**	
Does the written reflective notes guidelines request for information about what made those areas difficult for learners?	**Yes/No**	
Does the written reflective notes guidelines request for how the teacher addressed learners' difficulties which learners have in genetics teaching?	**Yes/No**	
Instructional strategies used for teaching		
Does the written reflective notes guidelines request for lesson objectives?	**Yes/No**	
Does the written reflective notes guidelines request for lesson effectiveness?	**Yes/No**	
Does the written reflective notes guidelines request for successes of the lesson?	**Yes/No**	
Does the written reflective notes guidelines request on achievement of lesson objectives?	**Yes/No**	
Does the written reflective notes guidelines request for information about learners' enjoyment of the lesson?	**Yes/No**	
Does the written reflective notes guidelines request for information about the organisation of the class during the lesson?	**Yes/No**	
Does the written reflective notes guidelines request for information about learner participation during the lesson?	**Yes/No**	
Does the written reflective notes guidelines request for information about learners' finishing of assigned tasks?	**Yes/No**	
Does the written report schedule request for the changes that the teacher will make next time with regards to the difficulties encountered while teaching the topic both on the part of the teacher or the learners?	**Yes/No**	

Comments

NAME AND SIGNATURE OF RATTER

Appendix P

Criteria for validating concept mapping exercise

Description	Options	Response
Does the concept mapping exercise require participants to list all key concepts for the topic of genetics (Inheritance) in the SGCSE biology curriculum?	**Yes/No**	
Does the concept mapping exercise require participants to arrange the listed concepts in hierarchal form?	**Yes/No**	
Does the concept mapping exercise require participants to show the relationship among the key concepts using a diagram?	**Yes/No**	

Comments

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NAME AND SIGNATURE OF RATER

Memorandum for concept mapping exercise

This rubric indicates how to evaluate the concept maps drawn by the participating teachers. It allocated marks, first, to the number of correct key topics or concepts that were listed; and second, to the number of concepts that were correctly arranged; and it deducted marks for incorrect arrangement of concepts. The Swaziland General Certificate of Secondary Education (SGCSE) biology syllabus was used as a basis for assessing teachers' concept maps in terms of key topics/terms, sequence and the linkage or relationship among the concepts.

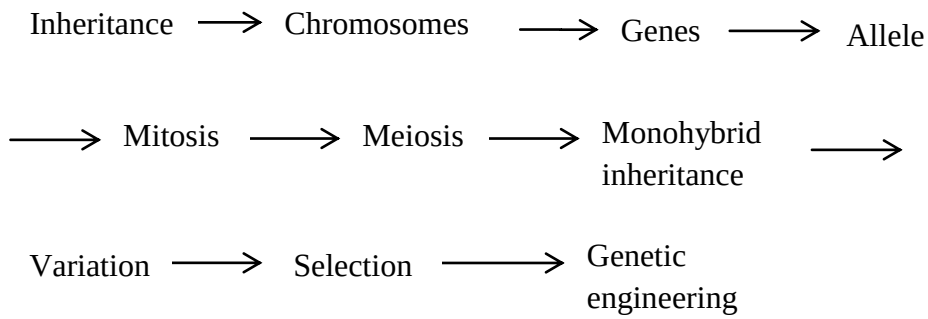
Question 1

A list of school genetics topics or concepts was compiled from the Grades 11–12 biology syllabus. The topics or concepts under Inheritance in the syllabus are: chromosomes, genes, allele, haploid nuclei, diploid nuclei, inheritance of sex in humans, mitosis, meiosis, monohybrid inheritance, genotype, phenotype, homozygous, heterozygous, dominant, recessive, monohybrid crosses, variation, mutation, selection, and genetic engineering (Examination Council of Swaziland, 2009). The rubric allocated one mark for each correct concept listed. The subtotal for this question was 20 marks.

Question 2

For the second question on sequencing the concepts, the teachers were expected to arrange the listed topics in such a way that the previous concepts formed the basis for the next one, in other words in hierarchical form. The rubric allocated marks to the number of topics that

were correctly arranged in hierarchical manner based on the SGCSE biology syllabus. This question was allocated 10 marks. An example of the sequence is as shown below.



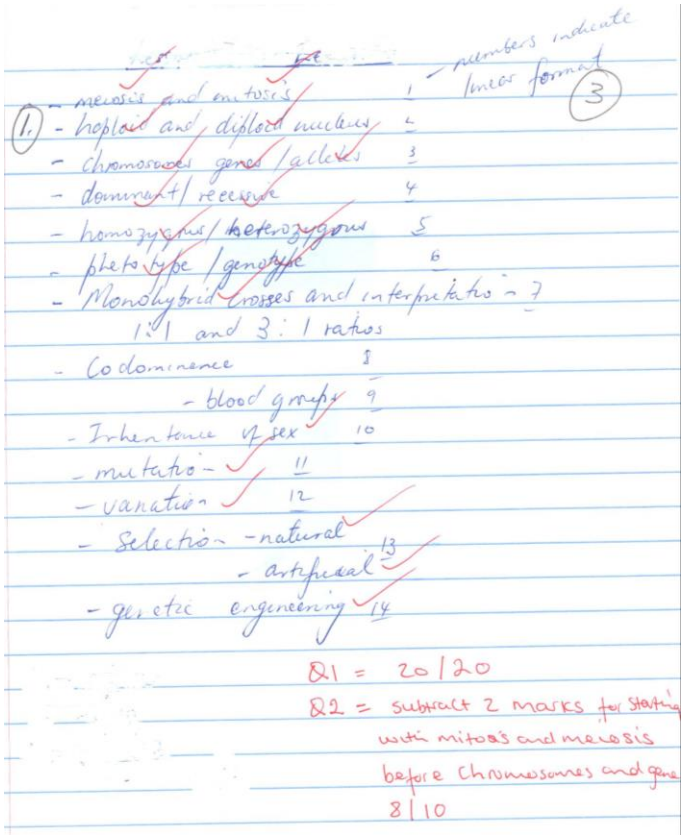
Question 3

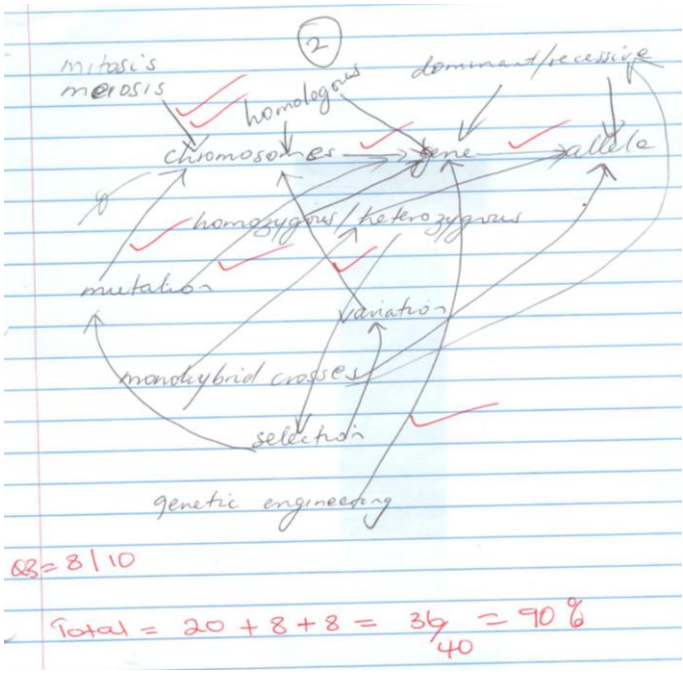
The focus was on the relationships among the genetics topics or concepts, particularly those of interest in this study, which are chromosome, gene, mitosis and meiosis, as well as among these and the other concepts in the topic. The rubric allocated one mark for indicating each of these connections: chromosome–gene; chromosome–mitosis; chromosome–meiosis; gene–mitosis; gene–meiosis; chromosome (gene)–variation; gene–selection; gene–genetic engineering; gene–monohybrid inheritance; meiosis–monohybrid inheritance. The mark allocation for this question was 10 marks.

The concept mapping exercise scored a total of 40 marks, that is, 20 marks for question 1), 10 marks for 2) and 10 marks for 3). Percentages of teachers' scores were calculated and used as determinants for their genetics content knowledge. A teacher who scored less than 32 marks (80%) would be regarded as not having the knowledge of the curriculum that would inform his or her insight into the topic.

Appendix Q

A sample for teachers' responses to concept mapping exercise



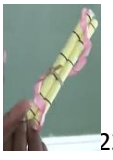


Appendix R

Transcription of Lucy's lesson observation video records

Lesson one topic: Inheritance, chromosomes and genes **Class**: Grade 11 **Time**: 70 minutes **Teacher:** Lucy greeted her learners and informed them that they were starting on a new topic 'Inheritance'. Earlier she had assigned them to read the chapter and make physical models of chromosomes: *I hope you have read the chapter and made your chromosome models as I assigned you*.
Teacher: *before we define inheritance; tell me about your families, do you in any way look similar to your mother, father or siblings?*
Learners: responded by stating how they were similar to or different from their family members in terms of their physical features namely, complexion, height and ear size.
Teacher: *let us define inheritance*.
Teacher: asked learners individually to define inheritance.
Learners: The learners responded as follows:
Learner: *'I think inheritance is the passing of certain characteristics from the parents to the offspring.'*
Learner: reading from a textbook, said *'Inheritance is the transmission of genetic information from generation to generation leading to continuity and variation of the species.'*
Teacher: *What can you say about learner B's definition?* Given that they were supposed to have read the chapter beforehand.
Learners: Learners gave varied responses from saying nothing to offering the suggestion that the definition *'Is too long'*.
Teacher: Lucy commented that the learner's definition was all right because *actually what we want is the full definition. Now that we are dealing with genetics, I would like you to use all the terminology that is related to genetics.*
Teacher: Using a textbook as her source, she repeated the definition read by learner B as *the passing on or transmission of genetic information from one generation to another generation leading to continuity of, and variation within, the species*.
Teacher: *What is the meaning of continuity?*
Learner: *'It goes on.'*
Teacher: *What goes on?*
Learner: *'The genes'.*
Teacher: *Yes, the genes. I was told that my child who is dark in complexion resembles his grandfather, which means the genetic information from the grandfather has been passed on from generation to generation. Like you also said that you do not look exactly like your mother or father, you may find that you resemble some of those great grandparents who died long time ago. I think you now all understand the meaning of 'inheritance'?*
Learners: *'Yes'*.
Teacher: *so in this lesson we will look at 'Inheritance', how the genetic information is passed on from one generation to another.*
Teacher: Lucy said *Remember in sexual reproduction there is the fusion of gametes which are the sperm and the ovum. Can you tell me what is there in the sperm or ovum that has resulted in you being the person you are? What do you think really brought up this creature that is you?*
Learners: responded to teacher's questions one at a time.
Learner: '*Parents had sexual intercourse'*
Learner: '*The genes'*
Teacher: Lucy probed further Learner B's response. *Where are the genes in this case?*
Learner: '*They are in the chromosomes'*
Teacher: *Did we see chromosomes during fertilization?*
Learners: *'No.'*
Teacher: *Where are the chromosomes?*
Learner: '*In the nucleus'*
Teacher: *We said during fertilization both the sperm and the ovum cells contain a nucleus and the two nuclei fuse to form a zygote. For now let us talk about the nucleus. We want to know the structures that are there in the nucleus that might have resulted in the formation of the whole being. In the nucleus of these cells there are chromosomes which contain genes*.
Before providing any definition of chromosomes and genes, Lucy requested learners to present their constructed models.
Teacher: Lucy asked volunteers to present and describe their models of chromosomes.

Model 1



Model 2

Learner: Model 1 was described by the learner: *'As we all know that chromosomes are always in pairs, these are my chromosomes, two of them* [the spiral wires]. *The chromosomes are held together by a centromere and that is why I used the magnet to hold the wires together. This is a gene* [pointing at darker sections of the wires] *which is DNA strand.*
Learner: The second learner described model 2: *'What I understood from my reading is that each chromosome has two chromatids that is why I did these two things (rolled yellow papers depicted in rod-like structures). My model represents one chromosome but the problem was that I had to put the DNA strand and I didn't know how so I put the pink paper around. The grey string is the centromere which holds the chromatids together. Then in my model the black marks are the genes. The genes are for different features like one would be for the ears and the other would be for eyes. But what is still confusing me is the chromatid thing. I do not know what it is and what is it for.'*
Teacher: asked other learners to describe what chromatids are.
Learner: The learner who presented the first model answered: *'Maybe I can use my artifact again. I said chromosomes always exist in pairs and so one of this strands here is a chromatid'* [not a chromosome as he said in his first presentation].
Learner: Another tried to explain chromatids by saying *'The book says that this chromosome is made up of two parallel strands called chromatids, meaning each of the rods on your (second learner) model is a chromatid.'*
Teacher: Lucy indicated to the class that they would discuss chromatids in the next lesson on cell division and proceeded to request for definition of chromosome from the class as chromosome was the focus of the lesson.
Teacher: After Lucy had thanked the three presenters, she asked the class: *From the presentations, do you think you can come up with a definition of a chromosome?*
Learner: defined a chromosome as *'a strand of DNA which carries genes and a protein'*, referring to the biology textbook.
Teacher: *Okay.*
Teacher: a chromosome is *a thread-like structure of DNA, made up of genes found in the nucleus*
Teacher: *What does DNA stand for?*
Learner: *'Deoxyribonucleic acid'.*
Teacher: *Chromosomes always exist in pairs;* and then drew a diagram of a pair of chromosomes on the chalkboard to illustrate this.

Teacher: *So these will be our 'thread-like structures' which are the chromosomes. Along the lengths of the chromosomes there are genes represented by the sections as drawn.* Pointing at the different sections of each of the paired chromosomes she said, *This section will be a gene and this will be another gene so they occur in pairs and so on.*
Teacher: *Have you heard about the term homologous?,* which drew a choral response from the class '*Yes.' What do you think are homologous chromosomes?*
Learner: *'I think they have the same genes.'*
Teacher: *You think they have the same genes? Yes somehow they are similar. A pair of similar chromosomes is called homologous chromosomes.*
Teacher: *Who can define a gene?*
Learners: Various learners raised their hands.
Learner: The first learner defined genes using a textbook: *'They are a series of chemical structures found on chromosomes.'*
Learner: The second said: *'They are chemical structures found on chromosomes carrying the genetic information.'*
Learner: The third said: *'They are chemical structures made up of DNA found on chromosomes.'*
Teacher: *Okay* and defined genes formally as *chemical structures made up of DNA found on chromosomes and control particular characteristics.*
Teacher: *Some books would say a gene is as a section of DNA which carries genetic information about a particular characteristic or protein.*
Teacher: Referring to the schematic diagram of chromosomes, Lucy pointed at different sections and stated that each of those sections are referred to as genes and that they are responsible for physical features of an organism, e.g. colour of eyes, shape of nose, etc.
Teacher: *If I were to use an example of a recipe book. For those of you who are doing Home Economics what is a recipe?*

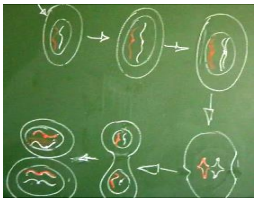
Learner: *'It is a list of ingredients for making a particular meal.'*
Teacher: *Yes. We would say a recipe book contains ingredients that are necessary for making different dishes e.g. Baking cakes, cooking rice, and ligusha* [a native dish]. *Here we would say the book would be the chromosome. The whole structure of a chromosome carries the genes, the genetic information. In this case if we liken a gene to a recipe it means that the gene carries some information about how to make a particular protein like haemoglobin.*
Teacher: *Are we all together?*
Learners: *'Yes.'*
Teacher: Lucy identified individual learners at random and asked them review questions: *We have now defined a chromosome and a gene? Can you please now re-define them for me?*
Learner: *Chromosomes are thread like structures found in the nucleus of all living things*
Learner: *They* [chromosomes] *are threadlike structures which contain genes which have instructions from both parents.*
Learner: *They* [chromosomes] *carry the genes which are passed on from one generation to another*
Learner: *Chromosomes carry the genes and the genes carry the genetic information*
Teacher: *What is the function of the chromosome?*
Learners: *'They carry the genes.'*
Teacher: *What is the function of the genes?*
Learners: *'They carry the genetic information.'*
Teacher: *Okay*
Teacher: *Chromosomes carry the genes and the genes carry the genetic information*
Teacher: Lucy introduced the concept of alleles: thus, *Let us now move on and talk about alleles. We want to know why we resemble our parents, grandparents or great grandparents for that matter. Or why we resemble one parent and not the other. From your chromosome models I think you can show me what alleles are. First of all can we have someone define an allele and then use his or her model to show alleles?*
Learner: One learner began by defining an allele whilst referring to her textbook: *'Alleles are genes occupying corresponding positions on homologous chromosomes and control the same characteristic.'* She used her model of beads on a thread to try to illustrate alleles.

Learner: *'In my model I would say the beads are the genes and those that go in pairs are the alleles although they are not straight but you can see the pairs. The genes in a pair control the same characteristic.'*
Teacher: After the girl had finished her presentation, Lucy asked other learners at random to define alleles. Learners gave the following responses:
Learner: *'Alleles are genes which occupy corresponding positions on homologous chromosomes and control the same characteristic',* reading from the textbook.
Learner: *'Alleles are two genes occupying the same position on homologous chromosomes and controlling the same characteristic'.*
Learner: *'These* [alleles] *are alternative forms of the same gene which affect a particular characteristic'*
Teacher: "Yes"
Teacher: Referring to the same schematic diagram on the chalkboard, Lucy described alleles: *When we talk about alleles we are still talking about genes but we are talking about genes that occupy the same position on homologous chromosomes or you can say they occupy the same locus on homologous chromosomes. Another thing about alleles is that they control the same characteristic.*

Teacher: Pointing to the two first genes on the two homologous chromosomes Lucy explained: *Which means that this one gene corresponds to this one. These two genes occupy the same locus on the homologous chromosomes and they control the same characteristic. For instance, suggest which characteristic they can control*
Learner: *'Skin colour'.*

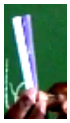
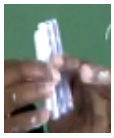
Teacher: *Complexion. This one may be responsible for the bright skin and the other one responsible for the dark skin. So because they are occupying the same position and they are controlling the same characteristic they are referred to as alleles. Some books refer to alleles as the alternative forms of the same gene.*
So I hope you now understand what chromosomes, genes and alleles are and make differences.
Teacher: As homework, Lucy instructed learners to read up about mitosis and meiosis, which were the concepts to be discussed in the next lesson.

Lesson two topic: Cell division: Mitosis and meiosis **Class**: Grade 11 **Time**: 70 minutes
Teacher: Lucy began her lesson by asking individual learners to define concepts learned in the previous lesson, namely, inheritance, chromosomes, genes and alleles.
Learner: *Inheritance is the transfer of genetic information from generation to generation leading to continuity*
Learner: *Inheritance is the transfer of genetic information from generation to generation leading to continuity of life and variation of species*
Learner: *A chromosome is a thread-like is a thread of DNA made up of genes*
Learner: *A gene is a DNA molecule which controls the development of characteristics of an organism*
Learner: *Genes are chemicals structures which control the characteristics of an organism*
Learner: *A gene is a chemical structure in the chromosome which control genetic information in an organism*
Learner: *Genes are chemical structures found along the length of a chromosome which carry the genetic information*
Teacher: *I think we were specific when we talked about a gene. We said a gene carries what?*
Learners: *'Genetic information'.*
Teacher: *For what?*
Learner: *'For the development of a particular characteristic'.*
Teacher: *Yes* and emphasized that a gene carries the genetic information about a particular characteristic.
Teacher: Lucy moved on to the topic of the day's lesson, mitosis and meiosis.
Teacher: Lucy introduced the concepts mitosis and meiosis by simply announcing that they would not cover the details of the processes as per the requirements of the syllabus for the grade level. She asked learners who volunteered to present on mitosis.
Learner: *'Mitosis is the division of cells. When the cell divides the chromosomes divide in stages.'*
Learner: Using his textbook, the learner drew cell diagrams on the chalkboard to illustrate the process of mitosis.
Learner: *'When you have a cell that has two chromosomes. The two chromosomes duplicate to form chromatids. The chromatids separate to form two new cells. The two cells have two chromosomes each like the first one'.*
Teacher: asked the class if the learner's description was correct.
Learner: A second learner offered to correct the description. Using his textbook he stated that "*before the cell divides, the chromosomes get short and fat. They duplicate to form chromatids. The nuclear membrane disappears. Chromosomes come to the centre of the cell and spindles form. The spindles pull the chromatids apart and one group of chromatids goes to each end of the cell. The nuclear membrane re-appears around each group of chromatids. Two new cells are formed like that. And two cells are like the first one and have two chromosomes".*
Teacher: Lucy asked individual learners about the importance of mitosis, *Why do we need mitosis?*
Learners: learners gave varied responses from: *'To form new cells' 'to repair damaged cells' 'for growth' to 'to form new cells necessary for the growth of an organism'*.
Teacher: *Okay*
Teacher: *We need mitosis to form new cells and to repair worn out tissues. Mitosis is the cell division responsible for growth and replacing worn out tissues.*
Teacher: Lucy used a diagram drawn by a learner, Figure 4.1.5, to explain the process of mitosis.



Teacher: *Mitosis occurs in stages. In the beginning we have a cell with these two chromosomes in the nucleus. Note that this is an illustration to show how you end up with the same number of chromosomes. The number of chromosomes in the nucleus depends on the particular species you are talking about. In human beings for*

instance you have 46 chromosomes in a cell and in the 46 chromosomes these are the stages that are followed during mitosis.
Teacher: *This is the parent cell* [first circle]. *Actually before cell division, the chromosomes prepare themselves for cell division by replicating. To replicate is to duplicate. Let me show you how it occurs.*
Teacher: Lucy used coloured chalk (white and blue) to illustrate replication of chromosomes during the process of mitosis.

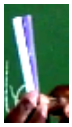



(a) (b)

Teacher: *So let us say in the beginning this is the parent cell it has two chromosomes depicted by the white chalk and blue chalk. The cell prepares itself for mitosis by replication of the two chromosomes. By replication we mean duplication. When they replicate each chromosome makes two chromatids called sister chromatids and now we have two whites and two blue. The chromatids are held together by a centromere.*
Teacher: *Why it is necessary for the chromosomes to duplicate?* One learner said *'To make chromosomes that are similar to them so that they can move to the different ends.'*
Teacher: *Okay*
Teacher: *Some of you may be wondering who is pushing these chromatids to move to the poles of the cell. There are fibres and the chromatids are attached to the fibres which then pull to the different poles of the cell. The nuclear membrane breaks into two nuclei. These nuclei will form two cells with the same number of chromosomes as the parent cell. So here we refer to this cell as a diploid cell.*
Teacher: *Is that clear?*
Learners: *'Yes'*
Teacher: *What can you say about the number of chromosomes in mitosis?*
Learner: *'The number of chromosomes is the same.'*
Teacher: Lucy moved on to meiosis and asked volunteers to present on the topic.
Learner: A learner offered to present the process of meiosis to the class.
Learner: *'I struggled a bit to understand meiosis particularly understanding how the number of chromosomes ends up being half because it is like the same process as mitosis occurs.'*
Teacher: *May you start by describing mitosis then so that we see where you fail to make the difference when you talk about meiosis.*
Learner: correctly described the process of mitosis, showing how the chromosome number is maintained.
Learner: Learner then described the process of meiosis. Referring to his textbook occasionally, he drew cell diagrams to show the stages of meiosis.

Learner: *'In the first stage of meiosis* (Figure 4.1.7) first cell diagram from left] *homologous chromosomes are close together, two long ones and two short ones. They pair up. The second stage, homologous chromosomes split, centrioles move to the poles and spindles pull the chromosomes apart. Then there is like the haploid number of chromosomes. How is it half as it happens the same way as in mitosis?'*
Learner: *'Is it correct? Do the resulting cells contain a haploid number of chromosomes?'*
Learners: some said *'Yes'* and others *'No.'*
Teacher: *I think when you have struggled a bit it would be much easier to understand when I explain.*
Teacher: *Why do we need meiosis? Why do we need another type of cell division different from mitosis? In other words what is the significance of meiosis?*
Learner: *'Meiosis results in the formation of gametes. It is necessary that we have the haploid number of chromosomes because the gametes form the zygote. If the gametes had the full number of chromosomes, each time a zygote was formed it would have double the number of chromosomes. And that will continue doubling.'*
Teacher: *yes*
Teacher: *Meiosis is the type of cell division specifically for the formation of gametes and therefore in meiosis the daughter cells should have half the number of chromosomes.*
Teacher: *Let us now follow the stages to see what happens in meiosis that results in half the number of chromosomes. Is that okay?*

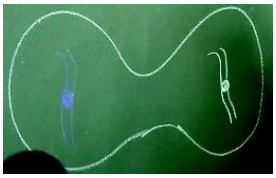
Learners: *'yes'.*
Teacher: *In meiosis we are forming the gametes, the sex cells. Our daughter cells shouldn't contain the same number of chromosomes as the parent cell as the learner explained. The chromosomes should be half. That is why sometime meiosis is referred to as the reduction division. Why reduction division? Because the number of chromosomes in the nucleus is reduced. We refer to such a nucleus as a haploid nucleus because it contains half the number of chromosomes as compared to the initial nucleus.*
Teacher: Lucy again used coloured chalk to illustrate replication and separation of homologous chromosomes during meiosis.



(b) (b) (c)

Pictures of coloured chalks used to illustrate chromosome replication and separation during meiosis

Teacher: *So in meiosis initially we have two chromosomes, the two white and purple chalk. Before cell division, the chromosomes replicate (Figure 4.1.8b) and now we have two white and two purple. Each chromosome (white and purple) has replicated to form sister chromatids. Why replicate? Because the chromosome has to make a copy of itself so that one copy can go to the other cell. When the cell first divides in meiosis the sister chromatids will not separate (Figure 4.1.8c) but the chromosomes do. Do you understand Learner1?* Lucy said pointing at the learner who had some difficulty describing meiosis and was confused about the reduction of chromosome number.
Learner: The learner responded by saying *'yes'.*
Teacher: Lucy drew a diagram on the chalkboard showing the separation of a pair of homologous chromosomes using different colours of chalk to represent different chromosomes.



Teacher: *So the first division in meiosis does not allow the sister chromatids to separate. So what happens is that they just move together to the poles of the cell.*
Teacher: *And then from there the sister chromatids will separate. The spindles will pull the sister chromatids of each chromosome so that one chromatid moves to each pole. From there the nuclear membrane is going to divide such that now we have four cells and each of these cells contains one chromosome which is half of the two that I was having at the beginning.* She drew a diagram as an illustration of the formation of the four haploid cells.

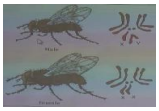
Teacher: *Do you get the difference between mitosis and meiosis?* The class responded as a whole and said *'Yes',* a response which did not tell her who knew and who didn't.
Teacher: Lucy asked learners individually to define meiosis in their own words: *How can you define meiosis in your own words from what we have done so far?*
Learners: The learners gave varied responses:
Learner: *I would say meiosis is the division of cells so that leading to into four parts.*
Learner: *Before meiosis we have four chromosomes from mother and the father, so after cell division they have to end up as one, one, one because we want half of the chromosomes in the original cell.*
Learner: *Meiosis is a reduction division whereby a nucleus with a diploid number of chromosomes divides to produce a nucleus with a haploid number of chromosomes to form gametes.*
Learner: *It is a nucleus that when it divides half the number of chromosomes is produced*
Learner: *Meiosis is the reduction division producing gametes with the haploid number of the mother cell from the father and mother producing four different chromosomes similar number of chromosomes.*

Learner: *Is the division of a cell resulting in daughter cells with the haploid number of chromosome*
Teacher: Lucy accepted the last response as correct.
Teacher: Lucy drew diagrams on the chalkboard representing mitosis and meiosis in terms of the number of chromosomes in resulting nuclei without labeling them and asked individual learners to identify which diagram represented each process.
Learners: Learners correctly matched the diagrams with the process
Teacher: Lucy reminded learners that in human beings there are 46 chromosomes in an ordinary cell and asked them how many chromosomes would be in cells resulting from meiosis?
Learners: Learners together said 23.
Teacher: explained using illustrations on the chalkboard that the 46 chromosomes in the initial dividing cell are in pairs (i.e. 23 pairs of chromosomes), but the resulting haploid cells contain a single set which is not in pairs (i.e. 23 single chromosomes). She stated that the resulting haploid cells are called gametes, which are the sperm and ovum.
Teacher: *Why is it important that the sex cells contain half the number of chromosome?*
Learner: One learner answered that it was to make sure that during fertilisation the zygote has 46 chromosomes.
Teacher: Lucy agreed and emphasised that *during fertilisation each gamete from male and female parents comes with half the number of chromosomes carrying the genetic information from the parents.*
Teacher: Lucy gave out photocopies of homework, in which learners were asked to define a chromosome, state the number of chromosomes in various human cells e.g. skin cell, egg cell and red blood cell; name the process which provides new cells for the growth of a young mammal; and explain why it is necessary for gametes to be formed by meiosis.

Appendix S

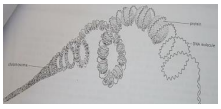
Transcription of Lily's lesson observation video records

Lesson one topic: Chromosomes and genes **Class**: Grade 11 **Length**: 80 min
Teacher: Lily began her lesson on chromosomes and genes by asking the class, *How many of you have siblings at home*? Most learners responded by raising their hands.
Teacher: *Who can tell us if there is anyone that you resemble in your family*.
Learner: *Father*
Learner: *brother*
Learner: *grandfather*
Learner: *great grandfather.'*
Teacher: *Do you look exactly like your father or your other relatives?*
Learners: *'No'*.
Teacher: *Why do you think we resemble our sisters, brothers, parents, grandparents and not any members of other families?*
Learner: *'It is because they* (family members) *share the same blood.'*
Teacher: *What do you mean by blood? A few weeks ago we were donating blood and told our blood groups. Do you mean they share the same blood group?*
Teacher: *What exactly is it that makes us resemble only the people we are biologically linked with and not any other person?*
Learner: One learner answered from her textbook. '*It is because of genes.'*
Teacher: *Okay*
Teacher: *Who has ever heard of genes?*
Learners: Most learners raised their hands.
Teacher: *I am not talking about the jeans you wear.*
Teacher: *What happens to these genes? How do they cause resemblance?*
Learners: Learners kept quiet.
Teacher: *What do you think happens?*
Learner: *'They are passed on.'*
Teacher: *Yes*.
Teacher: Using the example of the learner who said he resembled his great grandfather, Lily said, *He looks like his great grandfather. So what happened to the great grandfather's genes for him to look like the great grandfather?*
Learner: '*They were passed on.'*
Teacher: *Yes, they were passed on. So the genes were passed on from the great grandfather to the grandfather to the father and to him. Now the genes are in his body. What will happen to the genes in his body?*
Learners: *'They will be passed on.'*
Teacher: *Yes he will pass them on to his children.*
Teacher: Lily the class that the new topic was 'Inheritance' and enquired, *Who can tell us what inheritance is?*
Teacher: Without waiting for an answer from the learners, Lily defined inheritance by dictating for learners to write: *Inheritance refers to the transmission of genetic information from generation to generation. This leads to continuity of species and variation within the same species*
Teacher: *Where exactly are these genes found in the body*?
Learners: Learners kept quiet.
Teacher: *Where are they found? Are they in the blood? Are they in the cells? Where are they found?*
Learners: *'In the cells.'*
Teacher: *Where exactly in the cell are the genes? Which part of the cell carries the genes?* **Learner:** '*In the nucleus'*.
Teacher: *What are the structures found in the nucleus which carry genes?*
Learner: One learner said *'Chromosomes'*.
Teacher: *Yes, chromosomes are the structures that carry the genes.*
Teacher: Lily used a data projector to show chromosomes from male and female fruit flies



Teacher: Referring to the diagram Lily said, *So these are the structures found in the nucleus of a fruit fly cell and they are called chromosomes. As you can see the chromosomes are arranged in pairs. A pair of similar chromosomes is called homologous chromosomes. We will discuss homologous chromosomes later. For now let us focus on just a chromosome.*
Teacher: *What exactly is a chromosome?*

Learners: Learners kept quiet.
Teacher: *Have you ever had of DNA? Nowadays it is common to hear people saying the child is not mine let's go for a DNA test. You have heard of that?*
Learners: *'Yes'.*
Teacher: *What is this DNA?* Without waiting for a response, she said *DNA is the structure of a very big molecule a very long thread that is found in the nucleus. The DNA coils up to make the chromosome.*
Line 21: Lily referred learners to a simplified model of chromosome structure (Figure 4.2.2) in their textbook.



Simplified model of chromosome structure
(This is a '1974' model, which has been superseded by something much more complicated.)
Teacher: *The chromosome is the coiled DNA molecule. The chromosomes carry the genes.* **Teacher:** *Okay let us look at the genes.*
Teacher: *What are genes? What do you think?*
Learners: Learners kept quiet.
Teacher: *On a chromosome there are several genes. A gene carries specific information about a particular characteristic in an organism. Let me give you an example. You see that I am dark in complexion that means somewhere in my chromosomes there is information about dark complexion. On the same chromosome you will find information about the eyes. There is also information about the sex. There is information about the type of hair I have.*
Teacher: *Am I making any sense?*
Learners: '*Yes'.*
Teacher: *Where do you think genes are on the chromosomes?*
Learners: Learners kept quiet.
Teacher: *Where are the genes found?*
Learner: *'Inside'.*
Teacher: Lily drew a diagram on the chalkboard to illustrate the location of genes on a chromosome.

Teacher: *So the information is here on the chromosome* (depicted by the rod-like structure). *On this chromosome there are several genes* (depicted by the sections). She gave examples of genes controlling physical human features such as complexion, shape of nose and hair colour and located them on the diagram.
Teacher: Lily assigned classwork in which learners were asked to state in their own words (a) *What is a chromosome?* And (b) *What is a gene?* Lily walked around the class to monitor the learners. She checked, marked and gave learners feedback about their work. a few learners experienced difficulty in defining the concepts in full, e.g. stating both structure and function of a chromosome. For example, many learners defined a chromosome as '*a structure of DNA'* or *'a thread-like structure'* and a gene as *'a part of a chromosome', 'a chemical structure'* or *'a section of DNA.'* Lily's comment was usually, *Your answer is incomplete ….*
Teacher: Lily conducted a class review of the classwork exercise and decided to revisit the definitions:
(a) *Let us coin the definition of a chromosome together. Most of you said a chromosome is a thread-like structure. We all agree on that. Something is missing when you are talking about chromosomes. What is that?*
Learner: *'Genes'.*
Teacher: *Yes* and defined a chromosome on the chalkboard for learners to copy: *A chromosome is a thread-like structure of DNA found in the nucleus which carries genes.*
(b) *What is a gene?*
Learner: *'Protein'* and another said '*A section of DNA'*. Lily said, *I want the full definition* and then defined a gene through dictation for learners to write: *A gene is a section of DNA which codes for the formation of a protein and controls a particular characteristic of the organism.*
Teacher: *Any questions?*
Learners: Learners did not ask questions.
Teacher: *Now we are looking at information coming from two parents carried by genes controlling the same characteristic, the size of ears for example. May be the information from the father says the ears must be big and that from the mother says the ears should be small. So what will happen?*
Teacher: *It might happen that the ears will be small like the mother's. What else can we use? Let us use complexion. The gene from one parent may be carrying the information for a dark complexion and the gene from the other parent saying the complexion should be light. In this case both genes are describing the*

complexion of the child but the descriptions are different. Genes that are coming from two parents describing the same characteristic but in different forms are called alleles. Alleles are different forms of the same gene.
Teacher: *Is it clear?*
Learners: *'Yes'*
Teacher: Lily assigned learners homework to read about topics to be taught in the next lesson, namely mitosis and meiosis. She also handed out photocopies of homework in which learners were asked: *State the number of chromosomes in a human embryo and human sex cells,* given a diagram and, *Describe the purposes for the following types of cell division: (a) mitosis (b) meiosis.*
Lesson two topic: Cell division (mitosis and meiosis) **Class:** Grade 11 **Length:** 80 minutes
Teacher: Lily introduced the lesson on cell division by reviewing the previous day's homework, which she had marked before the lesson. She remarked: *I noticed that none of you scored the total marks.* She asked individual learners to state the answer to each question.
Line 2: For example, for the second question, a learner said the purpose of mitosis is to *'make cells for growth'.*
Teacher: *Yes, what else?*
Learner: A second learner said it is *'cell division for repair of worn-out tissues'.*
Teacher: *Yes. There is a third mark for mentioning the number of chromosomes and no one got that. What can you say about the number of chromosomes in mitosis?*
Learners: Learners kept quiet.
Teacher: *Look at the diagram, you have the embryo developing into an adult through the process of mitosis, what can you say about the number of chromosomes?*
Learners: *'They are the same'*
Teacher: *Yes.*
Teacher: *Now let us look at mitosis and meiosis. In which part of the body does mitosis occur? Which cells in our body undergo mitosis?*
Learners: Learners kept quiet.
Teacher: *What did the hand-out say?*
Learner: *'Somatic cells'.*
Teacher: Lily said *yes* and described mitosis on the chalkboard for learners to copy. *Mitosis occurs in body cells which are called somatic cells. It results in daughter cells which carry the same number of chromosomes as the parent cell. For an example, humans have 46 chromosomes so when mitosis occurs new cells must also have 46 chromosomes.*
Teacher: *Let us say I cut myself on my finger when chopping onion at home, new cells must form. How many chromosomes should the new cells have?*
Learners: *'46'.*
Teacher: *Before the cell divides the chromosomes must duplicate. Each one of them must duplicate itself. To duplicate is to make something identical. If I give you this paper and ask you to duplicate it, it should come out looking exactly like this one. There is a word used for duplication of chromosomes in a cell that is replication. When I say DNA I mean the chromosomes in the nucleus they must replicate.*
Teacher: *So in a human cell which has 46 chromosomes after duplication it must have how many?*
Learners: '*92'.*
Teacher: *A human cell has 46 chromosomes. Before the cell divides each chromosome makes a copy of itself. They replicate. In humans there are 92 chromosomes in a nucleus of a cell that is about to divide.*
Teacher: Referring to a diagram on a handout that she had given learners to read as homework, Lily described the stages of mitosis, writing brief notes about each stage on the chalkboard for learners to copy. She said: *The actual process of mitosis occurs in stages. Avoid using the names of the stages given in the handout because they are not required by the syllabus. Just use stages 1–4.*
Teacher: *After duplication of chromosomes has occurred the cell is ready to divide (refer to interphase stage on the handout).*
Stage 1 (refer to late Prophase on the handout):
The chromosomes become short and fat , so they can be seen with a light microscope
Stage 2 (refer to metaphase on the handout):
Nuclear membrane has disappeared. All chromosomes are arranged at the centre of the spindle to ensure that when they separate they do so in an orderly manner.
Stage 3 (refer to anaphase on the handout): *The chromosomes now separate. They go to opposite ends. One set of the chromosomes, half, is pulled by the spindles to one end and the other half goes to the other end.*
Stage 4 (refer to telophase on the handout): *Re-appearance or formation of a nuclear membrane around each set of chromosomes and the cell eventually divides into two cells. In humans each new cell formed has 46 chromosomes.*
Teacher: Lily assigned learners classwork in which they were required to work in pairs to *identify stages 1, 3, and 4 from six photographs taken at various stages through the process of mitosis in a plant cell* that were not in

any particular order and to *describe two important changes that chromosomes must undergo before cell division can take place.*
Teacher: Lily walked around the class to monitor the learners and mark their work. Most learners were able to identify the stages. For the few learners who had difficulty, Lily insisted they read the notes to help them identify the stages.
Teacher: *Okay even though some of you had difficulty at the beginning but almost all of you now got the stages right* and then asked the class: *which diagrams are showing stages 1, 3 and 4?*
Learners: *'f, d, and b'.*
Teacher: *Okay let us move on.*
Teacher: *Now we are moving on to another type of cell division, which is meiosis.*
Teacher: Lily described meiosis on the chalkboard for learners to copy: *Meiosis occurs in sex organs called gonads which are organs producing gametes or sex cells, the sperm and egg cells containing half the number of chromosomes. In humans it occurs in testis and ovaries. The mother cells that produce the gametes have the same number of chromosomes as other somatic cells which is 46 in humans.*
Teacher: *Like in mitosis the chromosomes must replicate. In humans the mother cell carries 92 chromosomes after replication. The cell is now ready to divide. Meiosis occurs in two phases, meiosis 1 and meiosis 2. During meiosis 1 two cells are produced. In the cells chromosomes are halved. The daughter cell carries 46 chromosomes in humans.*

Teacher: *If you look at this diagram you can see that there is first replication of chromosomes. The chromosomes separate to form two cells, which have half the number of chromosomes.*
Teacher: Lily explained that in meiosis 2, each of the two cells resulting from meiosis 1 (with 46 chromosomes) *undergo four stages similar to those of mitosis* and used a diagram to summarize meiosis 2.

Teacher: *So all in all, how many cells have been formed? Two or four cells?*
Learners: '*Four'.*
Teacher: Lily gave learners homework to *draw a table to compare mitosis and meiosis*.

Appendix T

Transcription of Leon's lesson observation video records

Lesson one topic: Inheritance, chromosomes and cell division **Class**: Grade 11 **Length**: 60 min

Teacher: Leon began his lesson by announcing the lesson's topic to the class while he spelled it out on the chalkboard 'inheritance'. He continued, *First of all let's start with some facts. All of us here as individuals have features similar to our parents. Isn't it? People always tell you so and so looks like their father or so and so looks like the mother. You have heard of such?*

Learners: *'Yes'*

Teacher: *Each and every offspring of every organism does resemble the features that are found in its parents. So that is why you have features that are similar to your father and you have features that are similar to your mother. So we could say that all offspring have features from the parent. That is one fact.*

Teacher: *In your family you have brothers and sisters. Isn't it?*

Learners: as a whole said *'Yes'*.

Teacher: *Although your brothers or sisters and you have got features similar to those of your parents, would you say you look exactly like them?*

Learners: as class answered *'No'*.

Teacher: *It means although you are coming from the same mother and same father you have inherited different features from your parents. And then offspring from same parents may also differ. If I may ask do you look exactly like your mother? Do you look exactly like your father?*

Learners: whole class responded *'No'*.

Teacher: *What is this inheritance?* Without waiting for a response from his class he said: *Inheritance is the transmission or passing on of features from your parents to you. In other words the things that you look like e.g. small ears.*

Teacher: *In Swazi culture when a man impregnates a young girl out of wedlock what is the procedure that has to be followed?*

Learner: One learner answered *"kubikwa sisu"* [meaning the impregnated girl is accompanied by an elder woman to report the pregnancy to the man's family].

Teacher: explained that during that visit, the man's family would not easily accept the pregnancy but normally responds by saying *"Siyobona ngemtfwana"* [meaning the family can only accept it when they have seen the baby]. *So when the baby is born the girl has to take the baby to the man's family. On that day the family calls elders to come and observe the features of the baby if they do in any way resemble the family. After that the family members give a verdict whether the child belongs to the family or not.*

Teacher: *For us to understand how features are transmitted from parents to offspring let's start where life starts. Where does life start? Wacalaphi wena?* [Meaning where did you start?] *It basically starts with fertilization whereby a male gamete from your male parent fuses with the gamete from your female parent in the form of an ovum forming one cell which is referred to as a zygote. Every person started as one cell, a zygote.*

Teacher: *Now if life starts as one cell and everything that happens in the cell is controlled by the nucleus then what is it that is there in the nucleus causes this cell to develop into a human being that is you? So in the cells of organisms are certain structures that are known as chromosomes. Chromosomes are not visible under the ordinary microscope only at certain times. They actually look like tiny threads within the cell and are made up of DNA. It is in these chromosomes where you find the instructions if I may put it like that, the factors, the plan or the information as to what a person will look like.*

Teacher: referred learners to diagrams of chromosomes from different species of animals in their textbooks.

Learner: Leon asked learners to state the chromosome number for each animal.

Teacher and Learners: kangaroo (12), human being (46), domestic fowl (36) and fruit fly (8).

Teacher: *Now there is something about these chromosomes in that each species has a specific number of chromosomes in its cells. You will notice that the chromosome number of each specific organism is an even number. This number of chromosomes is referred to as the diploid number of chromosomes denoted as 2n. So the number of chromosomes for me and you is 46.*

Teacher: *Now we have already seen how life starts as one cell and what is it in this one cell that eventually results in the features that are shown by the offspring after it is born. Now after life starts as one cell how does it then proceed from one cell to the whole organism? As a human being you start as one cell the cell divides into two cells, two cells divide into four cells. The cells continue dividing and start forming tissues, organs eventually resulting in human being who after nine months comes out as an individual. The cell does so by what we refer to as cell division. There are two types of cell division which are mitosis and meiosis. I want us to look at these two types of cell division. Let's start with mitosis.*

Teacher: *Mitosis is the type of cell division that is used by all ordinary cells. We refer to such cells as somatic cells. All somatic cells are diploid numbered. For example in human beings if you take any cell from the skin it will have how many chromosomes?*

Teacher and learners: *46*.

Teacher: *If you take any cell from the tip of your toe it will have 46* (teacher) *you take it from the liver? It will have 46 chromosomes* (teacher).
Teacher: *Now mitosis is like photocopying in that what is produced during mitosis is genetically similar or same as parent cell.*
Teacher: drew a circle on the chalkboard representing a cell and drew two others using arrows to show that they were from the first cell. He labelled the first cell the parent cell and the two resulting cells as daughter cells.
Teacher: *The daughter cells have the same number of chromosomes as the parent cell which is 46 in a human being. As a result, during mitosis what is produced is an exact duplicate of the previous parent cell which is why I was saying that mitosis is similar to photocopying.*
Teacher: explained how identical twins are formed as an example of mitosis. *Some people get identical twins. How does it happen? This is how it happens the first division from the zygote is a very delicate one. Normally when the zygote cell divides the cells remain attach to each other so that as the division continues they form a ball of cells. Sometimes during this first division of the zygote the two cells that are produced completely separate. When that happens each cell develops into a new individual. That is how then we get what we call identical twins.*
Teacher: then described meiosis: *The second type of cell division, which is called meiosis, is only used under special circumstances, which are during the formation of gametes. By gamete, remember we are referring to for an example the sperm or ovum. Now the major difference between the two types of cell division is whereas mitosis is the exact duplication of cells where both the parent and daughter cells have the diploid number of chromosomes, in the case of meiosis the chromosome number is halved. So when the gametes are formed the gametes will have half the number of chromosomes. And this number of chromosomes that is found in gametes is referred to as the haploid number. The haploid number is denoted with 'n' because diploid is '2n'.*
Teacher: Leon then described the significance of meiosis. *Now why is meiosis necessary? Why is it necessary that the chromosome number is halved during meiosis?* He asked, directing the question to an individual learner.
Learner: The learner kept quiet and
Teacher: Leon went on without reacting to the learner's silence. *We have said that the uniqueness of each species lies in the number of chromosomes they have. Human beings are unique due to the fact that in their cells they have 46 chromosomes. A change in this number results in something different as you are going to see later on in this unit. A mistake can happen during cell division where by a person ends up having 47 chromosomes. Such a person suffers the condition known as Down Syndrome.*
Teacher: assigned learners to read about Down Syndrome.
Teacher: *So we can say meiosis is necessary in order to maintain our chromosome number. Each gamete will have 23 chromosomes in the case of human beings so that when fertilization takes place the sperm will contribute 23 and the ovum 23 as well. This will result in 46 chromosomes and it is the 46 chromosomes that make it a human being.*
Teacher: *Am I clear there?*
Learners: as whole responded *'Yes'.*
Teacher: ended the lesson by telling learners next time they would look more into the terms used in genetics.

Lesson two topic: Chromosomes and genes **Class:** Grade 11**Time:** 60 minutes
Teacher: Leon began his lesson on chromosomes and genes by reviewing the previous lesson on chromosomes and cell division.
Teacher: Leon introduced the new topic, *Before we look at how features are transmitted from parents to offspring let us familiarize ourselves with some of the genetics terms.* Beginning with a description of homologous chromosomes, he said, *Now chromosomes in a cell exist in pairs. In the case of human beings the diploid number of chromosomes is 46 and there are 23 pairs of chromosomes. Now each chromosome in each pair is similar to the other in shape, in size, and most importantly the genes that are found in those particular chromosomes. Such a pair of chromosomes is called homologous chromosomes. 'Homo' when used as a prefix anywhere in biology means 'same'.*
Teacher: Leon referred learners to a diagram in the textbook. *A diagram in your book shows chromosomes from four animals including human being. The one I want us to concentrate on is the fruit fly* (Figure 4.3. 3) *because in the fruit fly the chromosomes have been arranged in their respective pairs.*
Teacher: *If we look carefully at the chromosomes of the fruit fly you will notice that there are 4 pairs of chromosomes. And you will see that in each pair one of the chromosomes looks like the other in its shape and size. We describe these pairs of chromosomes as homologous chromosomes.* Leon continued and described genes.
Teacher: then described genes. In the chromosome you have what we refer to as genes. What is a gene? Without waiting for a response from the class he went on, A gene is a part of a chromosome and because chromosomes are made up of DNA it means that the gene is also made up of DNA. In each chromosome you

may find many genes but one thing important about a gene is that a gene always controls one feature. Since chromosomes exist as homologous pairs genes also exist in pairs. Pair of genes control one trait.
Teacher: Leon drew diagrams on the chalkboard to illustrate genes on homologous chromosomes. Let me say I take two chromosomes, 1 and 2
Teacher: *And let us say I take chromosome 1 and I break it down (*Diagram b). *Since a gene is part of a chromosome* e*ach of these lengths or genes of the chromosome will control one feature. Let us think of some features that are found on human beings. Say in this position A is gene controlling eye-colour* (Diagram c) *and at position B there is a gene controlling nose shape. Can you think of any other feature which could be controlled by a gene at C? 'Height'*, a learner responded voluntarily. *And there we have other genes at positions D–G. In reality you will find a chromosome with thousands of genes each controlling one particular feature. I am just using this as an example.*
Teacher: *If we say the gene at position A of chromosome 1 controls eye colour of that particular organism in the same position of chromosome 2 you will also find a gene that controls eye colour because chromosomes 1 and 2 are homologous to each other. In position B there will be a gene controlling the nose shape and in Position C you will find the gene that controls height. So on and so forth throughout the length of that chromosome.* He located and labeled the same genes on chromosome 2.
Teacher: stated that at times the two genes found on the same position on homologous chromosomes *control the same character but cause two opposite expressions of the feature they control*. He made learners do some activities demonstrating the effects of genes.
Teacher: said, *Let us take this example of tongue rolling. Some people can roll their tongue and others cannot. Let us take a quick survey and find out how many of us in this room are able to roll their tongue. When rolling your tongue do something like this* [he demonstrated tongue rolling by rolling his]. He allowed learners to try to roll their tongue one at a time, while he tallied those who could and those who could not on the chalkboard. The survey results showed that 21 learners could roll their tongues and 4 could not. After the survey he went back to diagram (c) on the chalkboard and located the genes for tongue rolling at position D of chromosomes 1 and 2. He then explained, *The results imply that there is a gene that enables some individuals to be able to roll their tongue. There is also a gene that makes other people not to be able to roll their tongue.*
Teacher: used a second example 'clasping of hands' to illustrate alleles. He began by demonstrating clasping of hands by clasping his. He said "*some individuals will naturally put the left thumb on top and others will put right on top.*
Teacher: *Let us see by show of hands how many have the left on top?*
(a few learners put up their hands)
Teacher: *How many of us have the right on top?* (A majority of learners raise up their hands). He continued and said *More people have right on top. Now unclasp your hands and try clasping your hands with the other thumb on top. Do you notice that it feels unnatural to you? It is not you. So it means that there are two genes one gene causes left thumb to be on top and another makes the right to be on top.*
Teacher: said *another example is the folding of arms which is similar to clasping your hands. Some of you will put the left one on top while others the right will be on top*. The teacher asked learners to fold their arms and observe which one would be on top. He instructed them to try fold their arms the other way and said *Now unfold your arms and try to fold your arms with the other one on top. Do you see that it becomes unnatural with you?*
Learners: *'Yes'.*
Teacher: used the three examples of tongue rolling, clasping hands and folding arms to describe the term 'allele'. He stated: *The examples prove that features are being controlled by genes, which exist in pairs. So there is a word that we use in genetics. The word allele. Alleles are a pair of genes, which control one feature but cause different expressions of the feature. In the ability to roll the tongue some can and others cannot which means there is a gene that causes people to roll their tongues and another gene which makes others unable.*
Teacher: Leon ended the lesson by telling them next time they would learn about other genetics terms like heterozygous, genotype and phenotype.

Appendix U

Transcription of Lillian's lesson observation video records

Lesson one: Inheritance, chromosomes and genes **Time: 70 minutes**

Teacher: Lillian began her lesson by announcing the topic. *Today our topic is inheritance. But before we move on we have to define inheritance. What do you think inheritance is?* In the absence of a response from learners she gave them an idea of inheritance. *If we say someone has inherited something, maybe at home from parents, what do we really mean by inheritance?*

Learner: *'It is features or characteristics that are passed on from the parents' gametes or genes to kids or to the offspring.'*

Learner: *'It is the transmission of genetic material from one generation to another.'*

Teacher: Line 3: Without commenting on the learners' responses, Lillian defined inheritance on the chalkboard for learners to copy: *Inheritance is the transfer or transmission or passing on of genetic information from one generation to another leading to the continuity of life and variation within the species itself*.

Teacher: After giving the definition of inheritance, Lillian randomly asked learners to list physical features that were common in their families. *If you can reflect back at your families, you can find that there are characteristics or features which are common in your families. What are those features?*

Learner: *'Eyes'*

Learner: *'Ears'*

Teacher: Lillian said *Okay* and reiterated the focus of the lesson. *In this lesson we are going to study the inheritance of the characteristics. How the genetic information is passed from one generation to another. We will start by looking at chromosomes.*

Teacher: *Let's go back and look at the nucleus. During fertilization two gametes fuse to form an offspring. The gametes contain the nucleus. The nucleus contains chromosomes. The chromosomes carry the genetic information which are the genes. Is that clear?*

Teacher: *We will look at what a chromosome is and what are genes? You remember when we were looking at the cell structure using a light microscope. How did the nucleus appear?*

Learner: *'It was dark'* (whole class)

Teacher: The teacher said *yes* and continued. *So chromosomes in the nucleus are not easy to see unless a cell is dividing the reason being that when a cell divides chromosomes shorten and thicken. At this time they can be seen under the microscope.*

Teacher: Lillian defined chromosomes and genes on the chalkboard for learners to copy. *A chromosome is a thread of DNA made up of genes found in the nucleus. Along a chromosome are a series of chemicals called genes. Within a chromosome you have several genes. A gene is a section of DNA, which codes for the formation of a protein controlling a specific characteristic of the organism. Examples of characteristics controlled by genes can be eye colour, hair colour and tallness*.

Teacher: Lillian referred learners to a diagram in their textbook showing the relationship between chromosomes and genes.

Teacher: Each physical human characteristic is controlled by two genes one from each parent. Say, for instance, hair colour, one gene would come from the mother and another gene from the father. Is that clear?

Learner: Learners together said 'Yes'.

Teacher: *Chromosomes exist in pairs and chromosomes which belong to a pair we call them homologous chromosomes. They look alike that is they are homo.*

Teacher: copied the diagram from the textbook on the chalkboard and added another similar chromosome to show a pair of homologous chromosomes. On the two chromosomes, she located genes for eye colour, tallness and hair colour as examples. Genes for the same characteristic e.g. eye colour were located on corresponding positions of the two chromosomes.

Teacher: Referring to the diagram Lillian continued: *You find that on a pair of homologous chromosomes, you have genes which are found in the same position. If two genes are located on the same position it means they are controlling the same characteristic. The two genes may have different effects on that characteristic. We call them the alternative forms of the same gene. So then the alternative forms of the same gene we refer to them as alleles.*

Teacher: gave examples of alternative forms of the same gene. *For example, you find that some people are short, others are tall, which means tallness is controlled by a gene for being tall or a gene being short. For eye colour, some people have blue eyes, others have brown eyes. What can you say about the hair colour?*

Learner: *'Black*

Learner: *brown,*

Learner: *grey and white'*.

Teacher: *Okay, this means there is a gene for black hair, a gene for brown hair, and so on.*

Learner: asked a question '*Does it mean that the different sizes of rats are controlled by genes?*'

Teacher: *There could be many factors, but the genes play a role in the size of the rat.*

Learner: *'I think the environment and the nutrients the rats have can make them different.'*
Teacher: *Yes, we will discuss that later.*
Teacher: gave learners photocopies of homework in which they were asked to label parts of a sperm cell, and define the concepts chromosome and gene. She also instructed them: *Read about what we have looked at, chromosomes and genes. Also tomorrow we will look at mitosis and meiosis, so read from page 204 in your books.*

Lesson two topic: Mitosis and meiosis **Class:** Grade 11 Time: 70 min
Teacher: After handing out marked photocopies of homework one at a time, Lillian began the lesson by reviewing homework. In doing so, she drew learners' attention to questions where some learners made mistakes and corrected them. For example, she said: *Some of you wrote a chromosome is a thread-like structure. But because you already know that the structure is DNA you should be specific. So define a chromosome as a thread of DNA made up of genes. You should define a gene as a section of DNA which codes for the formation of single protein, controlling a specific characteristic of the organism.*
Teacher: After the review of homework, Lillian reminded learners: *Last time we discussed chromosomes, genes and alleles.*
Teacher: announced the day's topics. *Today we are going to look at cell division. How does the cell divide? Cells can divide in two ways by mitosis or meiosis. We will look at what happens in chromosomes during mitosis and meiosis. Let's start with mitosis.*
Teacher: defined mitosis as *a method or a process that involves the replication or duplication of chromosomes resulting in identical daughter nuclei or daughter cells.*
Teacher: She put a chart on the chalkboard showing the process of mitosis in an animal cell.
Teacher: *As you can see on the chart mitosis occurs in stages. We have interphase, prophase, metaphase, anaphase, and telophase; but it is not important to memorize the names of the stages because it is not required by the syllabus.*
Learner: Some learners complained that they could not see clearly from the chart.
Teacher: Lillian occasionally made enlarged sketches from the chart on the chalkboard. She described the stages of mitosis without using the specific names for them:
Teacher: *In the first stage we have a nucleus and inside the nucleus are the chromosomes. At this stage the chromosomes are long and thin.*
Teacher: *Before a cell divides, chromosomes shorten and become thicker so that one can see them under the light microscope. This means 'abamafisha abesidudla'* [vernacular used to mean short and fat].
Teacher: *At this stage a chromosome appears as two chromatids. When that occurs the nuclear membrane begins to disappear. And likewise the spindles form between the two poles of the cell.*
Teacher: *The chromatids start to divide at the centromere. When the chromatids separate, one chromatid will move to one pole and the other chromatid moves to the other end. Is that clear? So then in this way we have duplication of what? Multiplication of what? Of the cells. Is that clear?* Learners did not respond.
Teacher: *When cell division is completed, it gives rise to new cells, each containing the same number of chromosomes as the parent cell. The number of chromosomes is maintained the parent cell is diploid and daughter cells are diploid. When cell division is complete you have two daughter cells which are formed. Cells which are involved in the mitotic division we call them somatic cells. Is that clear?*
Learner: The class as a whole said *'Yes'.*
Teacher: *Mitosis occurs in plants and animals. In animals it usually occurs in the bone marrow where there is a production of new blood cells and in the skin. In plants it occurs in the root tips. Roots are the sites of cell division and cell elongation. It also occurs in the stem which results in the enlargement of the width of the stem and in the fruits which results in enlargement of fruit.*
Teacher: *It that clear?*
Learner: Learners as a class responded *'Yes'.*
Teacher: *We will talk about meiosis next time.*
Time might have been wasted during handing out learners' marked homework.

Appendix V

Participants' responses to the pre-lesson interview about teacher's content knowledge for teaching genetics

Items	Pre-lesson interview question	Responses				
		Lucy	**Lily**	**Leon**	**Lillian**	**Coding**
5	Would you tell me about your lesson plan and describe in detail how you will carry out the lesson (What is (are) the concept to be taught in this lesson?)	Inheritance, chromosomes, genes, alleles, haploid, diploid, mitosis, meiosis, inheritance of sex in humans, homozygous, heterozygous	Inheritance, chromosomes, genes, alleles, haploid, diploid, mitosis, meiosis, inheritance of sex in humans, homozygous,	Inheritance, Inheritance, chromosomes, genes, alleles, haploid, diploid, mitosis, meiosis, inheritance of sex in humans, homozygous, and heterozygous, dominant and recessive, genotype and phenotype	Inheritance, chromosomes, genes, alleles, haploid, diploid, mitosis, meiosis, homozygous,	All teachers had planned to teach the concepts of chromosomes, genes, mitosis and meiosis
5	(What do you intend the students to know about this idea?)	-definition of terms, description of mitosis and meiosis -differences between two processes -significance of each process	Definition of terms What makes up chromosomes (DNA) -description of mitosis and meiosis in terms of number of chromosomes in daughter cells -State number of cells formed in each process -state where they occur - compare mitosis and meiosis	Define inheritance Chromosomes are found in nucleus Chromosomes carry genes Genes carry genetic information Differentiate between mitosis and meiosis Differentiate between haploid and diploid nuclei	-define chromosomes, gene and allele -differentiate between diploid and haploid nuclei -differentiate between chromosome and genes and between gene and alleles -description of processes	All teachers wanted learners to know definition of genetics terms and differences between them, structure and function of chromosomes and genes, as well as descriptions of mitosis and meiosis. All teachers, except, Leon wanted learners to know stages of processes of cell division
5	(Why is it important for students to know this?)	-it is in the syllabus -understand inheritance of characteristic -it is an	-it is in the syllabus -Understand inheritance of characteristics Pursue further	-it is in the syllabus -They are the basis of genetics Understanding	-it is in the syllabus -to explain variation within species -understand	All teachers said it was in the syllabus, and in order to understand more complex

		interesting topic related to their lives -understand variation in species	studies -understand variation in within species	cell division will help them understand transmission of features from parents to offspring -solve genetic problems, answer exam questions	hereditary diseases -further studies Understand other concepts like cloning, genetic engineering	genetics concepts. Lucy said it was an interesting topic. Lily and Lillian said to help in further studies. Leon said to answer examination questions
5	(What else do you know about the concept, which you do not intend your students to know yet?)	-details of stages of processes of cell division	-formation of protein -details of processes of cell division due to syllabus limitation	-how transmission occurs -genetic crosses	-details of stages of cell division - disjunction of chromosomes, mutation	All teachers claimed to know more content than they were expected to teach

Appendix W

Participants' responses to the interviews, questionnaire and written reports about teacher's knowledge of instructional strategies for teaching genetics

Items	Pre-lesson interview question	Responses				
		Lucy	**Lily**	**Leon**	**Lillian**	**Coding**
5	Would you tell me about your lesson plan and describe in detail how you will carry out the lesson (What teaching procedures are you going to use to teach this concept and what are your particular reasons for using these to engage with this concept?)	-have assigned learners to read relevant chapter prior to lesson -questioning technique to find out prior knowledge and misconceptions, learners' understanding of new terms/concepts -learner presentation of self-constructed models – used because topic is difficult and enforce learners to read prior -teacher-led discussion to involve learners -start second lesson by recapping on previous lesson to determine whether learners still remember what they learned -classwork to reflect and evaluate whether learners have understood taught concepts	Discussion – to involve leaners Lecture Classwork, check and mark, one on one discussion with learners experiencing problems with classwork, class discussion -illustration to help learners visualise abstract concept	-lecture method- because quicker questioning- to get a feel if learners understand - practical activity, lecture Ask learners to read chapter before lesson and revise previous on reproduction. Begin lesson by telling learners about familiar situation, resemblance between parents and offspring to introduce the topic, inheritance -review fertilisation using questioning -review cell structure focusing on the nucleus in order to locate genetic information, introduce and locate chromosomes -refer learners to examples of chromosomes in textbook -talk about unique chromosome number for different species -state that genes are found in chromosomes -genes control characteristics of an organism -state life starts as one cell the zygote, which divide form many cell that develop into tissues, organs, system and whole organism -state cell divide by two types mitosis and meiosis -state differences between mitosis and	Questioning – to find out learners' prior knowledge and misconceptions about inheritance and chromosomes -Explain the terms using diagrams differentiate between chromosome and genes and between gene and alleles -past experience has shown that without illustration to help them visualise it was difficult - homework handout - Second lesson- start by reviewing homework -Use a chart to describe mitosis -worksheet with questions	Teachers reported to have planned to use different teaching methods and procedures for different reasons. Topic specific strategies included models for Lucy; illustration for Lily; Practical activity or demonstration and examples for Leon; and illustrations for Lillian

		-Questioning to identify areas where learners have difficulty, assess prior knowledge		meiosis Mitosis occur in all body cells called somatic cells while meiosis only used in making gametes -mitosis produces genetically identical daughter cells while meiosis produces genetically different daughter cells -in mitosis the chromosome number is the same, diploid while in meiosis number is halved, haploid -state reason why in meiosis number is half for maintenance of uniqueness of chromosome number in species during fertilisation -explain that meiosis is the type of cell division that results in variation between parent and offspring and among offspring linking to first part of the lesson -ask questions -give some notes		
Items	**Questionnaire questions**	**Lucy**	**Lily**	**Leon**	**Lillian**	**Coding**
	Lesson topic	Chromosomes and genes Mitosis and meiosis	Chromosomes and genes, Mitosis and meiosis	Inheritance and cell division. Common terms in genetics	Chromosomes and genes, Mitosis and meiosis	Teachers taught same genetics concepts
	Lesson duration	70 minutes	80 minutes	60 minutes	70 minutes	Teaching time varied among teachers
	Lesson objectives	Define inheritance, chromosomes, gene, allele, haploid and diploid nuclei Describe mitosis and meiosis	State what inheritance is, define a chromosome, gene, and allele, haploid and diploid nuclei Differentiate between terms. Describe	Define inheritance. Describe mitosis and meiosis and differentiate between them. Define and differentiate between: diploid and haploid number of chromosomes; chromosomes/gene/allele; homozygous/ heterozygous;	Define the terms chromosomes, gene, allele, haploid and diploid nuclei. Differentiate between terms Describe mitosis and	Definitions of genetics concepts. Differences among terms. Description of processes Differences between mitosis and meiosis

			mitosis and meiosis and their differences.	dominant / recessive; phenotype / genotype	meiosis and their differences	
1	What teaching methods and activities did you use during the lesson?	Question and answer method Teacher led discussion Presentation by pupils, using their models	Examples from everyday life, question and answer or discussion, diagrams of chromosomes and DNA and chalk board, classwork.	Question and answer Lecture , demonstration	Questioning or Teacher led discussion, use of diagrams and charts about cell division.	All teachers used questioning. Lucy also used learner presentation and models. Lily used familiar examples, illustrations and classwork. Leon used lecture and demonstration. Lillian used diagrams and charts.
2	What were your reasons for using those teaching methods and activities?	Question and answer was used to access learners' prior knowledge, what they have understood from their reading and what was taught. Presentation by learners was used to involve learners and help/assist in their understanding of the topic or terms Use of models was to enhance learners' understanding	Genes and chromosomes are too abstract and need illustrations to visualise them.	They are quicker regarding the available time and easier to use	Teacher led discussion was used So that learners could be actively involved throughout lesson. The chart was used to help learners see stages.	Teachers had varied reasons for using methods including eliciting learners' prior knowledge, engaging learners and promoting visualization of concepts
10	What changes would you make the next time you teach the same concept/con	Explain it in more details, using demonstrations and simulation experiments.	Change strategy, use more examples	More time, include written work that is then discussed to gauge understanding.	organise a video about chromosomes Explain how the division occurs using all the phases	Basically, all teachers would make changes in their instructional strategies

	tent?					
Items	**Post-lesson interview questions**	**Lucy**	**Lily**	**Leon**	**Lillian**	**Coding**
3	How do you know your teaching is effective?	learner performance in classwork, homework, tests and examination	learner performance in classwork, homework, tests and examination	Usually I use the performance of the students to know how effective I am with my teaching	learner performance in classwork, homework, tests and examination	All teachers judged their effectives through learner performance in classwork, homework, tests and examination
6	If learners have any problems in understandi ng the topic based on the instructional approach, what do you do to help them to understand?	Changes approach, give more exercises for practice, peer assistance	Repeating lesson or that difficult section, discussing with individual learners	Discusses learners ' work e.g. exercises, tests, sometimes discusses with individual learners	Changing teaching methods, assigning further reading, giving more exercises and encouraging learners to assist one another as peers	All teachers reported that they change instructional strategy to address difficulties e.g. peer assistance, give more work, individual discussion
Items	**Reflective notes questions**	**Lucy**	**Lily**	**Leon**	**Lillian**	**Coding**
	Lesson topic	Chromosome s and genes; mitosis and meiosis; monohybrid inheritance	Chromosom es and genes; mitosis and meiosis; monohybrid inheritance	Inheritance and cell division. Common terms in genetics; monohybrid inheritance	Chromosome s and genes; mitosis and meiosis; monohybrid inheritance	Teachers taught the same genetics concepts and study focused on chromosome s, genes, mitosis and meiosis
	Lesson duration	Each lesson was 70 (2x35) minutes	Each lesson was 80 (2x40) minutes	Each lesson was 60 (2x30) minutes	Each lesson was 70 (2x35) minutes	Teachers taught genetics concepts in different amounts of time depending on school time table
	Lesson objectives	Define inheritance, chromosomes , gene, allele, haploid and diploid	State what inheritance is, define a chromosom e, gene, and allele,	Define inheritance. Describe mitosis and meiosis and differentiate between them. Define and	Define the terms chromosome s, gene, allele, haploid and	Teachers focused on definitions of genetics concepts and differentiatin

		nuclei. State differences between terms. Describe mitosis and meiosis. Differentiate between processes. Define monohybrid inheritance, genotype, phenotype, homozygous ad heterozygous. Draw genetic crosses involving 3:1 and 1:1 ratio.	haploid and diploid nuclei Differentiat e between terms. Describe mitosis and meiosis and their differences. Define and use terms: dominant, recessive, homozygou s, heterozygou s. Work out genetic crosses controlled by 1 pair of alleles.	differentiate between: diploid and haploid number of chromosomes; chromosomes/gene/all ele; homozygous/ heterozygous; dominant / recessive; phenotype / genotype	diploid nuclei. Differentiate between terms Describe mitosis and meiosis and their differences. Draw genetic diagrams to show monohybrid inheritance and co dominance.	g between and among related concepts. Focused on description of mitosis and meiosis.
1	Was lesson effective? How do you know?	Yes, but some learners could not understand the division properly. Yes, most pupils were able to draw genetic diagrams.	Some because learners were able to solve given problems and give correct examples. In others I did not get positive feedback from learners.	Yes because there less questions from pupils, pupils answered questions correctly responded correctly to questions	Yes, most learners were able to tackle questions well and also ask questions	Lessons were generally viewed as effective as indicated by answering questions correctly and giving examples
2	What were your successes during the lesson?	Explaining chromosomes , genes, mitosis and meiosis and how to draw genetic diagrams involving 3:1 and 1:1 ratios	Achieving the lesson objectives and learners were able to work out given problems successfully	Delivered all concepts that had been planned. Keeping time and explaining each term.	Being able to explain the terms to the level learners could understand, using charts to explain how mitosis and meiosis occur.	All teachers felt lessons were successful as indicated by achieving objectives among others
3	Do you think students learned what you intended them to learn during the lesson?	Yes	Yes	Yes	Yes	All teachers felt learners learned what they were taught
7	What	Give it more	It is because	Make more time for	Try to use	All teachers

	changes would you make the next time you teach the same content/concept?	time, use more demonstrations	to say because for the past 18 years I am changing approaches and it never gets better I never repeat a lesson plan, I always plan anew. I always start a lesson afresh	exercises. Will give more practice exercises	more diagrams. Allow learners to read for themselves and present in groups. May teach about crossing over, disjunction of chromosomes	would make changes to their lessons e.g. spending more time on the topic, more exercise, group work, practical work
8	Did your learners enjoy the lesson? What were the indicators?	Yes. They freely participated	Not, they were just blank. Yes they did, knowing that it is easy to determine that a child is yours or not. I am not sure they were indifferent	Yes, laughter and jovial mood	Yes, most of them wanted to know more about topics and asked a lot of questions	Mostly enjoyed
9	Did learners work individually or in groups? Was that the best way? Why?	Individually. Yes, because I identified individual problems	Individually, none seemed to have mastered anything to be able to share. Individually so that each practices. In pairs to help each other	Individually, not really the best because some can benefit from group work.	Individually, yes it was the best because it makes it easy to identify difficulties per learner.	Mostly individually
10	What was the level of learner participation during the lesson?	Moderate to high	Differed in different lesson ranging from low to high	Good	High	Generally high
11	Were learners confident during the lesson?	Some yes	Not at all Yes they were A few yes, others hesitant	Yes	They seemed so	Learners were confident
12	Did learners complete assigned	Yes	Yes	Yes, they all did activities	Yes	Yes, learners completed tasks

	tasks?					

Appendix X

Participants' responses to the interviews, questionnaire and written reports about teacher's knowledge of learners' preconceptions and learning difficulties in teaching genetics

Items	**Pre-lesson interview question**	**Responses**				
		Lucy	**Lily**	**Leon**	**Lillian**	**Coding**
5	Would you tell me about your lesson plan and describe in detail how you will carry out the lesson (Learners' preconceptions and learning difficulties)	Questioning technique to find out learners' prior knowledge and misconceptions. Questioning to identify areas where learners have difficulty	Classwork to identify learners' learning difficulties One on one discussion with learners experiencing problems	Questioning to find out learners knowledge about previously taught concepts of sexual reproduction and cell structure	Questioning – to find out learners' prior knowledge and misconceptions	Lucy and Lillian planned to find out learners' preconceptions during lessons. Lily and Leon did not mention preconceptions
Items	**Questionnaire questions**	**Lucy**	**Lily**	**Leon**	**Lillian**	**Coding**
3	What preconceptions did you expect your learners to have about the topic/concept (s)?	Differences between sexual and asexual reproduction for lesson one. Chromosomes, sexual and asexual reproduction, number of chromosomes in human somatic cells for lesson two.	That they resemble parents and that characteristics are passed from generation to generation for lesson one. DNA, genes and alleles for lesson two.	Sexual reproduction in humans Structure and functions of a cell Inheritance in general	Function of nucleus, definition of inheritance, reproduction and cell division for lesson one. To know about diploid cells, haploid cells, chromosomes and somatic/germ cells for lesson two.	Teachers expected learners to have knowledge about previously taught topics and ideas about inheritance of characteristics
4	How did you find out the learners' preconceptions?	Questioning and through the teacher led discussion.	Questioning and homework	Questioning	Asking questions, The answers to homework exercise.	All teachers reported using questioning while Lily and Lillian said they also used homework
5	What learners' learning difficulties did you	Understanding the terminology associated with	Comprehending and visualising the gene and the concept of	Grasping the difference between haploid and diploid hence between mitosis	To differentiate between chromosomes, genes and	All teachers expected learners to have some difficulty in

	anticipate in planning your lesson?	inheritance. Difficulties in understanding meiosis	a code in the form of a protein to control characteristics .	and meiosis; homozygous and heterozygous; and phenotype and genotype	alleles. How the division of the chromatids occurs.	learning topic such as terminology, defining terms and differentiating among them.
6	What did learners find difficult to understand during the lesson?	Definitions of chromosomes and genes, chromatids. Meiosis, especially the stages that result in reduction division, differentiating between mitosis and meiosis.	The structure of DNA and the proteins formed to control characteristics . Defining the terms. Understandin g process of mitosis and meiosis	May not know because there wasn't enough time for evaluation.	The definition of a chromosome seemed difficult in most learners. Understanding the processes of cell division	Leon did not find out difficulties. Other teachers reported difficulties such as defining terms and differentiating among them and understanding processes of mitosis and meiosis
7	How did you discover or find out learners' learning difficulties?	Through questioning, learner presentation	I could tell from the look in their faces and the verbal feedback I got from them. During marking as I moved up and down while they were working.	-	The answers they gave in the handout questions i.e. homework. The questions learners asked	Lucy, Lily and Lillian discovered difficulties through questioning, learner presentation, classwork, homework and learners' questions for clarifications
8	What do you think made those areas difficult for learners to understand?	First time to meet concepts, abstract concepts	Topic is abstract	-	Such concepts are too abstract for learners.	Lucy, Lily and Lillian attributed topic difficulty to its abstract nature. Lucy also mentioned that learners are meeting concepts for the first time
9	How did you address learners' learning difficulties, if at all, during the lesson?	Peer assistance Explaining	I tried to ask them leading questions, go back to reinforce, discussed with individual learners	-	Re explained the term using the diagrams	Teachers used different approaches to address learners' difficulties e.g. Peer assistance, explaining , individual discussion

						and using visual aids
Items	**Post-lesson interview questions**	**Lucy**	**Lily**	**Leon**	**Lillian**	**Coding**
4	What learning difficulties do your learners experience in learning about genetics?	Understanding chromatids and differentiating between chromatids and homologous chromosomes, understanding meiosis and reduction of number of chromosomes, solving genetics crosses	Confuse genetics terms e.g. chromosomes, genes, alleles, DNA, homozygous and heterozygous, interpreting genetic crosses results	Confusing genetics terms e.g. homozygous/ Heterozygous, phenotype/genotype, solving genetics problems	Confusing genetics terms e.g. using them interchangeably: chromosomes, genes, understanding replication of chromosomes, solving genetics terms	Learners usually have difficulties with terminology of genetics, using terms interchangeable, process of meiosis, and working out Mendelian genetics problems
5	What makes those areas difficult for learners to learn or understand?	Genetics concepts are abstract, genetics not done at lower school levels and learners meet terms for first time, lack of understanding of basic terms e.g. alleles makes difficult for learners to solve problems	Abstract nature of genetics, mathematical nature of genetics problems	Teacher's teaching approach, mathematical nature of genetics problems	Learners meet genetics concepts for first time at this school level, concepts are abstract	All teachers attributed difficulties in genetics to abstract nature of the topic. other factors were the mathematical nature of genetics problems and that learners see concepts for the first time
6	If learners have any problems in understanding the topic based on the instructional approach, what do you do to help them to understand?	Changes approach, give more exercises for practice, peer assistance	Repeating lesson or that difficult section, discussing with individual learners	Discusses learners ' work e.g. exercises, tests, sometimes discusses with individual learners	Changing teaching methods, assigning further reading, giving more exercises and encouraging learners to assist one another as peers	All teachers reported that they change instructional strategy to address difficulties e.g. peer assistance, give more work, individual discussion
Items	**Reflective notes questions**	**Lucy**	**Lily**	**Leon**	**Lillian**	**Coding**
4	What did	Understandin	Defining	May not know –	To define	Usual

	learners find difficult to learn during the lesson?	g chromosomes in relation to DNA, chromatids, process of meiosis, correctly using different letters for the same characteristic	chromosomes and genes, understanding of alleles controlling features	no evaluation. But usually have problems with separating terms that go in pairs.	chromosome, gene and alleles. The stages that occur during cell division, the separation of chromosomes at the centromere	difficulties include understanding chromosomes, genes and processes of cell division
5	What do you think made those areas difficult for learners to understand?	How the chromosomes end up being halved from those of the parent cell. Using letters to represent alleles	It's probably to visualise the structure of DNA and relating protein formed with physical characteristics .	Less remembering of prior knowledge. No activity to give them to practice. Difficulty of the topic	Most of these terms are too abstract.	Teachers thought difficulties emanated from topic being abstract and not easy for learners to visualize as well as teaching approaches
6	How did you address learners' difficulties during the lesson?	Use of some demonstrations, other pupils to help their peers Explained again	I used diagrams and tried to describe it from different angles. I told them it is the standard way of representing alleles. Used illustrations	used examples but usually answer learners' questions, and give a lot of practice exercises	Demonstrate and explained using much simplified diagrams.	Teachers used different ways to address learners difficulties such as peer tutoring, use illustrations, give more exercises

Appendix Y

Participants' responses to the post-lesson interview about teacher's pedagogical content knowledge development in teaching genetics

Items	Post-lesson interview question	Responses				
		Lucy	**Lily**	**Leon**	**Lillian**	**Coding**
1	How have the courses that you learned at university/college helped you to prepare your lessons for teaching?	BSc courses gave content knowledge PGCE courses gained knowledge about teaching methods	BSc courses gave content knowledge PGCE courses gained knowledge about teaching methods	BSc courses gave content knowledge Education courses gained knowledge about teaching methods	BSc courses gave content knowledge PGCE courses gained knowledge about teaching methods	University courses helped teachers gain content knowledge and knowledge of teaching methods
2	Has teaching genetics over the years helped you teach the topic better? If yes, how?	Yes, discovered concepts or areas that usually learners difficulty to understand, and changed teaching methods as a result	Yes discovered concepts or areas that usually learners difficulty to understand, and changed teaching methods as a result	Yes get feedback from the performance of the previous group know difficulties in this and this aspect and then I would try and use other methods some of which have been gained through experience and workshop and then try and teach some of the topic in a better manner. Over the years, I have gradually improved due to experience of being exposed to all sorts of problems that are presented when the students are expected to write because they are the ones that show you that is how you are expected to teach a topic because this is how the topic would probably be asked and in that manner if you know not necessarily the	Yes, now understands topic better, discovered concepts or areas that usually learners difficulty to understand, and changed teaching methods as a result	Teaching experience contributed to teacher knowledge of content, instructional strategies and knowledge of learners' learning difficulties

				content but if you know all the possible ways in which the students can possibly be examined on the topic you then able you to teach them in a better way.		
3	How do you know your teaching is effective?	learner performance in classwork, homework, tests and examination	learner performance in classwork, homework, tests and examination	Usually I use the performance of the students to know how effective I am with my teaching	learner performance in classwork, homework, tests and examination	All teachers judged their effectives through learner performance in classwork, homework, tests and examination
4	What learning difficulties do your learners experience in learning about genetics?	Understanding chromatids and differentiating between chromatids and homologous chromosomes, understanding meiosis and reduction of number of chromosomes, solving genetics crosses	Confuse genetics terms e.g. chromosomes, genes, alleles, DNA, homozygous and heterozygous, interpreting genetic crosses results	Confusing genetics terms e.g. homozygous/ Heterozygous, phenotype/genotype, solving genetics problems	Confusing genetics terms e.g. using them interchangeably: chromosomes, genes, understanding replication of chromosomes, solving genetics terms	Learners usually have difficulties with terminology of genetics, using terms interchangeable, process of meiosis, and working out Mendelian genetics problems
5	What makes those areas difficult for learners to learn or understand?	Genetics concepts are abstract, genetics not done at lower school levels and learners meet terms for first time, lack of understanding of basic terms e.g. alleles makes difficult for learners to solve	Abstract nature of genetics, mathematical nature of genetics problems	Teacher's teaching approach, mathematical nature of genetics problems	Learners meet genetics concepts for first time at this school level, concepts are abstract	All teachers attributed difficulties in genetics to abstract nature of the topic. other factors were the mathematical nature of genetics problems and that learners see concepts for the first time

		problems				
6	If learners have any problems in understanding the topic based on the instructional approach, what do you do to help them to understand?	Changes approach, give more exercises for practice, peer assistance	Repeating lesson or that difficult section, discussing with individual learners	Discusses learners ' work e.g. exercises, tests, sometimes discusses with individual learners	Changing teaching methods, assigning further reading, giving more exercises and encouraging learners to assist one another as peers	All teachers reported that they change instructional strategy to address difficulties e.g. peer assistance, give more work, individual discussion
7	Have you ever been to a biology workshop on teacher development? If yes, what was the content, and duration of the workshop? Who were the facilitators (Biology educators)? As a biology teacher, how did you benefit from the workshop? Would you recommend that similar workshops be held for teachers?	Yes. A few about improving our teaching like teaching aids, some visuals to represent what you are teaching about for learner. One day it was mainly about examination performance discussing difficult questions, one dealt with content; workshops are facilitated by biology specialists from In-service and inspectorate. As a biology teacher she benefited from the workshop in that she identified topic/ways in which she could better teach topic. Yes workshops are recommended for other	Yes, one day duration, about exams and teaching methods trying to make different objects using plasticine with beads to show chromosomes and genes. Facilitated by biology educator. She benefited in that even though marking, the discussion helps because understand even the syllabus, estimate time and therefore able to time themselves, content get more. Yes, recommended for other teachers	Yes many times, duration one day, content of workshops differed, one dealt with genetics and not the whole topic of genetics, but variation; facilitated by Biology educators and other teachers, benefited by learning how to teach topics, yes they are recommended for other teachers.	Yes, two times. 1st about how to help students answer exam questions using verbs, what is expected for each verb 2nd was about microteaching how to teach certain topics, how one can approach such a topic. Duration – one day. Facilitated by Biology educator; Got ideas how to approach/teach other topics, teaching methods/aids e.g. projectors, chart, organize practical work. Learning about how to answer questions enabled me to help learners how to respond to questions. Yes, recommends them for other teachers.	All teachers have attended biology workshops dealing with different aspects of biology teaching

		teachers because the problem is usually with the teacher and not the students				
8	Have you ever been to a workshop, specifically on genetics? As a biology teacher, how did you benefit from the workshop? Would you recommend that similar workshops be held for teachers?	No	No	Yes, benefited in that in the workshop get experiences from other teachers and learn more effective ways of tackling certain topics which have already been tried by these teachers and have been found to be effective. Sometimes you find that you would be expected to try out some activities which then if you feel will be effective in teaching instead of trying them out for the first time in your class you try them out with other teachers and you brainstorm as to if this and that happen and you would know that you have learned something like this and that happen that is how you would be expected to deal with it instead of experiencing it for the first time in class. Such activities involved the use of picture cards to show different features due to the fact students like playing with cards there are some concepts that use that some other methods involve	No, genetics was one of the topics taught during microteaching in the 2nd workshop	None of the workshops they attended was specific to genetics

				using activities involving dices and things like that and other methods which are actually more learner-centred than teacher-centred. Yes, highly recommended such especially the new teachers who have not yet gained a lot of experience in teaching.		
9	Do you collaborate with other teachers in your department about teaching? If yes, how has that helped you in your teaching?	Yes, in departmental meetings they discuss some teaching methods and how they can improve their teaching. Also informally outside meetings like a teacher has a problem with teaching a particular topic she/would ask colleagues. The collaboration has not been used for genetics.	Not that much, but if I need help from the teacher but do not sit down formally to discuss, we share information whether from internet, hospitals	I do collaborate with other teachers we always liaise on how this can be taught and sometimes we even set the tests together make marking schemes together. Unfortunately, I am the most experienced and most of the time it is them that get help from me. I get in setting tests and doing marking schemes because some of the teachers come with different ways of asking questions	Yes, even with other departments. It was helpful e.g. Food and Nutrition, geography help with content and with colleagues about teaching of mitosis, differences between mitosis/meiosis and how to explain it to learners a teacher who taught biology before helped me when I had problem	All teachers collaborate with departmental colleagues but only Lillian benefited from such sharing about genetics teaching
10	What other sources of information do you use?	Textbooks, Internet	Internet in the schools, books from library, also rarely visit hospitals to get information	Internet, books from library.	Mostly textbooks, study guides, reference materials most of which are personal copies, Internet available in the school for	Other sources include textbooks, Internet

					teachers	

Appendix Z: Ethical Clearance Certificate

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

RESEARCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE	**CLEARANCE NUMBER :** SM 11/02/02
DEGREE AND PROJECT	PhD Exploring science teachers' pedagogical content knowledge in the teaching of genetics in Swaziland
INVESTIGATOR(S)	Eunice Khetsiwe Mthethwa
DEPARTMENT	Science, Mathematics and Technology Education
DATE CONSIDERED	05 September 2013
DECISION OF THE COMMITTEE	APPROVED

Please note:
For Masters applications, ethical clearance is valid for 2 years
For PhD applications, ethical clearance is valid for 3 years.

CHAIRPERSON OF ETHICS COMMITTEE Prof Liesel Ebersöhn

DATE 05 September 2013

CC
Jeannie Beukes
Liesel Ebersöhn
Prof GOM Onwu
Dr JJR de Villiers

This ethical clearance certificate is issued subject to the following conditions:

1. A signed personal declaration of responsibility
2. If the research question changes significantly so as to alter the nature of the study, a new application for ethical clearance must be submitted
3. It remains the students' responsibility to ensure that all the necessary forms for informed consent are kept for future queries.

Please quote the clearance number in all enquiries.