

**EXAMINING THE COMPONENTS OF PEDAGOGICAL CONTENT KNOWLEDGE AND
THE CONSTRUCTION OF PHYSICS TEACHERS' CLASSROOM PRACTICES**

By

NTHOESELE HLAELA

MSc Ed (WITS), BSc Hons. (WITS), BSc Ed (NUL)

Submitted in fulfilment of the requirements for the Degree of

Philosophiae Doctor in Education

(PhD Education)

in the

SCHOOL OF EDUCATION STUDIES

FACULTY OF EDUCATION

UNIVERSITY OF THE FREE STATE

BLOEMFONTEIN

SUPERVISOR: PROFESSOR L C JITA

JULY 2023

DECLARATION

I, Nthoesele Hlaela (2018697561) declare that the Doctoral Degree research thesis that I herewith submit at the University of the Free State, is my independent work and that I have not previously submitted it for qualification at another institution of higher education.

I, declare that I am aware that the copyright is vested in the University of the Free State.

I, declare that all royalties as regards to intellectual property that was developed during the course of and/or in connection with the study at the University of the Free State, will accrue to the University.

I, declare that I am aware that the research may only be published with the Dean's approval.



June 2023

Nthoesele Hlaela

Date 21/07/2023

DEDICATION

I would like to dedicate this work to my parents in heaven, 'Makhutlang Hlaela and Motlalepula Sylvester Hlaela, they have always been the wind beneath my wings.

This work is also dedicated to my daughters, Kananelo Ratlali and Mahlohonolo Mohlouoa and to my nephew Liteboho Hlaela, I am grateful for their love, patience, prayers and the faith they always had in me as their parent while I neglected them so much while studying.

I also dedicate this work to my sisters 'Malefu Hlaela and Nthabiseng 'Mampoi Rafolatsane, for the financial, emotional and spiritual support they gave me and for taking care of my children as I studied.

ACKNOWLEDGEMENTS

My sincere thanks to the following:

My supervisor, Professor Loyiso C. Jita for the financial support through the SANRAL bursary he provided me with when I began my study, as without this bursary I would not have been able to carry out my study at all. I am also gratified for his tolerance, inspiration and believing in me, even in my weakest moments. His intuitive comments have modelled my thinking for the better and I am appreciative for his valuable, constructive and intellectual guidance.

The SANRAL team, their dedication and unwavering support is highly appreciated. Through their tight work schedules, they read my drafts, guided me through their constructive comments, opened my eyes to better understand my study and myself, provided and organised writing support workshops that contributed a lot to my progress.

The Ministry of Education and Training for granting me permission to carry out this study in schools in Lesotho. I also thank the Principals, Science HODs and Physics teachers who allowed me to conduct this study in their schools. The Physics teachers gave me the time they did not have. The four case teachers spared so much time and allowed me to go into their classrooms and without their cooperation I would not have collected any data.

Mrs 'Mamomtena Jankie for all the contributions she made in my study as a very experienced Physics teacher trainer. My English language editors; Derek Gripper, Mrs Maleshoane Tlebere, Mrs Ntlokholo Kotele and Mr Kananelo Moea who spent sleepless nights making my study reader friendly.

Dr Maleho Letloenyane the SANRAL team member and Dr Sean Van Der Merwe of the UFS Statistical Consultation Unit for helping me analyse my data statistically.

My friends, pillars of strength, prayer partners and inspirations, Lieketseng Lematla Mphata, 'Maretsepile Molahloe,'Maqoni Malebanye, Ntlokholo Kotele, Mosiako Modise, Limpho Ntai, Dr Sets'eetso Matobako, Dr 'Maisaiah Phakisi and Dr Sandress Msuku, thank you for making this journey possible and for holding my hand in times of difficulties.

Lesotho College of Education for giving me permission to study while they were aware that I would be absent from work sometimes to attend writing support workshops and conferences. My requests to attend to my study needs have never been turned down.

My night shift study mates, Lucia Lisene, Dr 'Malisema Makoa and Kananelo Moea, they have always encouraged me without ceasing to go on with my study. My long distance driver, Thabang Molelle, thank you for sparing your time and being a very reliable driver, driving me safely to all reachable schools in Lesotho.

Canon Collins Scholarship, I sincerely appreciate the financial contribution they gave me to pursue this financially demanding study; the role they played will always be remembered.

The Almighty God for strength and wisdom to complete this thesis, at times I had God as my only hope to carry on.

CONTENTS

DECLARATION.....	i
DEDICATION	ii
ACKNOWLEDGEMENTS	iii
LIST OF APPENDICES.....	x
LIST OF FIGURES.....	xi
LIST OF TABLES	xiii
LISTS OF ACRONYMS AND ABBREVIATIONS	xv
SUMMARY OF THE STUDY.....	xvi
CHAPTER 1: BACKGROUND AND ORIENTATION OF THE STUDY	1
1.1INTRODUCTION	1
1.2 CONTEXT OF THE STUDY.....	3
1.3 PROBLEM STATEMENT AND RESEARCH QUESTIONS	4
1.4 AIMS AND OBJECTIVES OF THE STUDY	8
1.5 THE VALUE OF THE STUDY	9
1.6 CONCEPTUAL FRAMEWORK.....	10
1.7 RESEARCH DESIGN AND METHODOLOGY.....	12
1.8 LIMITATIONS OF THE STUDY	14
1.9 DELIMITATIONS OF THE STUDY	14
1.10 OPERATIONAL TERMS	15
1.11 SUMMARY OF THE CHAPTER AND THE STUDY OUTLINE	16
CHAPTER 2: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK	17
2.1 INTRODUCTION	17
2.2 PEDAGOGICAL CONTENT KNOWLEDGE (PCK).....	17
2.2.1 PCK background.....	17

2.2.2 Definition of PCK	17
2.2.3 Importance of PCK	18
2.2.4 PCK as a construct	20
2.3 COMPONENTS OF PCK	21
2.4 CONSTRUCTION OF CLASSROOM PRACTICES	24
2.5 THE ROLE OF PCK IN CLASSROOM PRACTICES	27
2.6 MEASURING AND PORTRAYING PCK	31
2.7 CONCEPTUAL FRAMEWORK	38
2.7.1 Teachers' professional knowledge bases: PCK components	44
2.7.1.1 Assessment knowledge	44
2.7.1.2 Pedagogical knowledge	46
2.7.1.3 Content knowledge	46
2.7.1.4 Knowledge of students	48
2.7.1.5 Curricular knowledge	49
2.8 CONCLUSION	53
CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY	55
3.1 INTRODUCTION	55
3.2 RESEARCH QUESTIONS AND THE PURPOSE OF THE STUDY	55
3.3 RESEARCH METHODOLOGY AND DESIGN	56
3.3.1 Research paradigm	56
3.3.2 Research approaches	57
3.3.3 Research design	59
3.4 SAMPLING PROCEDURE	62
3.5 SAMPLING STRATEGY	62
3.6 DATA COLLECTION	63

3.6.1 The PCK test	64
3.6.2 Interviews.....	68
3.6.3 Classroom Observations.....	72
3.6.4 Post Observation interviews	74
3. 7 DATA ANALYSIS.....	75
3.7.1 Analysis of quantitative data	75
3.7.2 Descriptive statistics of the PCK test	85
3.7.3 Analysis of qualitative data	86
3.7.4 Integrating quantitative and qualitative data.....	87
3.8 THE PILOT STUDY	88
3.9 VALIDITY AND RELIABILITY	89
3.9.1 Content validity, expert judgment and construct validity	90
3.9.2 Legitimation	91
3.10 RESEARCH ETHICS.....	92
3.11 CONCLUSION	92
CHAPTER 4: ANALYSIS OF THE PCK COMPONENTS AND PHYSICS TEACHERS' CLASSROOM PRACTICES	93
4.1 INTRODUCTION	93
4.2 ANALYSIS OF PCK COMPONENTS THAT PHYSICS TEACHERS POSSESS: QUANTITATIVE ANALYSIS	94
4.2.1 Description of PCK test Participants	95
4.2.3 Analysis of the PCK test using the Extended Rasch Model	101
4.2.4 Descriptive statistics of the PCK test	105
4.3 MANIFESTATIONS OF PCK COMPONENTS IN CLASSROOM PRACTICES: QUALITATIVE ANALYSIS	107
4.3.1 Case1: Jay's narrative on the teaching of 'turning effects of force'	108

4.3.2 Case 2: Gift's narrative on the teaching of the 'turning effects of force' for Grade-11	125
4.3.3 Case 3: Jimmy's narrative on the teaching of the 'turning effects of force' for Grade-11	135
4.3.4 Case 4: Joy's narrative on the teaching of the 'turning effects of force'	148
4.4: THE ROLE OF PHYSICS TEACHERS' PCK IN CLASSROOM PRACTICES: A COMPARISON BETWEEN THE FOUR TEACHERS	161
4.4.1 CoRes (Content Representations) for the four teachers	163
4.4.2 Comparison of four teachers' PCK components	168
4.5 CONCLUSION	175
CHAPTER 5: DISCUSSION OF RESULTS AND CONCLUSION	176
5.1 INTRODUCTION	176
5.2 STUDY OVERVIEW.....	176
5.3 KEY FINDINGS OF THE STUDY	179
5.3.1 PCK components possessed by Physics teachers	180
5.3.2 Manifestation of PCK in classroom practices	181
5.3.3 Explanation of the role of Physics teachers' PCK in classroom practices....	187
5.4 CONTRIBUTION TO NEW KNOWLEDGE	189
5.5 CONCLUSION	193
5.6 LIMITATIONS	194
5.7 RECOMMENDATIONS.....	196
5.7.1 Recommendations for Policy	196
5.7.2 Recommendations for practice	197
5.7.3 Recommendations for future research.....	198
5.8 MY FINAL THOUGHTS AND EXPERIENCES AS A RESEARCHER	199
REFERENCES.....	201

APPENDICES.....	213
------------------------	------------

LIST OF APPENDICES	page
Appendix A: PCK TEST INSTRUMENT.....	213
Appendix B: PCK TEST RUBRIC.....	221
Appendix C: DESCRIPTION OF THE PCK TEST ITEMS.....	227
Appendix D: INTERVIEW SCHEDULE.....	231
Appendix E: ETHICS CLEARANCE APPROVAL (letter 1).....	232
Appendix F: ETHICS CLEARANCE APPROVAL (letter 2).....	233
Appendix G: MINISTRY OF EDUCATION PERMISSION LETTER.....	234
Appendix H: PRINCIPAL CONSENT FORM.....	235
Appendix I: TEACHERS' CONSENT FORM.....	236
Appendix J: DECLARATION OF EDITING.....	237
Appendix K: TURNITIN REPORT.....	238

LIST OF FIGURES

FIGURE 1.1:	2019 PHYSICAL SCIENCE PERFORMANCE BY DISTRICT.	5
FIGURE 2.1:	THE CONSENSUS MODEL.....	41
FIGURE 2.2:	MODIFIED CONSENSUS MODEL.....	53
FIGURE 4.1:	GENDER REPRESENTATION OF PARTICIPANTS.....	95
FIGURE 4.2:	PCK TEST RESPONDENTS PER DISTRICT.....	96
FIGURE 4.3:	PCK TEST RESPONDENTS' QUALIFICATIONS.....	97
FIGURE 4.4:	PCK TEST PARTICIPANTS' YEARS OF EXPERIENCE.....	98
FIGURE 4.5:	ILLUSTRATION OF RATING THE PCK TEST ITEMS.....	99
FIGURE 4.6:	WRIGHT MAP.....	102
FIGURE 4.7:	JAY PUSHING THE DOOR AT DIFFERENT POSITIONS.....	111
FIGURE 4.8:	JAY IMITATING A SPANNER.....	112
FIGURE 4.9:	REPRESENTATION OF A SEESAW.....	114
FIGURE 4.10:	WEIGHTS REPRESENTING PEOPLE ON THE SEESAW....	115
FIGURE 4.11:	CALCULATIONS OF TORQUE.....	117
FIGURE 4.12:	UNITS IN CALCULATIONS.....	120
FIGURE 4.13:	CONVERSION OF MASS TO WEIGHT.....	121
FIGURE 4.14:	JAY'S ASSESSMENT QUESTION 1 SOLUTION.....	123
FIGURE 4.15:	JAY'S ASSESSMENT QUESTION 2.....	124
FIGURE 4.16:	GIFT SHOWING A MASK THREAD.....	128
FIGURE 4.17:	STUDENT MEASURING LENGTHS OF AN ELASTIC MATERIAL.....	129

FIGURE 4.18:	A CROWBAR WITH EQUAL LOADS.....	143
FIGURE 4.19:	MARKED EXERCISE.....	145
FIGURE 4.20:	TOPICS TO BE COVERED.....	149
FIGURE 4.21:	MATHEMATICAL VERIFICATION OF THE PRINCIPLE OF MOMENTS.....	154
FIGURE 4.22:	CLOCKWISE AND ANTICLOCKWISE DIRECTIONS.....	155
FIGURE 4.23:	CALCULATION OF MOMENT.....	156
FIGURE 4.24:	ASSESSMENT QUESTION ON MOMENTS.....	159
FIGURE 4.25:	RESPONSE TO ASSESSMENT QUESTION.....	159
FIGURE 4.26:	ASSESSMENT QUESTION 2 ON MOMENTS.....	160

LIST OF TABLES

	page
TABLE 1.1: 5 YEAR TRENDS - PHYSICAL SCIENCE PERFORMANCE.	6
TABLE 2.1: CLASSROOM PRACTICES - EXAMPLES THAT EXHIBITED THE TEACHER'S DEVELOPED PCK.....	30
TABLE 2.2: ASSESSMENT OBJECTIVES.....	46
TABLE 3.1: A DISPLAY OF EXPLANATORY SEQUENTIAL STUDY DESIGN METHOD.....	62
TABLE 3.2: PCK TEST DISTRIBUTION AND COLLECTION.....	68
TABLE 3.3: CORE PROMPTS AND RELEVANT PCK COMPONENTS....	71
TABLE 3.4: CLASSROOM OBSERVATIONS PER TEACHER.....	74
TABLE 3.5: INTERPRETATION OF COHEN'S KAPPA.....	78
TABLE 3.6: INTER-RATER AGREEMENT.....	79
TABLE 3.7: ITEM FIT STATISTICS.....	83
TABLE 3.8: PERSON FIT STATISTICS EXAMPLE.....	84
TABLE 4.1: PARTICIPANTS QUALIFICATIONS MEANING.....	98
TABLE 4.2: PCK TEST RUBRIC EXAMPLE.....	100
TABLE 4.3: PCK TEST RAW SCORES.....	101
TABLE 4.4: LEVEL OF DIFFICULTY OF PCK ITEMS.....	103
TABLE 4.5: PCK COMPONENTS AND THE LEVEL OF DIFFICULTY OF THEIR COMPOSITE ITEMS.....	104
TABLE 4.6: DESCRIPTIVE STATISTICS OF THE PCK COMPONENTS...	106
TABLE 4.7: PCK COMPONENTS RANKING ORDER AND LEVELS.....	107

TABLE 4.8:	HOOKE’S LAW GRAPHS.....	133
TABLE 4.9:	EXAMPLES USED FOR TEACHING PRINCIPLE OF MOMENTS.....	138
TABLE 4.10:	CASE C AS AN EXAMPLE.....	141
TABLE 4.11:	ASSESSMENT QUESTIONS AS CASE C.....	144
TABLE 4.12:	DEMONSTRATIONS INVOLVED BY JOY.....	151
TABLE 4.13:	DESCRIPTIONS OF THE FOUR TEACHERS.....	162
TABLE 4.14:	JAY, JIMMY AND JOY’S CORE FOR TEACHING PRINCIPLE OF MOMENTS.....	164
TABLE 4.15:	GIFT’S CORE FOR TEACHING EFFECTS OF FORCE ON SHAPE.....	166
TABLE 4.16:	CASE TEACHERS’ PCK COMPONENTS RAW SCORES AVERAGE.....	168

LISTS OF ACRONYMS AND ABBREVIATIONS

AK	Assessment Knowledge
CK	Content Knowledge
CoRe	Content Representation
CuK	Curricular Knowledge
KS	Knowledge of Students
LGCSE	Lesotho General Certificate of Secondary Education
MoET	Ministry of Education and Training
PaP-eRs	Pedagogical and Professional experience Repertoires
PCK	Pedagogical Content Knowledge
PK	Pedagogical Knowledge
POI	Post Observation Interview
ProwiN	Professional Knowledge in Natural sciences
QuIP	Quality of Instruction in Physics
SPSS	Statistical Package for Social Sciences
TPK&S	Teacher Professional Knowledge and Skill
TPKB	Teacher Professional Knowledge Bases
TSPK	Topic-specific Professional Knowledge
VRT	Video Record Transcript

SUMMARY OF THE STUDY

Research considers teachers' pedagogical content knowledge (PCK) as knowledge that differentiates a teacher from a subject specialist. PCK is needed to help the teacher transform the knowledge of content to be teachable to students. Research has shown that when the PCK of teachers is not well established, classroom practice is jeopardized. The quality of teaching Science is a concern in many countries including Lesotho. There have been inconsistent findings on the large-scale studies to relate PCK and classroom instructional practices, thus the call for more studies that explore the relation of PCK and classroom practices so as to understand the role of PCK in teachers' classroom actions. This study investigated the components of PCK that Physics teachers in Lesotho possess and how they draw on the components of PCK to construct their classroom practices in a variety of secondary school contexts. The PCK components were examined across Physics teaching as domain PCK while the manifestations of PCK were explored in the teaching of a specific topic in Physics, "the effects of force".

The Consensus Model of PCK was used as a conceptual framework guiding this study. This Model was adapted to incorporate the Model of Magnusson *et al.* (1999) to explore the PCK components and to portray the manifestations of PCK in classroom practices. The Consensus Model consists of five knowledge bases termed PCK components in this study being: assessment knowledge (AK), pedagogical knowledge (PK), content knowledge (CK), knowledge of students (KS) and curricular knowledge (CuK). This model allowed the researcher to explore both the knowledge on-action and the knowledge in-action, which are helpful in differentiating what the teacher knows about teaching Physics and how the teacher actually teaches Physics in the classroom.

This study followed an explanatory sequential mixed method design where data were collected in two phases. In Phase one, a quantitative part, a paper-and pencil PCK test was administered to 87 qualified Physics teachers teaching the last two years of secondary education. The responses were scored using a rubric that was in line with the five PCK components, which were rated on a four point scale from 1 to 4, where 1 indicated undeveloped PCK and 4 indicated developed PCK. Data were analysed using

the Extended Rasch Model and SPSS. Phase two, the qualitative part, involved four case teachers selected among the 87 teachers. These were purposively selected teachers with the highest and lowest scores from the PCK test. The qualitative data were collected through different methods. The audio-recorded pre-observation interviews, the video recorded classroom observations and the audio-recorded post-observation interviews. Data were analysed by presenting the narratives of the four case teachers.

The findings revealed that the Physics teachers' PCK was rather low since the person measures ranked in the interval $-1.37logit < PCK < +0.95logit$ with the PCK components of CK and KS being the least developed. It was also found that the PCK components measured through the PCK test did not show the same level of development as the components manifested in classroom practices and this study argues that contextual factors shape classroom practices construction more than pedagogical content knowledge of the teacher. This study recommends the involvement of Physics teachers in regular refresher workshops that are meant to engage teachers in reflection on what they know about the topics they teach, focusing on different PCK components.

Key terms: professional knowledge, pedagogical content knowledge, classroom practices, PCK components, knowledge on-action, and knowledge in-action, physics teaching

CHAPTER 1: BACKGROUND AND ORIENTATION OF THE STUDY

1.1 INTRODUCTION

Teacher pedagogical content knowledge has in previous research been identified as the foremost predictor of student achievement (Keller, Neumann & Fischer, 2017). Shulman (1986) termed the knowledge of transforming content knowledge into a teachable form that can be comprehended by students as pedagogical content knowledge (PCK). Teachers draw on different knowledge bases to construct their classroom practices of which PCK is but one (Shulman, 1987). These Knowledge bases are referred to as PCK components by some researchers (Ezic-Kiran, Boz & Oztay, 2021; Magnusson Krajcik & Borko, 1999). PCK components have to work in unison to produce high quality PCK in classroom practices (Sæleset & Friedrichsen, 2022). This means that the PCK components have to be well developed to be used as an amalgamation of individual components, complementing each other to produce effective teaching in classrooms. When PCK is not well formed, the quality of classroom practice is often compromised (Barendsen & Henze, 2017; Rollnick, 2017). Oztay and Boz (2022) argue that a teacher has to possess an in-depth understanding of the content knowledge of the discipline they teach in order for content knowledge and other components that form the PCK of the teacher to interact in the process of teaching. In the process of assisting their students grasp what is taught, Physics teachers often resort to various teaching strategies and different representations to convey their knowledge of the subject matter in a form that can be easily understood by students. They teach in certain ways in part because of the knowledge bases each teacher possesses and draws on (Gess-Newsome, 2015). To understand and explain classroom practices, it is therefore important to investigate the knowledge bases, termed PCK components in this study, that teachers draw on to execute their classroom practices.

The quality of teaching Science is a concern in many countries including Lesotho. In a study conducted in the Netherlands, Barendsen and Henze (2017) found that teachers with a weak knowledge base of students often resort to the use of teacher-centred

approaches. Similarly, in South Africa, Rollnick (2017) found that experienced teachers, who had little knowledge on a topic, exhibited weak PCK in teaching the topic but their PCK developed after an intervention that was aimed at improving their content knowledge. Qhobela and Moru (2014) signpost that most Physics teachers in Lesotho opt to use teacher-centred approaches for a variety of reasons, such as the challenges of planning a student-centred lesson when they have little knowledge on the topic to be taught and also the poor working conditions due to the lack of resources. In an earlier study conducted in Lesotho, Qhobela and Moru (2009) had found that Physics teachers in Lesotho tended to use teaching strategies that they considered not appropriate for teaching Physics. This was primarily because of the challenges they experienced in their classroom practices, such as a lack of resources. Put together, the findings of these two studies conducted in Lesotho suggest that Physics teachers' PCK may not be well developed.

Research suggests that the PCK of Science teachers is portrayed by their classroom practices (Qhobela & Moru, 2014; Gess-Newsome, 2015; Pitjeng-Mosabala & Rollnick, 2018). Gess-Newsome (2015) asserts that PCK is the knowledge base that teachers draw on when planning and enacting their classroom practice in a specific classroom context. Recent studies of PCK have gone beyond generalities to locate PCK at topic specific level. Mavhunga and Rollnick (2013) report on a study intended to improve pre-service teachers' PCK when teaching chemical equilibrium and found that PCK can be improved. Mavhunga, Ibrahim, Qhobela and Rollnick (2016) explored the transfer of the competence to transform content knowledge learned in electric circuits to a new topic in either Physics or Chemistry by pre-service teachers and the findings revealed that PCK is indeed transferable between topics. Pitjeng-Mosabala and Rollnick (2018) investigated the development of topic specific PCK in uncertified novice graduate teachers teaching the particulate nature of matter as an intervention to improve the teachers' PCK and found evidence of developed topic specific PCK following a professional development intervention. Following Shulman, different researchers have therefore engaged PCK as a construct to study professional knowledge, where others situated PCK as domain specific (Cauet, Liepertz, Borowski & Fischer, 2015; Kirschner, Borowski, Fischer, Gess-

Newsome and von Aufschnaiter, 2016), while others viewed PCK to be topic specific (Pitjeng-Mosabala & Rollnick, 2018; Melo-Niño, Cañada, Martínez & Mellado, 2016). Other studies have focused on measuring PCK and relating it to the quality of instruction (Cauet *et al.*, 2015; Ergöner, Neuman and Fischer, 2014; Liepertz and Borowski, 2019). Viewed together, these studies suggest that PCK can be measured and transferred from one topic to another, it can be improved and it can also be related to instructional quality.

1.2 CONTEXT OF THE STUDY

Many countries consider Science an important discipline for its contribution to socioeconomic development of various countries (Ogunniyi & Rollnick, 2015). The Lesotho Curriculum and Assessment Policy of 2009 identifies Science as a core subject, implying that every student in the country is expected to study this subject (MoET, 2009). Following the introduction of the Lesotho General Certificate of Secondary Education (LGCSE) in 2013, every student studies Science across all school levels of education in Lesotho, including the LGCSE level (George, Kolobe & Moru, 2018). Although every child studies Science, the Council on Higher Education (2012) reports a low percentage of students enrolled in science related fields compared to other fields and a lower number of males than females in these fields.

Before the inception of the LGCSE in 2013, the structure of education in Lesotho consisted of 10 years of basic education, made up of 7 years of primary and 3 years at junior secondary and 2 years of senior secondary education (MoET, 2009). In grade 12 students would write a national examination for selection and certification purposes. However, this system has been phased out and secondary education now takes four years where students write their LGCSE examination in Grade 11. The last grade 12 group that wrote the LGCSE examination sat for examination in 2022. The first pilot group to write LGCSE sat for examination in 2020. According to MoET (2009), students must register for at least one Science subject, either Biology and/or Physical Science in the last two years of secondary level. Physical Science comprises of both Physics and Chemistry where each is allocated 50% of the certification examination content at the end of grade

12. This study was carried out in Lesotho schools with qualified teachers who teach Physics in the last two years of schooling at secondary level, LGCSE.

Free Primary education was introduced by the Ministry of Education and Training (MoET) in 2000. This initiative resulted in increased enrolment in primary schools, which also gave rise to higher enrolment in high schools, thereby posing challenges in education such as overcrowded classrooms and a shortage of Mathematics and Science teachers (Ogunniyi & Rollnick, 2015). The situation is somewhat changing, as well as the increasing numbers of qualified teachers of Science that have different levels of qualification. The 2016 Education Statistics Report (2018) of Lesotho shows that there has been an increase in the number of qualified teachers at secondary level (Bureau of Statistics, 2018). According to this report, there were 5367 registered secondary school teachers in 2016, with about 94% of them being qualified teachers. This study aims at investigating the PCK of qualified Physics teachers in Lesotho. It is therefore necessary to conduct a study on qualified teachers rather than on unqualified teachers.

Lesotho, like other developing countries, does suffer from a multitude of poor teaching conditions. These are outlined by Qhobela (2008) as empty libraries, overcrowded classrooms and a lack of teaching and learning facilities such as computers and teaching aids. In addition, George (2017) highlights other conditions as being the absence of laboratories and a lack of laboratory equipment and chemicals. To cope with such adverse conditions teachers in the country often resort to teaching methods that may not be ideal for teaching Physics, especially teacher-centred methods (Qhobela & Moru, 2009).

1.3 PROBLEM STATEMENT AND RESEARCH QUESTIONS

Researchers associate PCK with the quality of students' achievement (Keller, Neumann & Fischer, 2017), while other researchers argue that PCK is related to the quality of classroom practices (Gess-Newsome, 2015; Pitjeng-Mosabala & Rollnick, 2018). Gess-Newsome *et al.* (2019) relate teachers' PCK to both students' achievement and

classroom practice. Kirschner *et al.* (2016) contend that teachers' professional knowledge has an effect on both teaching and student outcomes. Researchers have found PCK to be related to the poor quality of classroom practice in both developed and developing countries. In the Netherlands, Barendsen and Henze (2017) reported the dominant use of teacher-centred methods in the teaching of Science when teachers have a weak knowledge base of students as a PCK component. In South Africa, Rollinick (2017) found teachers with a weak knowledge of content in a topic having a challenge when teaching the same topic to students. These reports unveil the dire straits in the pedagogy of Science, leading to compromised classroom practices.

The knowledge of Science is viewed as a requirement for participation in the society and further studies in Science related fields (Keller, Neumann & Fischer, 2017). Despite the importance of Science in the future life of students, the low quality of education in Science classrooms is of much concern to scholars and policy makers in Lesotho (George, 2017; MoET, 2016; Qhobela & Moru, 2014). This is emphasised by the Ministry of Education and Training in the education sector plan of 2016-2026, namely that there has been a record of poor performance in Science across all districts of Lesotho as one challenge of secondary education (MoET, 2016). For instance, Figure 1.1 shows the LGCSE Physical Science performance by district in 2019 (Statistical Bulletin, 2019: 25).

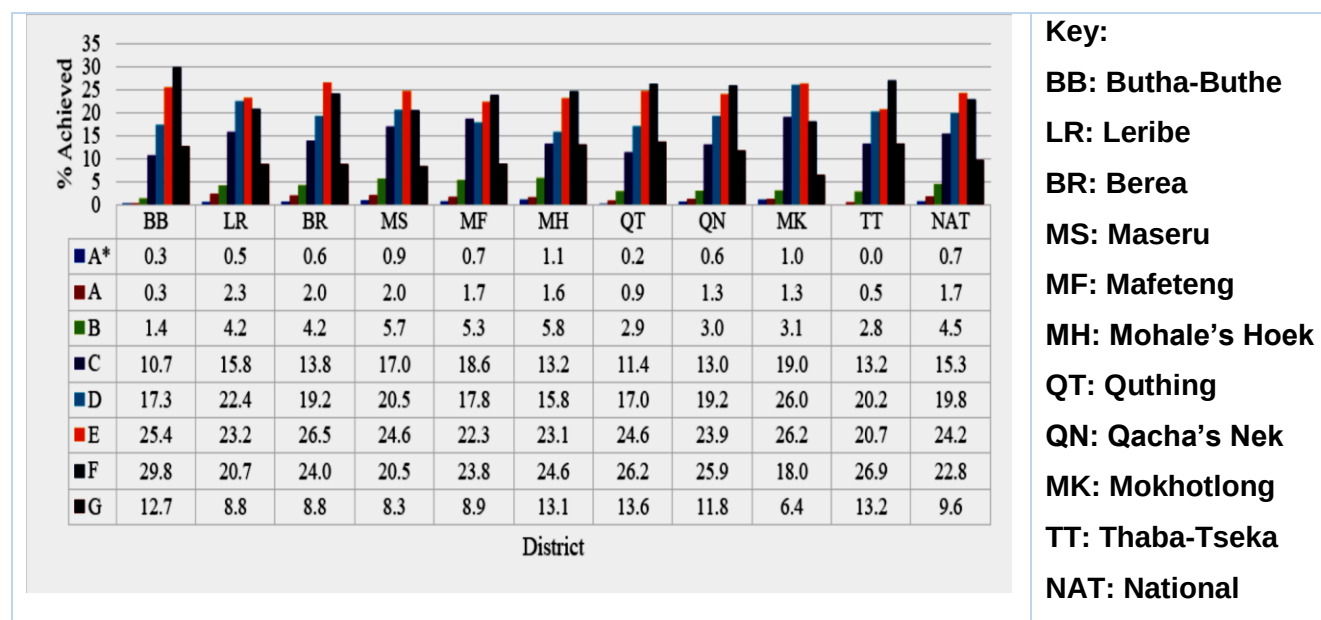


FIGURE 1.1: 2019 PHYSICAL SCIENCE PERFORMANCE BY DISTRICT

Figure 1.1 shows poor performance, in general, in all districts of Lesotho where the quality grades A* to C seem to have a low percentage of students while the percentage of students increases from grade D to F. This challenge of poor outcomes in Lesotho has not improved, as the education system is still characterised by high failure rates at the secondary school leaving examination level (Lekhetho, 2021). Among the subjects that record poor performance is Physical Science. This is exhibited by the trend of a low percentage of students who pass Physical Science in different years. In the Physical Science subject, Physics constitutes 50% of the total mark. The poor performance in Science is evident even in schools that tend to perform well in the general national examinations. The unpublished report of the Examinations Council of Lesotho (ECOL) shows the trends in Physical Science performance from 2017 to 2021 (see Table 1.1).

TABLE 1.1: 5 YEARS TRENDS PHYSICAL SCIENCE PERFORMANCE

Year	Physical Science performance 2017 -2021 (%)										
	A*	A	B	C	D	E	F	G	U	X	Total
2017	0.54	2.16	5.13	14.6	17.9	27	19.1	10.3	2.88	1.2	13673
2018	0.57	1.6	4.16	15.1	18.3	24.3	21.1	11.6	3.14	1.87	15529
2019	0.62	1.56	4.12	14.3	20.3	24	22.9	9.85	2.12	1.89	15161
2020	0.45	1.42	3.43	14.1	16.6	28.6	21.3	11.1	2.69	3.38	17930
2021	0.36	1.22	3.19	10.88	13.13	22.10	21.83	18.28	9.01	1.92	16766

Table 1.1 shows a low percentage of students obtaining A to C grades and the percentages increasing from grade D to F. The table indicates a large number of students obtaining marks that may not allow them to further their studies in Science related careers.

In the examiners' reports for LGCSE Physical Science papers 2, 3 and 4 for the 2018 results which include: Core theory paper, Extended theory paper and Practical knowledge paper respectively, the following were recorded about the candidates who sat for examinations:

- Poor expression of scientific language in giving explanations (paper 2, 3 and 4) (ECOL, 2019a; ECOL, 2019b, ECOL, 2019c)

- Lack of exposure to laboratory practical work (paper 2 and 4) (ECoL, 2019a; ECoL, 2019c)
- Poor content knowledge (paper 2, 3 and 4) (ECoL, 2019a; ECoL, 2019b; ECoL, 2019c).

The examiners' reports highlight some of the causes of poor performance in Physical Science, which invite an investigation into the teachers' PCK to find out how they teach in the classroom with respect to the PCK they have.

Physics teachers in Lesotho often use inadequate teaching strategies to teach Physics in classrooms partly due to what is considered to be weak PCK on the topics they teach (Qhobela & Moru, 2014). Makhechane and Qhobela (2019) also found that Chemistry teachers in Lesotho use teacher-centred methods to teach Chemistry. This was evident in the chemistry teachers' choice of teacher-centred strategies to teach Chemistry. The two studies carried out in Lesotho suggest that Science teachers might have a weak PCK as PCK is seen in the ability of the teacher to select appropriate strategies to transform the content (Shulman, 1986). Qhobela and Moru (2014) and Makhechane and Qhobela (2019) agree that teaching Science through teacher-centred methods contributes to low students' performance. It is in this regard that this study sought to measure the PCK components that Physics teachers in Lesotho possess and to investigate how these PCK components are manifested in classroom practice. It is important to find out what Lesotho teachers know about teaching Physics and how their professional knowledge shapes their teaching by looking at the teachers' classroom practices in the process of using the pedagogical content knowledge that they have.

Barendsen and Henze (2017) assert that there have been inconsistent findings in large-scale studies to relate PCK and classroom instructional practices, thus the call for more studies that explore the relation of PCK and classroom practices so as to understand the role of PCK in teachers' classroom actions. While we are becoming better informed about the relationship of PCK and classroom practices, we know much less about how this relationship varies across subjects and country contexts. For instance, not much has been done in Lesotho to measure Physics teachers' PCK and/or to portray what teachers

with more or less developed PCK do in class when teaching Physics. This study sought to close the gap and contribute insights by measuring Physics teachers' PCK and illustrating how Physics teachers use their PCK in a senior secondary level classroom context of a developing country. To understand better the relationship between PCK and the construction of classroom practice by Physics teachers in Lesotho, the following research questions are proposed:

Primary question

How do Physics teachers in Lesotho draw on the components of PCK to construct their classroom practices in a variety of secondary school contexts across the country?

Secondary questions

1. What components of PCK do Physics teachers use to teach Physics?
2. How are the components of PCK manifested in Physics teachers' classroom practice?
3. How can the role of Physics teachers' PCK in classroom practices be understood and explained?

1.4 AIMS AND OBJECTIVES OF THE STUDY

The aim of this study is to identify the PCK components that Physics teachers draw on to construct their classroom practices and to examine how classroom practices are constructed with respect to the PCK components that teachers possess.

Objectives:

This study seeks to:

- Identify the PCK components that Physics teachers use to teach Physics
- Investigate what Physics teachers do in their classroom practice with respect to the components of PCK they possess
- Explain the role of PCK in Lesotho Physics teachers' classroom practices for the relationship of PCK components and classroom practices construction to be better understood.

1.5 THE VALUE OF THE STUDY

Professional knowledge of teachers comprises the teachers' knowledge of concepts and the expertise needed to solve problems encountered in classroom practice in different learning and teaching contexts (Cauet *et al.*, 2015). The present study sought to understand teachers' professional knowledge, with a specific focus on their PCK components that inform their classroom practices, in order to find out how these knowledge components reflect on teachers' classroom practices, if at all.

PCK is viewed as a complex construct to measure due to its idiosyncratic and tacit nature (Park, Suh & Seo, 2018) and that makes it difficult to relate teacher knowledge to classroom practice, leading to inconsistent findings reported by large studies on PCK. This supports the necessity for more studies on PCK measurement and how this PCK is executed in a classroom context, so as to add more knowledge about this complex relationship.

It is important for teachers to have PCK in the disciplines they are teaching to enhance the quality of classroom practice (Mim, Rahman & Jahanara, 2017). Although PCK may not be at the same level for different teachers, it is necessary that certain PCK components are developed for the teacher to portray competency in the classroom context (Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008). In the literature reviewed on PCK studies in Lesotho, there is limited research on studies that engaged with a paper-and-pencil PCK test to measure the PCK components possessed by Physics teachers. Research shows that teachers transform the knowledge they have into a teachable form by drawing on different PCK components to shape their classroom practices. This makes it necessary to find out the PCK components that Physics teachers possess and how this knowledge is manifested in the classroom to better understand the PCK of Physics teachers and to direct professional development initiatives at the specific PCK components that need to be developed.

Kirschner *et al.* (2016) argue that teachers' professional knowledge influences teaching and learning outcomes. Therefore, it is important to find out what teachers know about teaching Physics. This should be done in line with how their professional knowledge shapes teaching by looking at what Physics teachers do in their classrooms with the pedagogical content knowledge they have. Understanding what teachers know may point researchers and policy makers to the best ways of helping teachers improve the quality of their classroom practices. Additionally, understanding the professional knowledge domains that shape Physics teachers' PCK and that are useful for Physics teaching may be helpful for teacher educators in the preparation of both current and future teachers.

It is not only necessary to understand Physics teachers' professional knowledge but also important to look at the relevance of this knowledge in activities that take place at classroom level. It is necessary because it gives insight into the teachers' knowledge, classroom experiences and classroom practices to broaden access and sharing among teachers and for professional development. This may help to improve other Physics teachers' classroom practices and direct new thinking about classroom practices.

1.6 CONCEPTUAL FRAMEWORK

This study draws on research that explores the professional knowledge base for teaching. Shulman (1987) views the knowledge base of teachers as being organised into seven categories: (1) content knowledge, (2) general pedagogical knowledge, (3) curriculum knowledge, (4) PCK, (5) knowledge of students and their characteristics, (6) knowledge of educational contexts, and (7) knowledge of educational ends, purposes, and values. PCK is seen as a distinct category of a knowledge base that separates the teacher from a subject specialist (Shulman, 1987). A teacher is expected to understand the content in the subject area being taught and the different techniques for teaching that content, while PCK is needed by the teacher to effectively transform the subject matter knowledge into a format comprehensible to students.

Following the work of Shulman, different researchers established different views on how PCK can be conceptualised. Some researchers view PCK as the result of integrating different knowledge bases (Gess-Newsome, 1999; Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008), while others view PCK as the transformation of different knowledge bases to form a new distinct knowledge base (Grossman, 1990; Gess-Newsome, 1999; Magnusson, Krajcik, and Borko, 1999; Gess-Newsome, 2015). The differences in conceptualising PCK have led to different ways of defining the nature of PCK and how to measure it. To address these issues a summit was held by international PCK researchers in 2012. The 2012 summit outcome was the Consensus Model of PCK, which was used as the conceptual framework guiding this study.

The modified Consensus PCK Model of Gess-Newsome (2015), which incorporates the model of Magnusson *et al.* (1999) is used in this study to show the manifestations of PCK in classroom practices. This model was chosen because it incorporates more knowledge bases transformed to form PCK than in other models. It also allows the researcher to consider both canonical and personal PCK, which are helpful in differentiating what a teacher knows about teaching Physics and how they actually teach Physics in the classroom. This suggests that even though teachers might have many knowledge bases from which to build their PCK, they may use only a few knowledge bases in the classroom context. This is a transformative model which allows PCK to be researched as a distinct knowledge base. In order to describe PCK in classroom practices, the model of Magnusson *et al.* (1999) is incorporated in the model by Gess-Newsome (2015). In this model, classroom practices are viewed as the pedagogical actions and reasoning of the teacher in the instructional process (Magnusson *et al.*, 1999). Examples of classroom practices include the use of different representations, activities, certain teaching strategies and different methods of assessment. The modified Consensus PCK Model of Gess-Newsome (2015) was used to construct a PCK test containing items from the following PCK components: Assessment knowledge (AK), pedagogical knowledge (PK), content knowledge (CK), knowledge of students (KS) and curricular knowledge (CuK). The model was also used to develop interview items to provide evidence of PCK in specific topics taught by teachers and to codify classroom practice activities.

1.7 RESEARCH DESIGN AND METHODOLOGY

This study was situated within a pragmatic paradigm, which facilitated using mixed methods, in other words, combining quantitative and qualitative research methods (Kivunja & Kuyini, 2017). This study strived to quantitatively measure Physics teachers' PCK and qualitatively track and illustrate the use of this PCK in a classroom context.

The study involved explanatory sequential design which comprised two phases of data collection: firstly, quantitative data was collected and secondly qualitative data (Lodico, Spaulding & Voegtle, 2006). According to Lodico, Spaulding and Voegtle (2006: 284), qualitative data is collected and analysed to investigate "outlier scores or extreme cases in more depth". The qualitative data was used to broaden the explanation of the quantitative findings. In this study a PCK test was first given to Physics teachers and then analysed to examine teachers with the highest and the lowest PCK test scores. The teachers with extreme PCK test scores were chosen as cases to see how these teachers used their PCK in the classroom context and to see if PCK played a specific role in classroom practices.

Data were collected by administering the individual PCK test to assess Physics teachers' PCK. The PCK test was developed using the modified Consensus Model of Gess-Newsome (2015) that included knowledge bases which comprise teachers' PCK. The PCK test items were developed to assess the knowledge base of Physics teachers that builds their PCK. The PCK test was used to measure Physics teachers' canonical knowledge that excludes the context of classroom practices.

Interviews were also used to find out how Physics teachers use the components of PCK in a classroom context. These discussions involved interpretations of the contexts through which the participant teaches as well as discussions of the participants' own opinions regarding their situation (Cohen, Manion & Morrison, 2018). In order to understand how

teachers use their components of PCK in the classroom context, their views about their classroom experiences were taken into consideration.

Video recorded classroom observations were also included to collect data. Cohen, Manion and Morrison (2018) contend that observations are essential in the data collection process, as they yield data occurring in the natural setting of the participant. In this study, it was not enough for teachers to talk about their classroom practices and how they use their knowledge to teach effectively, but it was necessary to observe the teachers' practices and to identify the unspoken activities that illustrate their knowledge of teaching.

Among the mixed method sampling strategies, this study used a sequential mixed method sampling that involves the sequential use of non-probability convenience sampling and purposive sampling strategies (Cohen *et al.*, 2018). Quantitative data from the first non-probability sample of 87 Physics teachers was used to draw the second extreme case-purposive sample (Teddlie & Yu, 2007; Teddlie & Tashakkori, 2009). The type of purposive sampling that was engaged is extreme case sampling, in which the participants represent the extreme (Lodico, *et al.*, 2006; Creswell & Creswell, 2018). The researcher selected Physics teachers based on their extreme scores in the PCK test. Two teachers with the highest scores and two teachers with the lowest scores were selected.

The PCK test was analysed quantitatively by means of a rubric constructed using the five context-free knowledge bases used to build the teachers' PCK, as depicted in the model by Gess-Newsome (2015). The scores obtained from the PCK test were compared using statistical Extended Rasch Model analysis and SPSS to show the different levels of PCK of the Physics teachers. Interviews were analysed qualitatively and were used to construct the CoRes and the narratives for the cases to illustrate Physics teachers' PCK in classroom practices as established by Loughran *et al.* (2004). The videos of classroom observations were transcribed picking the activities that depicted the use of knowledge bases in a classroom context. The transcriptions of the video recordings were also used to construct CoRes when unspoken PCK was manifested in classroom practices.

1.8 LIMITATIONS OF THE STUDY

The study sought to understand the PCK of teachers through testing what Physics teachers know with respect to teaching Physics through the use of paper-and-pencil test. Although a considerable number of qualified Physics teachers were engaged in the study, not all Physics teachers were involved. This means that even though some generalization of results were possible regarding the knowledge domains for Physics teachers, the results were not representative of all Physics teachers in Lesotho. The paper-and-pencil test could not cover all the domains of knowledge that Physics teachers have for the logistical reason of avoiding too many items in the test. Thus the test could not cover all the Physics topics taught. Individuals whose inferences could be subjective in interpreting the meaning of the responses scored the PCK test responses. The study involved classroom interviews and observations, which were limited to a small number of school visitations due to COVID-19 restrictions in schools, and this led to a finite access to teachers' PCK since PCK needs to be articulated over extensive engagement in classroom observations. Furthermore, the study engaged mixed methods where a multiple case study was used to understand in depth the classroom practices of the teachers. The results of the case study are not generalizable to the entire population of Physics teachers in the country.

1.9 DELIMITATIONS OF THE STUDY

The study focused only on qualified Physics teachers who taught the last two years of senior secondary level. This does not mean that all teachers in senior secondary schools are qualified to teach Physics, but for the purposes of this study, unqualified teachers were excluded.

The causes of the possibility of different PCK levels in qualified teachers were not explored. The assumption was that all qualified Physics teachers have developed PCK from their teacher training Colleges and universities and through their experience of teaching Physics.

1.10 OPERATIONAL TERMS

Professional knowledge is regarded as the teachers' knowledge of concepts and competencies needed to solve pedagogical problems and, to address a variety of teaching and learning issues in different ways in the context of their classroom practice. The knowledge of concepts and competencies are expected to meet in general the standards of teacher education agreed on in the community where the teacher teaches (Cauet *et al.*, 2015).

Pedagogical content knowledge (PCK) is defined by Shulman (1986) as the knowledge of the aspects of content significant to making that content easy to understand for the students by engaging a variety of ways of representing and formulating the content, involving different examples, analogies, illustrations and explanations.

Classroom practices are considered as pedagogical actions and the reasoning of the teacher in the instructional process (Magnusson *et al.*, 1999).

PCK components are considered as the knowledge bases from which teachers draw the PCK they execute in their classroom practices and these knowledge bases are viewed as "the secret of an expert system's expertise, the body of understanding, knowledge, skills, and dispositions that a teacher needs to perform effectively in a given teaching situation" (Wilson, Shulman & Richert, 1987: 106).

Knowledge on-action is the knowledge the teacher possesses (Barendsen & Henze, 2017).

Knowledge in-action is the knowledge that the teacher uses in classroom practices (Barendsen & Henze, 2017).

1.11 SUMMARY OF THE CHAPTER AND THE STUDY OUTLINE

This chapter has articulated the background of the study, problem statement and research questions guiding the study. The aim, objectives, value and limitations of the study have also been outlined. The chapter has also highlighted the conceptual framework guiding this study together with the research design and methodology. The outline of the subsequent chapters is as follows:

Chapter 2: The literature germane to this study is reviewed to identify gaps and find the niche for this study. This chapter also discusses the conceptual framework directing this study.

Chapter 3: Elaborates the research methodology, looking at the research design, its rationale, the methods and instruments for data collection, the discussion on the ethical considerations and how validity and reliability are to be ensured in this study.

Chapter 4: Presents and analyses both quantitative and qualitative data gathered in this study.

Chapter 5: Provides a summary of the findings, conclusion, recommendations, and suggestions for future research.

CHAPTER 2: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 INTRODUCTION

This chapter presents literature reviewed on the professional knowledge base for teaching with a focus on PCK as a construct. It looks at how different researchers have conceptualized PCK and how teachers construct their classroom practices with respect to the PCK they have. The role of PCK in classroom practices is also discussed. The study aims at measuring the PCK of Physics teachers and looks at how this PCK is manifested in the classroom practices of these teachers. Some of the literature reviewed therefore highlights the issues of measurement and portrayal of PCK. The conceptual framework guiding this study is also discussed.

2.2 PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

2.2.1 PCK background

The idea of ‘pedagogical content knowledge’ was introduced by Shulman (1986) after noticing the shift in focus in Science teacher education from the 1970s to the 1980s where Science teacher education moved from training teachers to a content knowledge emphasis and further to focusing on general pedagogical knowledge. Shulman argued that subject matter knowledge should be given attention in Science education, emphasizing that teachers should possess content knowledge in the subject of specialisation they taught. This knowledge is organized into three categories: subject matter content knowledge, pedagogical content knowledge (PCK) and curricular knowledge. The following paragraph discusses the definition of PCK.

2.2.2 Definition of PCK

PCK, according to Shulman (1986, 1987), is a form of content knowledge which cuts across both the knowledge of content as well as how that content can be teachable to students. In this position, PCK is taken as a combination of content and pedagogy, forming a special knowledge of transforming subject matter into a form that can easily be grasped by students. In agreement with Shulman (1986), Ball, Thames and Phelps (2008)

assert that the transformation of content knowledge involves the use of different representations and examples. On the other hand, different from Shulman, they include the problems experienced by teachers during the teaching process. Although Shulman (1986) did not incorporate all the problems experienced by the teacher in a classroom context, he broadened the transformation of content knowledge to include analogies, illustrations and explanations, which he viewed as important in teaching Science. According to Shulman (1987) PCK is the knowledge base considered a contributing factor in the professional knowledge of the teacher, which is the knowledge used to teach effectively. The teacher with PCK has the knowledge of what makes the content easy or difficult to understand and knowledge of students' misconceptions of the content being taught and also the capability to adequately select content (Shulman, 1987). In defining PCK, Cochran *et al.* (1993) took a constructivist perspective and defined PCK using the four different knowledge bases: content knowledge, pedagogical knowledge, knowledge of students and knowledge of environmental context, so as to help students construct their own knowledge in the contexts they are learning in. Cochran *et al.* (1993) define PCK as the special knowledge possessed by teachers to teach content to a certain group of students in a particular context. These researchers argue that PCK develops as a result of integrating the four knowledge bases, which forms a new distinct knowledge different from the individual knowledge bases. In this view, PCK is referred to as a developing knowledge base, growing with experience and the argument is that the PCK of an experienced teacher is more developed than the PCK of a novice teacher. As the four knowledge bases grow with experience, PCK also expands. In this regard, PCK is not static but is a growing knowledge, whereby this knowledge grows with the integration of the four knowledge bases mentioned above, in the process of teaching.

2.2.3 Importance of PCK

Researchers envision PCK as an important constituent of professional knowledge that contributes towards effective teaching (Pitjeng-Mosabala & Rollnick, 2018; Keller, Neumann & Fischer, 2017; Ekiz-Kiran, Boz & Oztay, 2021). In order to teach successfully, teachers need to have knowledge of different PCK components and the skills to confront

classroom challenges (Ekiz-Kiran, Boz & Oztay, 2021). In emphasising the necessity of PCK, Keller, Neumann and Fischer (2017) assert that PCK is the principal ingredient contributing towards students' achievement. PCK has been considered a special knowledge base that is necessary for teaching Science subjects effectively (Barendsen & Henze, 2017; Magnusson *et al.*, 1999). This implies that a teacher cannot be viewed as being able to transform content if the teacher has an undeveloped PCK. Chapoo, Thatong and Halim (2014) emphasize that it is through PCK that a teacher can be described as an expert or a professional. The teacher's PCK is also regarded as an important ingredient in designing and implementing classroom teaching (Großschedl, Welter & Harms, 2019).

PCK has different knowledge components which do not contribute in isolation to valuable teaching but rather complement one another. To illustrate this, Ekiz-Kiran *et al.* (2021) conducted a study that was meant to develop pre-service Chemistry teachers' PCK and also found that subject matter knowledge, termed content knowledge by other researchers, contributed towards improving the teachers' knowledge of the curriculum. This study identifies the knowledge of content as a vital component of PCK that improves the knowledge of teaching. To illustrate the importance of content in the subject taught, Neumann, Kind and Harms (2019) agree with Shulman (1986) that to find suitable representations of the content taught, to select and sequence concepts require the teachers to have PCK that enables them to convert a subject-matter structure into an instructional structure. Cochran, deRuiter and King (1993), as well as Davidowitz and Potgieter (2016) agree with Shulman (1986) who advocates for the importance of subject matter knowledge as a fundamental aspect of PCK, and share a common view that subject matter alone does not contribute to a developed PCK, but the experience of teaching students of different character in different classroom settings, that grows over time, contributes to a developed PCK.

2.2.4 PCK as a construct

Literature on teachers' knowledge of teaching has used PCK as a construct and as a specific component of professional knowledge. Coetzee, Rollnick and Gaigher (2020) view PCK as a complex construct composed of components which can be differentiated, but work in unison to form the central part of the knowledge of teaching. In explaining PCK as a construct Gess-Newsome (1999) gives two extremes of the models helping to understand PCK as a construct. Considering the three knowledge bases: subject matter knowledge, pedagogical knowledge and contextual knowledge, Gess-Newsome illustrates the distinction between the two models being the integrative model and the transformative model. In the integrative model, teachers draw on the three knowledge bases to inform classroom practice, which can be explained by referring to each of the knowledge bases separately. This means PCK does not represent a new knowledge that is used in a classroom context but represents the knowledge bases held separately in the teaching of subject matter. In this perspective, individual knowledge bases that form the PCK of the teacher can be measured on their own or within the PCK of the teacher or they can be compared to the PCK of the teacher, since PCK does not represent a new knowledge but the intersection of the different knowledge bases. The transformative model takes into consideration the three knowledge bases that come together to form a new knowledge of teaching, which can be explained by involving complex analyses of the teachers' classroom practice since the knowledge bases are difficult to explain on an individual basis (Gess-Newsome, 1999). According to the transformative model, PCK is another new component of professional knowledge since it has different characteristics from subject matter knowledge, pedagogical knowledge and contextual knowledge. In the classroom context, PCK is the combination of individual knowledge bases that make the subject matter teachable to students and is exemplified by the way the teacher transforms subject matter knowledge (Gess-Newsome, 1999). This implies that from the transformative framework, researchers may consider PCK to be the product of everything known, thought about and done by teachers in the act of teaching, which may include the knowledge bases and how they are tailored to produce the teaching activities in the classroom.

Following Shulman, different researchers have engaged PCK as a construct to study professional knowledge, where others situate PCK as domain-specific (Cauet *et al.*, 2015; Kirschner *et al.*, 2016) while others view PCK to be topic-specific (Pitjeng-Mosabala & Rollnick, 2018; Barendsen & Henze, 2017; Davidowitz & Potgieter, 2016). The difference between these two notions of PCK has been clearly articulated by Veal and Makisinter (1999) where domains-specific PCK is considered the general knowledge of transforming the subject matter of a discipline while topic-specific PCK is the knowledge of transforming a particular topic within the discipline. Although some studies focused on either domain-specific or topic-specific PCK, it is important to investigate both the domain-specific and topic-specific PCK of the teacher to explain what the teacher knows more generally about teaching a certain discipline. Oztay and Boz (2022) emphasize the need to develop an in-depth knowledge of the discipline and how the teacher actually teaches a certain topic in that discipline. The topic-specific PCK can be accessed through classroom observation while the domain specific PCK can be accessed through a pen-and-pencil test outside the classroom context. This might help to understand the PCK of the teacher as a whole in relation to teaching a certain discipline. To articulate PCK as a construct, different models have been used. The following section discusses the components of PCK from the different models used by different researchers.

2.3 COMPONENTS OF PCK

Since Shulman (1986) coined the idea of PCK in education, there has been a noticeable divergence in how different researchers conceptualize PCK in the different disciplines of Science education and within these disciplines. This has been a concern to PCK researchers, which led to a PCK summit that was held for active PCK researchers. One of the reasons for the summit was to address the issue of divergence in models, interpretation and understanding of PCK (Carlson *et al.*, 2015). Carlson *et al.* indicate that these divergences have resulted in the loss of interest by researchers who wish to pursue the importance of PCK in education. The discussion that follows shows examples of how

different researchers conceptualise PCK in the different disciplines of Science education and within these disciplines.

Shulman (1986) categorised PCK as a component of content knowledge, which is a result of merging the knowledge of content and pedagogy. Content knowledge in this model has two other categories, being subject matter knowledge and curricular knowledge. Unlike in Shulman (1986), Shulman (1987) views the professional knowledge base of teachers as being organised into seven categories of which PCK is the most important. The categories are: content knowledge (CK), general pedagogical knowledge (PK), curriculum knowledge, pedagogical content knowledge PCK, knowledge of students and their characteristics, knowledge of educational contexts, and knowledge of educational ends, purposes, values and their philosophical and historical grounds. In this model, PCK is considered as a knowledge base on its own and not a category of content knowledge as it was placed in the earlier Shulman (1986) model.

Grossman (1990) arranged knowledge base components suggested by Shulman (1987) and illustrated how the knowledge bases interact, situating PCK in a central position. Grossman shows that PCK results from the interaction of different knowledge bases considered as: general pedagogical knowledge, subject matter knowledge and knowledge of context. Grossman further views PCK as illustrating both the canonical knowledge of the teacher through the interaction of different knowledge bases and practical knowledge. In this model, PCK is guided by the teachers' conceptions of the purposes of teaching content. In Grossman's position, PCK is drawn from the knowledge of content, pedagogy and context. These components are used in connection with how teachers perceive the purposes for teaching a particular content with regard to knowledge of students' understanding, knowledge of curriculum and knowledge of instructional strategies.

Different from other researchers, Magnusson *et al.* (1999) deem PCK to be the teachers' knowledge of transforming subject matter knowledge guided by orientations to teaching Science that the individual teachers have. These orientations operate as a framework that directs the actions of the teacher in classroom practice. Magnusson *et al.* (1999)

emphasise the significance of PCK for classroom practice and the role that is played by orientations in classroom practice. Shulman (1987) considers PCK as a knowledge base that articulates the teachers' knowledge of transforming content knowledge to teach effectively without considering the teachers' inclination, while Magnusson *et al.* (1999) opine that PCK comprises the teachers' orientation to teaching Science. These orientations to teaching Science shape and are shaped by a combination of the four knowledge bases; namely knowledge of Science curricula, knowledge of students' understanding of Science, knowledge of instructional strategies, and knowledge of the assessment of Science literacy. This shows that what the teacher knows about each of these knowledge bases is influenced by the teacher's orientations towards teaching Science. While Magnusson *et al.* (1999) consider knowledge of the assessment of Science literacy required in classroom practice; Shulman (1986, 1987) is silent about assessment, although assessment is an important ingredient in teaching.

Rollnick *et al.* (2008) developed the work of Cochran *et al.* (1993) and considered the same PCK components as in Cochran *et al.* being "knowledge of subject matter, knowledge of students, general pedagogical knowledge and knowledge of context" (Rollnick *et al.*, 2008: 1380). Rollnick *et al.* contend that these teachers' internal knowledge domains are used in combination to form manifestations of PCK in classroom practice. The manifestations are: "subject matter representations, topic-specific instructional strategies, curricular saliency and assessment" (Rollnick *et al.*, 2008:1380). Manifestations are visible actions of the teacher in the class. According to this model, what the teacher does in the classroom is the product of the internal thought process of that teacher.

In their perspective, (Park & Chen, 2012; Park & Oliver, 2008) view PCK as the amalgam of five different components: orientations towards Science teaching, knowledge of students' understanding in Science, knowledge of Science curriculum, knowledge of instructional strategies and representations and knowledge of assessment of Science learning. These components are not viewed in isolation to build the teachers' PCK but are interrelated and they form the unified whole PCK of the teacher, and they are all equally needed to develop the PCK of the teacher. While (Park & Chen, 2012; Park &

Oliver, 2008) accentuate the interrelationship between the four components, Magnusson *et al.* (1999) show the interrelationship of the four components of the teachers' orientations to teaching Science, but do not show the interrelationship between the components. This makes PCK discussed by Magnusson *et al.* to be viewed as the transformation of four components instead of the integration of the four components.

Having been conceptualised in different ways by different researchers, PCK results in a complex construct to understand. Carlson, Stokes, Helms, Gess-Newsome and Gardner (2015) assert that the divergences in PCK were the cause of the construct being less utilised in application, which triggered the PCK researchers to come up with a joined vision of PCK that will be discussed later in this chapter. Looking at the PCK conceptualizations by different researchers, it can be concluded that PCK is taken as an important body of knowledge, which teachers have to possess to teach effectively in their classrooms. This calls for a need to understand teachers' PCK that informs their classroom practices. The following section discusses PCK and how it is used to construct classroom practices.

2.4 CONSTRUCTION OF CLASSROOM PRACTICES

The teacher with pedagogical excellence is envisioned as a teacher who has a deeper understanding of the knowledge base for teaching, understands the sources of knowledge and appreciates the complications of the pedagogical process (Shulman, 1987). This section discusses the complexity of classroom practice and how teachers draw on their knowledge base to build their classroom practices.

Having noticed the importance of content knowledge in the PCK of the teacher, Shulman (1986) emphasizes that the knowledge of content alone is not enough to teach effectively, but the integration of content and pedagogy leads to a developed PCK that can be helpful to transform subject matter knowledge. Shulman indicates the importance of understanding the transformation of content knowledge in classroom practices. He illustrates these engaging questions, which may be asked to understand the need to incorporate content knowledge as a requirement for teachers' professional knowledge.

These are: Where do teachers' explanations come from? How do teachers decide what to teach, how to represent it, how to question students about it and how to deal with problems of misunderstanding?' (Shulman, 1986: 8). In a later paper, Shulman (1987) argues that in order to teach, teachers draw on their knowledge base for teaching. This knowledge base does not only regard content knowledge and pedagogical knowledge as the only two knowledge bases that guide teaching, but expands the knowledge bases to seven as indicated in **section 2.3**. The process of teaching requires teachers to refer to their knowledge base to reason for the choices they make on how to teach and for the actions they involve in the process of teaching (Shulman, 1987). Shulman (1987) and Oztay and Boz (2022) agree that the knowledge base for teachers is built from the teachers' knowledge of content from their training, the materials such as the curriculum and textbooks and the setting of the institutionalized educational process being the school organization and teaching profession structure. The knowledge base, according to Shulman, is also constructed from diverse research areas that affect the teaching process and the experience of teachers. Pedagogical reasoning and action result from the teachers' knowledge of content taught and the ability of the teacher to transform the content known by the teacher for the students. Shulman (1987: 15) argues that

The key to distinguish knowledge base of the teacher lies at the intersection of content and pedagogy, in the capacity of transforming the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students.

This means that different teachers might construct their classroom practices differently, depending on how they understand the content they teach and the students they are teaching. This suggests that understanding of the content might be the same for teachers, but how the individual teacher tailors the transformation of the content knowledge depends on the type of students in a particular classroom.

The earlier models of PCK concentrated on the intellectual part of teacher knowledge looking at the cognitive component of teachers' professionalism and teaching as taking

decisions, thinking and solving problems in their teaching, leaving out teachers' actions during instruction (Shulman, 2015). The focus on the cognitive part of teacher professionalism has been due to the belief that cognition shapes teachers' classroom practices (Jüttner, Boone, Park & Neuhaus, 2013). As PCK was developed, some researchers took into consideration the skilful performance of teaching, taking into account the actions of the teacher in the classroom. For instance, in the opinion of Riese and Reinhold (2010), the teaching process requires that teachers take certain actions in their classrooms and good PCK helps teachers to decide on the actions that should be taken during the teaching process.

PCK is located in classroom practice where personal PCK and classroom context interact (Gess-Newsome, 2015). Gess-Newsome further emphasises that classroom practice is a complex process since there occurs transformation of different knowledge bases that are static and explicit in different contexts in which teachers enact their knowledge. In the act of teaching, the transformation of knowledge bases may be planned or occurs to respond to the situation that the teacher experiences in class, which require quick decision-making drawing on the teachers' knowledge bases. While other researchers focus on the knowledge bases which are required and integrated to guide lesson planning and classroom practice (Nilsson & Vikström, 2015; Park & Chen, 2012; Park & Oliver, 2008), Gess-Newsome asserts that classroom practice is not only guided by what the teacher knows, but it is also shaped by the context of the classroom. The context includes "the types of curriculum materials, supplies, and support available" and all these influence the way the instruction is delivered (Gess-Newsome, 2015: 37). Nilsson and Vikström (2015: 5) characterized PCK using two components, being "knowledge of representations of subject matter and understanding of specific learning difficulties and student conceptions." They contend that these are the main components of PCK which guide the teachers' decision making in both planning and classroom instruction so as to help students understand the content being taught. Through the findings of their study Nilsson and Vikström assert that knowledge for teaching is not learned from what other teachers do but grows with the experience of the teacher.

Park and Oliver (2008) found that PCK was manifested as a feature of knowledge-in-action where the teacher integrated all components of PCK possessed by the teacher to confront classroom situations where teaching difficulties appear. Gess-Newsome (2015) maintains that the way the teacher teaches is influenced by what the teacher knows. This implies that a teacher draws on the PCK components that they have to enact classroom practices to help students understand when a learning difficulty is presented to the students. This raises curiosity of how the teacher behaves in cases where the teacher has limited knowledge in one PCK component that they need to draw on to make learning possible in times of challenges arising in the classroom. It has been shown by the studies reviewed in this section that teachers draw from their professional knowledge base to construct their classroom practices, either in their planning or during the teaching action in the classroom. It is therefore important to understand what teachers know with respect to what they teach, so that their classroom practices can be better understood.

2.5 THE ROLE OF PCK IN CLASSROOM PRACTICES

PCK is said to play an important role in effective teaching but Barendsen and Henze (2017) argue that relating teachers' PCK and their actions in the classroom is not straight forward. A challenge arises from relating the knowledge on-action, that is the knowledge the teacher possesses and the knowledge in-action, being the knowledge that the teacher uses in classroom practice. Although, in theory Shulman (2015) argues that PCK plays an important role in effective classroom practice, he argues that earlier works on PCK did not shed enough light on the outcomes of PCK on either learning or instruction. Barendsen and Henze (2017) add that there have been inconsistent findings on large-scale studies that relate PCK to classroom instructional practice, which calls for more studies that relate PCK to classroom practice, so as to understand the role of PCK in teachers' classroom actions. The following discussion looks at findings on the role of PCK in classroom practices.

Several studies on teachers' professional knowledge have been conducted to investigate the significance of PCK on instruction and student learning. For instance, Germany engaged researchers in a ProwiN project aimed at investigating the relationship between

components of teachers' professional knowledge: content knowledge, PCK and pedagogical knowledge, quality of instruction, student achievement and motivation in the different disciplines: Biology, Physics and Chemistry (Cauet *et al.*, 2015). In this project, Cauet *et al.* (2015) investigated the relationship between Physics teachers' domain-specific professional knowledge measured through a test and the quality of instruction measured by the ability of the Physics teachers to cognitively activate students in the classroom. This was done through analyzing videotapes and students' achievement measured through a multiple choice test. The results indicate no significant correlation between Physics teachers' CK and PCK and their students' cognitive activation in the classroom or student learning gains. In another project in Germany, the QULP project whose aim was to investigate the effect of teachers' PCK on their instruction and student learning, Ergönenç, Neumann and Fischer (2014) compared Physics teachers' PCK in Finland, Germany and Switzerland. This study found a correlation between Physics teachers' PCK and students' cognitive activation for a joint subsample of German and Swiss Physics teachers.

As part of the second phase of the project carried out in Germany aimed at investigating the relationship between professional knowledge bases, in-class actions and students' outcomes in Chemistry, Biology and Physics, called ProwiN II, Liepertz and Borowski (2019) investigated the relationship between professional knowledge and Physics teachers' in-class actions. Another focus of this investigation was to find out whether professional knowledge and in-class actions have an impact on students' achievement. The assumption in this study was that teachers who possess a more developed pedagogical knowledge (PK) and content knowledge (CK) and also good PCK use this knowledge better in classroom practice to provide a meaningful environment to successfully initiate student learning. The results of this study show no significant relationship between teachers' professional knowledge and their classroom in-actions and a negative relationship of PCK and student achievement. Another study related the teachers' professional knowledge to instructional practices, focusing on professional knowledge that encompasses CK, PK and PCK (Kulgermeyer *et al.*, 2020). This study measured the professional knowledge of pre-service teachers before and after their

teaching experience and then measured the enacted PCK focusing only on one aspect of classroom actions; being able to explain Physics. The study found that pre-service teachers with high scores in professional knowledge were engaging in better explanations of Physics topics in their classrooms.

Chapoo *et al.* (2014) used a case study method to investigate a Biology teacher's understanding and practice that entail the PCK of a teacher. The teacher studied was an experienced Biology teacher who exhibited a developed PCK in the components of PCK investigated. The investigation was framed in the model of Magnusson *et al.* (1999) to depict classroom practice that portrayed the teacher's PCK. The components examined were: Science teacher's orientations to teaching Science, knowledge of students' understanding of Science, knowledge of instructional strategies, knowledge of the Science curriculum and knowledge of assessment of Science. The findings revealed that the teacher had a good understanding of what comprises PCK and this was also reflected in how the teacher integrated the different components of PCK into the classroom practice of teaching Science. This study suggests that a Science teacher must have a variable understanding of the different components of PCK in order to teach successfully. Table 2.1 illustrates classroom practice against the PCK components possessed by the teacher (Chapoo *et al.*, 2014: 467- 469).

TABLE 2.1: CLASSROOM PRACTICE EXAMPLES THAT EXHIBITED THE TEACHER'S DEVELOPED PCK

PCK component	Classroom practices
Knowledge of student's understanding of Science	• Use of instructional media inside and outside the classroom such as organisms found around the school and PowerPoint to cater for students with different needs and ability. • Allowing small group interactions to cater for those students who learn best from their peers.
Knowledge of instructional strategies	• Used questioning to stimulate students' curiosity • Discussion • Allowing students to interact with real objects • Designed an investigation to allow students to survey
Knowledge of assessment	• Use of multiple choice tests • Oral questions stating reasons for the given answer • Observations during student activities • Member checking • Written journal • Drawing practical homework • Concept mapping

In Lesotho, Qhobela and Moru (2014) indicate that there is a challenge faced by Lesotho Physics teachers to implement student-centred approaches to teach Science. One of the contributing factors to this challenge is asserted to be the teachers' weak PCK, which leads to the teachers failing to plan student-centred lessons when they are not familiar with the topic. This emphasizes that classroom practices are compromised when the teachers have weak PCK but the question is: What could it be that the teachers do not know about the topic they are to teach? Could it be the content knowledge or the lack of other knowledge bases?

In another study conducted at the National University of Lesotho with fourth year pre-service teachers looking at their teaching practice when teaching Biology or Physics, Mabejane, Nyabanyaba, Koliopouluos and Ravanis (2017) reported that the teaching strategies engaged by the pre-service teachers as being: discussion or classroom talk, group work, question and answer, engaging students in research followed by classroom presentations and lecturing. In agreement with Qhobela and Moru (2014), lecturing was

found to be the dominant strategy. However, the reasons for engaging lecturing differed since the pre-service teachers mentioned time constraints and lack of resources as limiting factors. They needed to use other teaching strategies even though they knew that lecturing was not the best method to teach Science. Mabejane *et al.* (2017) also found that assessment knowledge was lacking in student teachers' classrooms, as they only involved recall questions to ascertain students' understanding, arguing that they felt they did not get much assessment training at University. These were student-teachers in their fourth year, who, after their teaching practice graduated and were expected to start working as professional teachers. In this light, there could be implications on practice from components of PCK, which seem to be undeveloped from their training; such as the use of appropriate strategies in addition to assessment knowledge that could define the type of Physics and Biology teachers practicing in schools. As a result, this study seeks to understand the teachers' knowledge of PCK components out of the classroom context, considered to be PCK on-action (Barendsen & Henze, 2017; Kirschner *et al.*, 2016) and to investigate how this knowledge is manifested in teachers' classroom practices in order to find out whether this PCK has a role to play in classroom practice. Following large studies that present results that are far from conclusive in relating PCK to classroom practice and student outcomes, this study will contribute to the current debate on PCK as a construct and its relationship to classroom practice.

2.6 MEASURING AND PORTRAYING PCK

Since Shulman's (1986) introduction of PCK as a characteristic that teachers possess, one that distinguishes teachers from content experts, researchers have involved different methodologies to understand the construct and to portray, assess and develop it in pre and in-service teachers. Großschedl, Welter and Harms (2019) argue that teachers' PCK needs to be rigorously examined as it relates to classroom teaching quality parameters and has an impact on the learning process of students and also their success. A variety of methodological attempts have been made to demarcate the complex construct of PCK where some researchers relied on qualitative methods, which are mainly descriptive in nature, while others relied on quantitative methods. For example, some researchers

engaged quantitative methods to measure PCK (Kirchner *et al.*, 2016; Cauet *et al.*, 2015; Jüttner, Boone, Park & Neuhaus, 2013; Davidowitz & Potgieter, 2016; Liepert & Borowski, 2019; Marake, Jita & Tsakeni, 2022) while others engaged qualitative ways (Shulman, 1987; Mugnusson *et al.*, 1999; Rollnick *et al.*, 2008; Melo-Niño, Cañada, Martínez & Mellado, 2016; Barendsen & Henze, 2017; Nilsson & Karlsson, 2019; Nilsson & Vikström, 2015) of measuring and depicting PCK.

Although researchers have tried to use different methods of measuring teachers' PCK, Park, Suh and Seo (2018) argue that there are challenges associated with assessing PCK. They illustrate challenges, such as the lack of a common definition of PCK, which was addressed at the PCK summit in 2012 after which PCK has still been refined and examined. The challenges include the tacit nature of PCK, which may be addressed by engaging multiple data collection methods and also the idiosyncratic nature of PCK that makes it difficult to compare the PCK of teachers working in different contexts. With these challenges existing in PCK research, different researchers pursued different studies to measure and articulate teachers' PCK. In this section various methodological efforts, which have been engaged by different researchers to measure and portray PCK, are reviewed.

Shulman (1987) qualitatively investigated how knowledge of teaching grows in the process of teaching by following secondary school student-teachers from their last year of training to the time when they became novice teachers and then veteran secondary school teachers. He did this through case studies, which involved discussions with teachers and also classroom observations to see teachers applying their knowledge in action. This enabled Shulman to compare the knowledge of teaching exhibited in the classroom practice of these two different groups to find the source of their knowledge base for teaching and to form categories of the knowledge bases. It enabled Shulman to explain the process of pedagogical reasoning and to suggest implications for teaching policy and educational reform.

Kirchner *et al.* (2016) engaged a test instrument that was used to measure Physics teachers' professional knowledge quantitatively, to find the relationship between the

professional knowledge domains of CK, PCK and PK. An instrument was administered to teachers of different subjects, different school types, pre-service and Physics teachers. With more focus on PCK, Kirchner *et al.* (2016) found that the CK, PCK and PK are distinct constructs of professional knowledge and PCK is the only construct that differentiates Physics teachers from other teachers. According to Kirchner *et al.* a paper-and-pencil test gives generalizable results but measures the verbalized and canonical knowledge referred to as knowledge-on-action, but does not measure the knowledge that is applied in the classrooms that is referred to as knowledge-in-action. Kirchner *et al.* (2016) emphasise the need to engage qualitative studies that will describe the knowledge teachers use to teach.

Cauet *et al.* (2015) used a paper-and-pencil test to measure the domain specific professional knowledge of Physics teachers in order to relate the knowledge to students' cognitive activation, as a measure of the quality of instruction in classrooms and also of students' achievement. Cuaet *et al.* (2015) found that there is no significant relationship between Physics teachers' content knowledge and PCK and their support of students' cognitive activation in the classroom or achievement. The findings of this study raised the need to relook at the domain-specific knowledge domains that lead to the effective teaching of Physics. The findings also reveal that more content knowledge does not lead to better teaching in Physics classes. The study could not clarify which teacher professional knowledge is relevant for effective teaching. This suggests that research on specific knowledge domains needs to be carried out to investigate the domain leading to the effective teaching of Physics.

Jüttner *et al.* (2013) developed and used a test instrument to measure Biology teachers' content knowledge, pedagogical knowledge and PCK quantitatively. The aim of the study was to find the relationship between CK and PCK. Through the use of a paper-and-pencil test, Jüttner *et al.* found that CK and PCK interrelate but can be measured separately. This study pointed at a theoretical model guiding the development of the test instrument and provided steps that could be followed to validate an instrument that measures PCK.

In a study that quantitatively investigated the relationship between parts of the PCK Consensus model, focusing on how the professional knowledge of teachers relates to the teacher's in-class actions and how professional knowledge and in-class actions impact on student achievement, Liepertz and Borowski (2019) engaged a paper-and-pencil test for both teachers and students. This study could not verify the correlation between teachers' knowledge and their in-class actions. Liepertz and Borowski suggest that the pedagogical reasoning of teachers should be taken into consideration in measuring teachers' PCK, which has an impact on the classroom practice of the teacher. A study that also measured PCK quantitatively is that of Marake *et al.* (2022). Unlike Liepertz and Borowski (2019), Marake *et al.* investigated Physics teachers' perceptions of their PCK components using a questionnaire that was analyzed through descriptive statistics. This study reported that teachers had positive views about their knowledge base but found no correlation between the sub-components of curricular knowledge.

Mazibe, Coetzee and Gaigher (2020) conducted a qualitative case study that measured reported topic specific PCK (TSPCK) and enacted PCK, measuring all the components of TSPCK. Reported PCK was measured through the CoRes which were constructed by the teachers and also interview data. The enacted PCK was measured through classroom observations. The PCK was scored using rubrics. The study found that enacted PCK was seldom higher than reported PCK. There were cases of lower reported PCK than enacted PCK and also cases of reported and enacted PCK at the same level.

Loughran, Mulhall and Berry (2004) developed a tool to capture, articulate and document professional knowledge in practice by detecting PCK in different areas of teaching such as laboratory work, role-playing, demonstrations and other work of the teachers. The tool is named CoRe (Content Representation). This tool documents professional practice knowledge through discussions with teachers about their teaching and also classroom observations. CoRe is an interview tool used to access Science teachers' knowledge and a way of characterising this knowledge. For the purposes of this study, CoRe helps to identify the knowledge bases of teachers, which compose their PCK, and how these knowledge bases are used in their classroom practice; through interviews, classroom observations and post observation interviews. Loughran *et al.* (2004) indicate that CoRe

helps researchers to codify knowledge of content in a common way concerning how teachers characterise the content they are teaching, the challenges around the concept being taught and their ways of dealing with these in their classroom practice. CoRes and PaP-eRs are qualitative methods of capturing and portraying PCK.

The PaP-eRs (Pedagogical and Professional experience Repertoires) are rich descriptions or narratives of the teachers' classroom practices associated with the content under consideration in the CoRe (Loughran *et al.*, 2004). The descriptions are informed by interviews, classroom observations and post-observation interviews. The PaP-eRs bring into life what was done in the classroom, considering teachers actions, students' actions and voices, the response of the teacher towards different classroom experiences and the reasons for the teacher responding in a certain manner to different classroom activities. A diversity of PaP-eRs is required to show the PCK of the teacher in action. CoRes and PaP-eRs help to categorise knowledge of the teacher in action, to better understand professional knowledge and aspects of PCK of the teacher in their classroom practice and to make the unspoken knowledge of teachers explicit so that the knowledge is measurable and can be accessed by other teachers, teacher educators and also novice teachers.

Different researchers have engaged CoReS and PaP-eRs as useful methodological tools to capture teachers' PCK, which is often tacit and useful to assist teachers with reflection on their practice and in other studies this tool has also been used for professional development (Nilsson & Karlsson, 2019, Melo-Niño *et al.*, 2016; Pitjeng-Mosabala & Rollnick, 2018). However, since this approach includes rich descriptions of PCK in the form of detailed narratives, it requires a considerable amount of time to construct CoRe and PaP-eRs and for analyses by researchers.

Melo-Niño *et al.* (2016) qualitatively described and characterized the PCK of an experienced secondary school teacher with two years of experience teaching electric fields, before and after a programme of intervention. In this study data was collected through: (a) a questionnaire with open-ended questions on what the teacher viewed as teaching strategies to teach Physics and the role of planning in the teaching and learning process, (b) curriculum materials used by the teacher, (c) the planning template, (d) the

modified CoRe designed by Loughran (2006), (e) semi-structured interviews and (f) classroom observations. Data was analysed following content analysis where units of information were identified from each data collection instrument, units of information were coded into categories and subcategories and the units of information were analysed. The categories that emerged were then incorporated into a description and characterisation of the teacher's PCK. Categorisation was based on the model of Magnusson *et al.* (1999) involving the following categories: the vision and goals of Science education, curriculum knowledge, knowledge of students' learning difficulties and needs, knowledge about evaluation and knowledge about teaching strategies. The analysis was subdivided into a declarative phase, a design phase and an action phase looking at traditional tendencies, intermediate tendencies and constructivist tendencies in each phase. The results of this study show that teacher's PCK is mediated by the teacher's conception of Physics and the relationship of Physics to Mathematics in an electric field. In addition, PCK is shaped by the experiences of the teacher as a student that has influenced the idea of Physics learning, concepts expression and the selection of teaching strategies. This study also revealed the difference between declared PCK and PCK in action, showing that declared PCK has more impact on planning than in action. For example, the participant teacher proclaimed to consider students' ideas in her teaching, but this was not seen in her design and action phases.

Nilsson and Karlsson (2019) conducted another study where they used CoRe together with video self-records for reflection on teaching so as to capture student teachers' professional knowledge for practice. The CoRe was designed before the student teacher taught certain content so as to increase the student teacher's knowledge of issues about teaching this content. This also helped in developing pedagogical reasoning and decision making, as student teachers enact their professional knowledge in their specific classroom contexts. Reflective writing was used as an evaluative tool for the student teachers to learn professional knowledge through the CoRe. The study found that the student teachers' self-reflection was improved by the use of CoRe and video connected tools, by making clear what is significant in relation to their PCK.

In a study to find out how teachers develop topic specific PCK in Chemistry, Pitjeng-Mosabala and Rollnick (2018) used a mixed method approach that involved topic specific PCK, TSPCK and CK tests to quantitatively describe TSPCK of Chemistry teachers and CoRe to qualitatively describe TSPCK of teachers in practice because it is argued that PCK is situated in classroom practice (Gess-Newsome, 2015). A study about Chemistry teaching carried out by Davidowitz and Potgieter (2016) engaged a quantitative method to relate teachers' content knowledge and TSPCK through the use of paper-and-pencil tests. It was found that CK is a necessary prerequisite of TSPCK, but having a broad knowledge of CK does not ensure high levels of TSPCK.

These studies mentioned have assessed PCK quantitatively (Cauet *et al.*, 2015; Kirschner *et al.*, 2016; Liepertz & Borowski, 2019) and quantitatively related PCK to the quality of instruction (Cauet *et al.*, 2015; Liepertz & Borowski, 2019). This study is different in that it measures the PCK of Physics teachers quantitatively and qualitatively describes how this PCK is manifested in the classroom context. The CoRe is used as a tool to capture teachers' PCK that helps the teacher conceptualise their professional knowledge, to differentiate between different knowledge areas and to relate content knowledge, pedagogical knowledge and the knowledge of other aspects of PCK needed to teach a particular topic in Physics. In the studies that used the CoRe as a tool, the CoRe was used to investigate professional development after an intervention programme (Melo-Niño *et al.*, 2016; Pitjeng-Mosabala & Rollnick, 2018). In this study the CoRe is used to document and portray Physics teachers' classroom practices and how PCK is articulated as they teach. Narratives are used to describe PCK in-action.

Having shown how different researchers involve various methods to measure, capture and portray PCK in different disciplines, we see that PCK is a difficult construct to measure and portray. The difficulties in measuring and portraying PCK result from the nature of the construct argued by researchers that PCK is tacit (Park, Suh & Seo, 2018; Rollnick, 2017; Maryati *et al.*, 2019) and that PCK is idiosyncratic (Park & Chen, 2012). To indicate this idiosyncrasy, Park and Chen (2012) show that PCK maps, which were used to portray the teachers' PCK, were not the same for teachers teaching the same topic and having the same lesson plan. This study contributes knowledge about the

measured professional knowledge that in-service teachers have and how they draw on their knowledge to build their classroom practices. The study used different data collection methods to gain knowledge about Physics teachers' PCK. A PCK test was used to measure the general PCK for teaching physics; being domain PCK. The pre-observation interviews accessed the teachers' knowledge about specific topics they taught in real classroom situations. The video recorded classroom observations were used to capture the PCK of the teacher in the act of teaching a particular topic. The video stimulated recall post the observation interviews and were used to gain more knowledge of the reasons for the teachers' classroom actions and decisions to teach in particular ways.

2.7 CONCEPTUAL FRAMEWORK

This study explores PCK components that Physics teachers draw on to construct their classroom practices and aims to examine how classroom practices are constructed with respect to the PCK components that teachers possess, drawing on the research that explores a professional knowledge base for teaching. Professional knowledge for teachers has seven different categories of knowledge bases outlined by Shulman (1987) as discussed in **section 2.3**. Shulman argues that these knowledge base categories are the ones that teachers draw from to direct their actions and make choices as they enact their knowledge of teaching. Shulman adds that the intersection of content and pedagogy provides the key to distinguish the knowledge base of teaching. This key enables the teacher to transform the content into a form that is comprehensible to students. Therefore, in order for the teacher to have different ways of representing the content covered in different topics or to present the problems or issues in the subject being taught to students of different interests and abilities, the teacher should have the knowledge of content blended with pedagogical knowledge (Shulman, 1987). Additionally, for the teaching to be effective, different scholars argue that teachers need to possess diverse knowledge bases discussed as components of PCK in the previous **section 2.3**, PCK being the knowledge to teach. Knowledge bases are viewed as “the secret of an expert system’s expertise, the body of understanding, knowledge, skills, and dispositions that a teacher needs to perform effectively in a given teaching situation” (Wilson, Shulman & Richert, 1987: 106).

In their classrooms teachers, in order to teach, navigate from their own understanding of the content to transforming the content with the main goal of helping students understand what they are teaching. Shulman (1987: 13) illustrates this shift from the teacher's understanding by indicating that teachers move

[...] from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students.

This implies that in the act of teaching, the teachers' PCK, being their knowledge of teaching, results from their understanding of what they teach, making decisions on how the content should be presented which involves pedagogical reasoning, transforming their understanding and then delivering content in ways that students' learning is targeted. In his definition of PCK, Shulman (1987: 8) asserts that PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of students and presented for instruction." In Gess-Newsome (2015), the understanding and pedagogical reasoning that is part of teacher knowledge is considered as the knowledge used in planning and delivering of an instruction based on a certain topic.

This study examines Physics teachers' PCK components, being the knowledge base that teachers draw on to construct their classroom practices and how this knowledge is expressed in their classroom practices. Teachers use their professional knowledge base, being what they understand with respect to teaching and modify it into a form that can be understood by their students (Shulman, 1987). This ability to make learning possible is referred to as teachers' professional knowledge (Nilsson and Vikström, 2015). Park and Oliver (2008) argue that this type of knowledge is explicit and can be found in different ways and involving lesson plans or directly from teachers through interviews.

It has been shown in previous sections by different researchers that PCK is conceptualised to have different knowledge bases. After realizing that the

conceptualisation of PCK is different coming from different researchers (Shulman, 1986; Grossman, 1990; Gess-Newsome, 1999; Rollnick *et al.*, 2008), PCK researchers convened a summit that was meant to share their different understandings so as to come up with a unifying model for PCK. The model is called the model of teacher professional knowledge and skills (TPK&S) that includes PCK or the consensus model (see figure 2.1 below) (Gess-Newsome, 2015: 31).

The model was formulated to reveal the connection between knowledge bases, which collectively form teachers' professional knowledge bases, topic-specific professional knowledge, classroom practice that situates PCK and student outcomes.

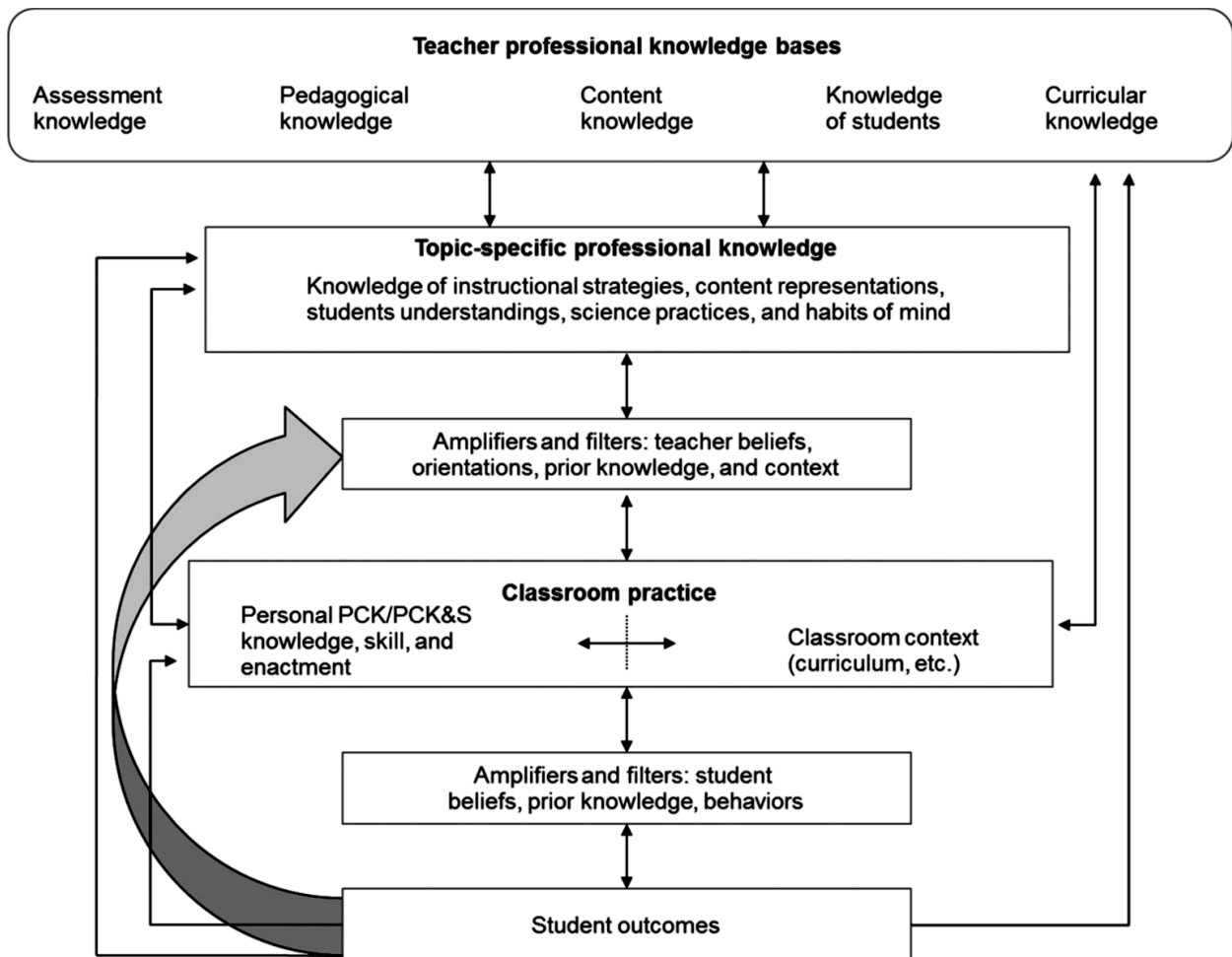


FIGURE 2.1: THE CONSENSUS MODEL (Gess-Newsome, 2015:31).

This model originates from the characteristic knowledge bases that form teachers' professional knowledge emerging from research and best practice (Gess-Newsome, 2015). The model shows that the TPKB informs us and is also informed by the teachers' topic specific professional knowledge (TSPK). In the Consensus model the knowledge base of teachers is viewed as a general knowledge of teaching and this knowledge base can be used to assess what teachers know with respect to their teaching (Gess-Newsome, 2015).

The Consensus Model helps to understand how the teachers' knowledge of teaching, being professional knowledge, is related to the teachers' practical knowledge, being the knowledge used in a classroom setting and how students' outcomes are related to teachers' professional knowledge. The TPKB are linked directly to classroom practice which is also linked to students' learning gains. This model looks at the five knowledge bases: assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students and curricular knowledge (Gess-Newsome, 2015). The Consensus Model does not only value the knowledge of content as the most important knowledge that is required for best classroom practices, but it also takes into consideration other knowledge bases. Liepertz and Borowski (2019) agree that teaching a particular subject needs other knowledge bases to be incorporated. Although different scholars differ in the number of knowledge bases required to teach effectively, most of the scholars agree on some of the knowledge bases considered in the Consensus Model. For instance, pedagogy, students' knowledge and content knowledge have been considered in different models (Cochran *et al.*, 1993; Rollnick *et al.*, 2008; Shulman, 1987).

The Consensus Model separates the TPKB and TSPK. The TSPK is viewed as the knowledge for teaching that is related to topic level while the TPKB is considered as the general knowledge of the teacher in the discipline. The TPKB is directly connected to the teachers' PCK in their classroom practice. The model shows that these knowledge bases are transformed into the knowledge exhibited as PCK in classroom practice. The TSPK on the other hand may be directly linked to the PCK of teachers in classroom practices or linked to classroom practice PCK through the influence of teacher's amplifiers and

filters which encompass the teacher's beliefs, orientations, prior knowledge, Science practices and habits of mind (Gess-Newsome, 2015).

The Consensus Model suggests a strong framework for understanding how different professional knowledge bases are related to PCK. This model suits this study because this study seeks to assess the knowledge of teaching that Physics teachers have by looking at the different knowledge bases included in this model. TPKB is the canonical knowledge of the teacher that excludes the context in which the teacher teaches. Gess-Newsome (2015) argues that the TPKB is context free, meaning this can be investigated outside the classroom context. TPKB is used in this study to construct the PCK test to assess what teachers know with respect to the professional knowledge components that inform their PCK. The knowledge of teaching Physics results from knowledge of teaching certain topics; TSPK within Physics, and in order to teach certain topics effectively the teacher has to have a blended knowledge of the separate knowledge bases (Shulman, 1987), which are referred to as TPKB in this model.

This model situates PCK in classroom practice. In this model, the teacher's PCK depends on the beliefs and orientation held by the teacher about teaching Science. The model emphasises the personal nature of PCK, which is in agreement with the view of Magnusson *et al.* (1999). Although the Consensus Model has PCK as a knowledge base and a skill for classroom practice, it describes what PCK manifestation in classroom practice encompasses in a limited way, which makes it difficult to use for an analysis of PCK as a construct in classroom practice. It is therefore in this illumination that the model of Magnusson *et al.* (1999) has been incorporated into The Consensus Model to clarify what is to be viewed as PCK manifestations in classroom practices.

This study adapted the Consensus Model of Gess-Newsome (2015) because it considers more knowledge bases than other models to be incorporated into the knowledge that the teacher has. It allows the researcher to consider both the personal PCK and personal knowledge and skills (PCK&S) which are helpful in differentiating what the teacher knows about teaching Physics and how the teacher decides to teach Physics in the classroom.

Gess-Newsome (2015: 36) differentiates this knowledge and describes personal PCK as follows:

[T]he knowledge of, reasoning behind, planning for, and enactment of teaching a particular topic in a particular way for a particular reason to particular students for enhanced student outcomes (reflection-on-action) while personal knowledge and skills (PCK&S) is the act of teaching a particular topic in a particular way for a particular reason to particular students for enhanced student outcomes ... reflection-in-action.

These definitions are both related to this study where the aim is to investigate what the teacher knows about teaching Physics and how that knowledge is manifested in the act of teaching Physics.

The Consensus Model indicates that PCK occurs in the context of classroom practice and allows PCK to be looked at as a knowledge base when used in the classroom and as a skill when involved in the act of teaching. The Model allows the researcher to differentiate the PCK components known by the teacher and the PCK components used by the teacher in practice when the teachers interact with students in a particular context. This suggests that teachers might have many knowledge bases that build their PCK but use only a few of these in the classroom context, depending on the teachers' amplifiers and filters. In order to enrich the description of PCK in action, the model of Magnusson *et al.* (1999) is incorporated in the Gess-Newsome (2015) Consensus Model to compliment the description of the manifestations of PCK in classroom practices.

In the original Gess-Newsome TPK&S model, there is students' outcome, which is linked to the teachers' PCK through amplifiers and filters. The students' outcomes are not relevant to this study since PCK is not investigated in relation to students' outcomes, but is viewed as the transformation of the teachers' knowledge base into practice. For the purpose of this study, students' outcomes are removed.

The model of Magnusson *et al.* (1999) could not be used as it is in this study, because it excludes content knowledge as one of the knowledge bases important in teacher knowledge, while most researchers (Shulman, 1986; Shulman, 1987; Rollnick *et al.*, 2008; Riese & Reinold, 2010; Pitjeng-Mosabala & Rollnick, 2018) consider content knowledge

to be inseparable from the teacher's professional knowledge. Having noticed how Gess-Newsome's (2015) Consensus Model describes what to look at per knowledge base in the classroom practice of the teacher, concerning the knowledge bases which inform the PCK and the classroom practice, the model of Magnusson *et al.* (1999) was considered and incorporated in this study to expand on the descriptions of classroom practice associated with knowledge bases. The description of what to look at in the classroom concerning different knowledge bases is according to Gess-Newsome (2015) and Magnusson *et al.* (1999) and is discussed in the next section.

2.7.1 Teachers' professional knowledge bases: PCK components

The knowledge bases discussed in this section are the ones assumed to be in use for the construction of Science teachers' classroom practices. This does not mean other knowledge bases are not important but for the scope of this study, only the knowledge bases included in the Consensus Model (Gess-Newsome, 2015) are discussed. These knowledge bases were also used to construct the PCK test as Gess-Newsome indicates that these knowledge bases are generic, they do not depend on the content to be taught, they are also normative and therefore can be used to assess what teachers know. In this section a description of what constitutes each knowledge base in terms of specific knowledge examples used to illustrate this specific knowledge and how this knowledge has been exhibited in different studies that assessed teachers PCK is discussed.

2.7.1.1 Assessment knowledge

The specific knowledge in this knowledge base is the ability of the teacher to design formative and summative assessments and use the designed assessments' results to modify or redesign instruction (Gess-Newsome, 2015). Magnusson *et al.* (1999) divide this knowledge into two categories: knowledge of the dimensions of Science learning that are important to assess and the knowledge of the methods by which the learning can be

assessed. It is expected that a teacher with developed PCK would consider the dimensions of Science learning to assess aligned with the goals of the curriculum to test students' scientific literacy around a particular concept. Due to the different nature of the topics in the discipline, the dimension of Science learning may differ and it is the duty of the teachers to choose the most important aspects of Science to assess. The knowledge of different methods to assess Science learning may be seen through the teachers' use of a variety of methods of assessment to ascertain students' understanding of Science. Magnusson *et al.* outline examples of such methods to include written tests, journal entries, laboratory reports, drawings and designing working models.

In the LGCSE Physical Science syllabus, there are three assessment objectives, which physical science teachers are supposed to be familiar with when engaging their students in effective assessment. These are stated together with the weight of marks they carry during Physical Science examinations (NCDC, 2019: 6) as shown in Table 2.2.

TABLE 2.2: ASSESSMENT OBJECTIVES

Assessment Objective	Weighting
A: Knowledge with understanding	50% (not more than 25% recall)
B: Handling information and problem solving	30%
C: Experimental skills and investigations	20%

These assessment objectives give direction for teachers on how to construct their classroom assessments, which inform their instruction, and how to engage all of these assessment objectives in their formative assessments to prepare their students for examinations. The different assessment objectives call for a variety of assessment tasks to be used to ascertain students' understanding in the classroom. Chabongora and Jita (2013) assert that the impact of instruction is detected through the use of a variety of assessment tasks that resemble the curriculum. This implies that in the case where there are different assessment objectives from the curriculum, teaching should be characterised by the use of assessment methods that address the different objectives.

2.7.1.2 Pedagogical knowledge

This knowledge base takes into consideration the knowledge of classroom management strategies, the designing of lesson plans, ways to engage students which may be illustrated through questioning techniques, applying instructional strategies which address the different needs of students (Gess-Newsome, 2015). Unlike Gess-Newsome, Magnusson *et al.* do not have the component of pedagogical knowledge but have knowledge of instructional strategies, which appear within the component of pedagogical knowledge in Gess-Newsome (2015). Pedagogical knowledge as a TPKB is broader in the model of Gess-Newsome but more focused in the model of Magnusson *et al.* In this study, TPKB is narrowed to the teachers' knowledge of instructional strategies. Instructional strategies are taken to be all ideas the teacher involves to enact Science instruction. They may be general subject specific strategies or constrained to topic specific strategies (Magnusson *et al.*, 1999). Magnusson *et al.* argue that subject instructional strategies depend on the teacher's orientation to teaching Science, the teacher's knowledge of content, knowledge of pedagogy and context. Topic specific strategies are divided into knowledge of representation and possible activities used for the topic being taught. Representations include illustrations, examples, models or analogies. Chabongora and Jita (2013) classify representations as being visual, verbal or symbolic and argue that a variety of representation should be engaged with in the teaching process, so as to better develop the understanding of concepts by students. Activities on the other hand include demonstrations, simulations, investigations or experiments. It is not enough for the teacher to know different strategies, but it is also required that the teacher knows both the advantages and the disadvantages of using particular strategies for the particular concept being taught (Magnusson *et al.*, 1999).

2.7.1.3 Content knowledge

Gess-Newsome (2015: 32) regards content knowledge as comprising "the Science and engineering practices used to generate knowledge, the disciplinary core ideas, and the recognition of cross-cutting concepts." Oztay and Boz (2022) define content knowledge as knowledge about fundamental concepts, facts and principles of the subject. In his definition

of PCK, Shulman (1987, 1986) emphasizes the importance of content knowledge for the teacher to teach effectively by pointing out that the PCK of the teacher is the integration of content and pedagogy. According to Shulman, to teach a particular subject teachers should have content knowledge in that subject and not only understand the concepts of the discipline, but also be able to explain the concepts. This said, Magnusson *et al.* (1999) do not include content knowledge in their model, therefore making their model incomplete to consider in isolation when examining teachers' PCK.

Gess-Newsome (2015) considers content knowledge to be academic knowledge, meaning it is the knowledge the teacher gains from school or university in a certain discipline. Compared to the content taught to students, teachers are expected to have a more developed understanding of the content they teach in their disciplines (Rollnick, 2017). Although the quantity and quality of content knowledge required to teach has not yet been agreed upon, Rollnick (2017) asserts content knowledge is regarded as the principal anchor of the professional knowledge base of the teacher. To emphasise the importance of content knowledge in teaching, Jacob, John and Gwany (2020) point out the influence of content knowledge on students' achievement and quality classroom practice. Jacob *et al.* (2020) provide examples of findings in empirical studies, which found that teachers with insufficient content knowledge led to the development of misconceptions and misunderstanding.

In a study aimed at developing teachers' subject matter in a specific topic where teachers lacked content knowledge, Rollnick (2017) found that CK and PCK are strongly related. Evidence was given by the fact that teachers' growth in content knowledge in a teaching context came with their knowledge growth in how to teach the topic. With their growing in understanding of the content, teachers were able to establish richer representations, illustrate greater awareness of students' prior knowledge and develop teaching strategies to teach the topic in hand. In other studies, researchers (Davidowitz & Potgieter, 2016; Oztay & Boz, 2022) found that teachers with low levels of content knowledge were likely to have low levels of PCK. This suggests that teachers with a deep understanding of content knowledge are expected to illustrate better classroom practices enacting their knowledge for teaching in the classroom context.

2.7.1.4 Knowledge of students

Knowledge of students helps teachers focus their instruction on targeted learning of scientific knowledge that encompasses student cognitive and physical development, understanding of student differences that might require instructional differentiation and how to capitalize on personal and community assets to enrich instruction (Gess-Newsome, 2015). Magnusson *et al.* (1999) divide this knowledge into two categories: the knowledge of the requirements for learning and the knowledge of students' difficulty. The knowledge of the requirements for learning entails the teacher's knowledge of students' prerequisite knowledge, knowledge of students' different learning styles and knowledge of different ways to represent the content to a particular group of students. To the knowledge of students' understanding of Science, Smith and Banilower (2015) add the knowledge of how to sequence ideas, moving from less complex to more complex ideas so that students can understand the concepts.

Knowledge of areas of students' difficulty encompass the teachers' knowledge of what makes a particular concept difficult to understand, the abstract nature of the concept, the possible disconnection of the concept from the students' experiences, problem solving, insufficient skills and misconceptions around the concept (Magnusson *et al.*, 1999). Considering early definitions of PCK, Shulman (1986) defines PCK as knowledge that encompasses the teachers' knowledge of what students of different age groups are likely to bring as their preconceptions of a targeted learning area. Aykutlu, Bezen and Bayrak (2015: 391) contend that students do not go to class as empty vessels but go to class with preconceived ideas emanating from their "previous knowledge, attitudes, beliefs and values" and these preconceptions are most likely to be in the form of misconceptions. Coetzee *et al.* (2020) term this knowledge as 'learner prior knowledge' and consider it as one component of topic-specific PCK that enables the teacher to shape their teaching around what is already known by the students, whether they have correct or incorrect ideas. According to Shulman (1986) and Ergönenç, Neuman and Fischer (2014) this knowledge helps teachers select strategies, which might be fruitful to change the misconceptions of the targeted scientific knowledge.

In a study carried out on Physics teachers' opinions about factors considered to hinder the learning of Physics concepts in the curriculum by Aykutlu, Bezen and Bayrak (2015: 390), some of the topics which teachers said students had difficulties to understand included motion, torque and simple harmonic motion in the unit of "Force and Motion". In a similar study the conclusions drawn were that students experienced challenges in some topics due to various factors, such as a lack of conceptual knowledge of the concepts, misconceptions possessed by students, the abstract nature of the topic, lack of basic Mathematics knowledge and insufficient time allocated to complete the course. Ergönenç, Neuman and Fischer (2014) found that teachers with knowledge of students' difficulties were able to cognitively activate their students, adapting difficult tasks in the form of questions directed at the students' cognitive level so that it would be easier for students to answer such questions. This suggests that knowledge of the challenges that students might have in a Physics classroom may better inform the teacher about their approach to teaching the concepts targeted.

2.7.1.5 Curricular knowledge

This knowledge "include[s] the goals of a curriculum, curriculum structures, the role of a scope and sequence, and the ability to assess a curriculum for coherence and articulation" (Gess-Newsome, 2015: 32). Coetzee *et al.* (2020) refer to this PCK component as "curricular saliency" and define it as the knowledge that teachers have about identifying the key concepts in the topic and sequencing them in a manner that enables the students to understand. Magnusson *et al.* (1999) divide curricular knowledge into two categories: knowledge of goals and objectives in the mandate of teaching Science and specific curricular programmes and materials. Knowledge of goals and objectives focuses on how the goals and objectives are stated in the curriculum guiding the teaching and how they can be achieved within specific topics taught in a certain discipline. One of the national goals of education that shows the value of Science education in Lesotho, as stated in the Curriculum and Assessment Policy of 2009 by MoET (2009: 9) is that:

Educational programs will reflect Lesotho's requirements and development needs. In this case the focus shall be on the development of scientific thinking; problem-solving; entrepreneurial technological skills; connecting productive skills and learning; and the practical application of knowledge to the improvement of living conditions.

This goal makes the central objective of teaching Science in schools as the development of the following skills: scientific thinking, problem-solving, entrepreneurial and technological skills. In the development of these skills, this Policy advocates for student-centred approaches which support independent learning and states the following:

The focus in pedagogy has therefore shifted more to teaching and learning methods that can further develop creativity, independence, and survival skills of students. Students are expected to become more responsible for their own learning processes and thus should be able to identify, formulate and solve problems by themselves and evaluate their work. Hence teaching methods which are *student-centred* are based more on students' own activities (MoET, 2009: 22)

The Policy points to a direction for teaching, moving from teacher-centred approaches to student-centred approaches. It points to the expected pedagogical practice in classrooms to be one where teachers help students build knowledge and become independent and responsible in knowledge creation, rather than waiting for the teacher to transmit knowledge.

From this Policy, Science is envisioned as one discipline that can contribute to the development of better living conditions and as such it is viewed as a core subject that is important to be learned by all Basotho children for the betterment of their lives and the lives of others. The Policy also views student-centred approaches in teaching as important in developing skills, which are viewed as important for the future of the lives of the students. With this line of thought, this Policy gives direction on the expected pedagogy of teachers in classroom situations in the implementation of the curriculum. As a matter of fact, more activities are expected from students than their teachers. Thus, the teachers are expected to engage students in activities that may help them to develop scientific thinking, independence and responsibility.

Magnusson *et al.* (1999) agree with Shulman (1986) that curricular knowledge constitutes teachers' knowledge of how topics develop from lower levels to higher levels of education in the school years, the knowledge of what has been covered in the previous years, the present year and what will be covered in the years ahead. Shulman adds that knowledge of specific curricular programmes includes knowledge of materials and programmes appropriate for what is currently taught in the domain to help in the selection of suitable teaching aids and activities to develop the concepts. Ergöner, Neuman and Fischer (2014) indicate that knowledge about curriculum is exhibited in the teachers' planning of instruction, being able to analyse the content to select what is central to what is being taught and also designing artefacts to help students understand within the context of learning. According to Nilsson and Vikström (2015), knowledge of selecting the correct content and focusing on the important ideas exhibits the teachers' knowledge of the Science curriculum - one of the PCK components in the knowledge base of the teacher. In explaining knowledge of the Science curriculum, Park and Oliver (2008) assert that this is the knowledge that enables the teacher to select core concepts to be taught; referred to as big ideas by Loughran *et al.* (2004). Park and Oliver (2008) add that this knowledge is used to adapt activities to suit the teaching context and to select only the aspects deemed central to the topic.

2.7.2 The adapted Consensus Model

This study has adapted the Consensus Model of Gess-Newsome (2015) to explore the PCK components that Physics teachers have and to guide the selection of the components incorporated in the PCK test that is used. The model of Magnusson *et al.* (1999) has been incorporated into the model of Gess-Newsome (2015) to guide the analysis of how these PCK components are used in the classroom practices of the teachers. The Consensus model acknowledges the role played by amplifiers and filters in the PCK exhibited by teachers as a skill in teachers' classroom practices. This study does not include the influence of these filters and amplifiers in the teachers' PCK but focuses on the PCK of the teacher and how classroom practices are constructed with respect to the PCK components of the knowledge bases of the teacher. The following

model shows how the Consensus Model has been modified for the purposes of this study. Figure 2.2 below shows the modified Consensus Model and the details of classroom practice manifestations per PCK component.

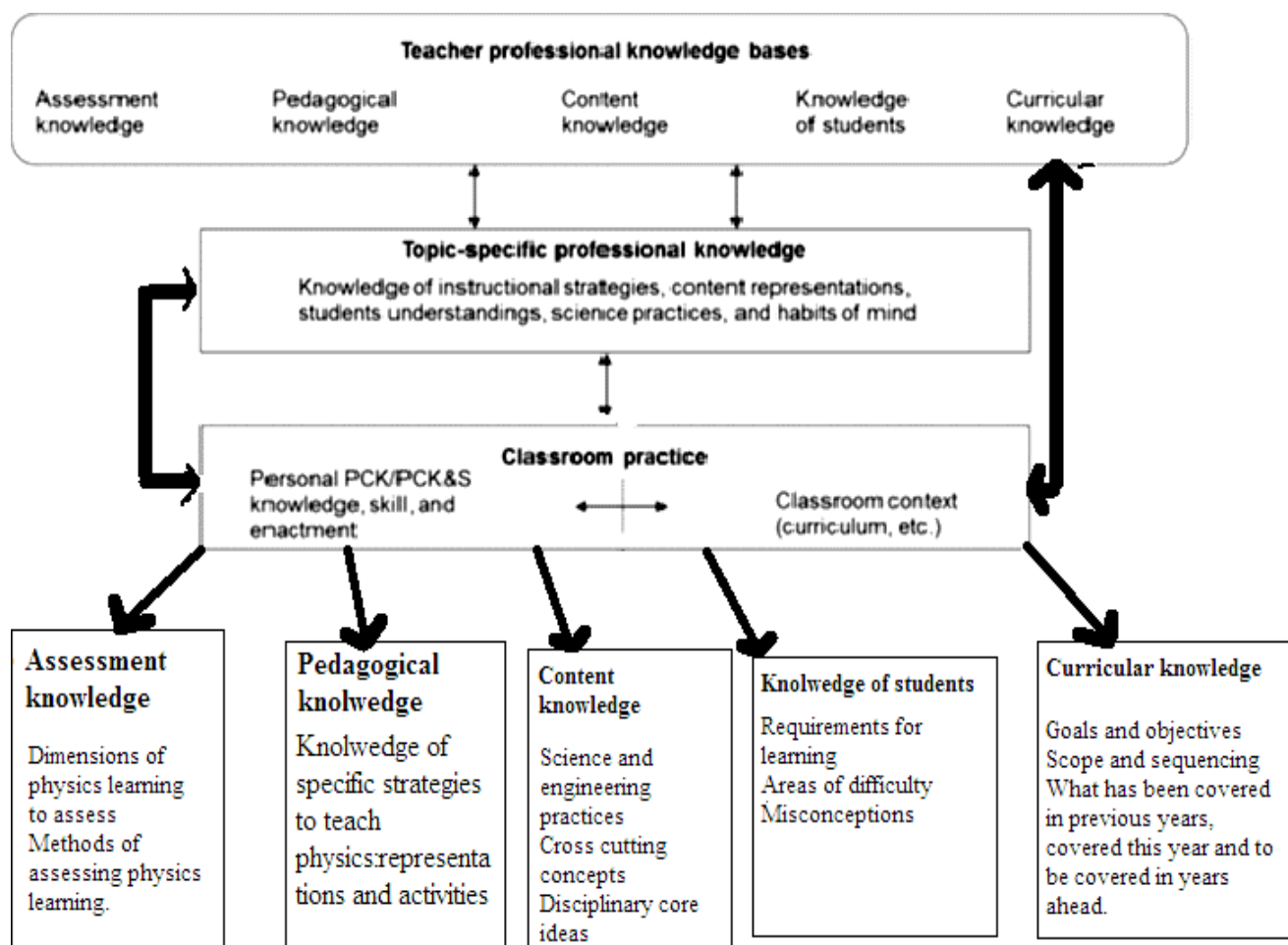


FIGURE 2.2: MODIFIED CONSENSUS MODEL (adapted from Gess-Newsome, 2015)

According to Gess-Newsome (2015), the teachers' professional knowledge bases are the knowledge bases characteristic of the teachers' knowledge that can be expected from all teachers in the teaching profession irrespective of their disciplines; this knowledge is context free. This model allows PCK to be explored at topic level since the teachers' professional knowledge bases are informed and inform topic-specific professional

knowledge. This acknowledges that the knowledge for teaching a certain discipline begins with knowledge of specific topics within a discipline. Gess-Newsome adds that these knowledge bases can be used in the construction of instruments measuring what teachers know and to describe the desired knowledge of teachers. This model allows PCK to be researched as canonical PCK and personal PCK enacted as a skill in classroom practice. In this model, the professional knowledge bases for teaching are viewed as components of teachers' canonical PCK investigated through a PCK paper-and-pencil test, while the personal PCK is investigated through the teachers' classroom practices and is the knowledge found in teachers' preparations to teach, in the act of teaching and teachers' reflections on their teaching (Smith & Banilower, 2015).

Magnusson *et al.* (1999) assert that for the teacher to teach effectively the knowledge of components of PCK, which are referred to as TPKB by Gess-Newsome (2015), should be well-developed in all topics that are taught in the discipline. In addition, the knowledge of all these components forms a strong PCK, which makes the classroom practices of the teachers effective. When some components are more developed than others, classroom practice becomes less effective because these components complement each other in the daily practice of the teacher. Liepertz and Borowski (2019) engaged the Consensus Model of Gess-Newsome (2015) in an empirical study to find out the relationship between professional knowledge and the in-class actions of the teacher and whether the professional knowledge of the teacher and their actions affect student achievement. Thus, to teach effectively, teachers do not only need to have the knowledge of the content in their domain but also need to have other different knowledge bases incorporated into their teaching such as knowledge of teaching strategies and knowledge of students' points of view (Liepertz & Borowski, 2019).

2.8 CONCLUSION

This study focuses on PCK as a construct to direct thinking about the teachers' professional knowledge and practices. PCK is a helpful construct to shed light on how teachers engage their knowledge in the construction of classroom practices and to understand how teachers construct their classroom practices so as to help students learn.

Understanding the knowledge teachers have in different areas such as assessment, pedagogical, content, students and curriculum might help teacher educators to target areas that need improvement in teacher education programmes. This suggests the need for more research on different knowledge areas and how they relate to the teachers' classroom practices. Having explored how different researchers conceptualise PCK, it is quite difficult to identify the knowledge base components that best build the teachers' PCK. Therefore, there is a need to investigate the components of the teachers' knowledge base possessed by Physics teachers and to engage a large number of Physics teachers so as to shed light on the components of PCK that inform their classroom practice.

Liepertz and Borowski (2019) argue that to measure PCK, which has real impact on classroom practices, teachers' pedagogical reasoning about their classroom actions should be taken into account. To cater for this, the present study does not only investigate the components of PCK of Physics teachers but also seeks to understand how these components are exhibited in the actual classroom practices of the teacher and the reasons for taking these actions in the classroom.

The literature reviewed in this chapter should help to highlight the different conceptualisations of PCK by researchers and also shows that there is an agreement that PCK is needed for effective teaching and that PCK can be measured and portrayed. The literature also shows the inconsistent results about the relationship between PCK and instructional quality, which invites more studies on PCK and its role in the quality of instruction. The next chapter articulates the research methodology and design of the study.

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter presents the research methodology and design used to examine the components of pedagogical content knowledge (PCK) and the construction of Physics teachers' classroom practices. The sampling procedure and sampling strategies are discussed. Data collection process and data analysis are highlighted. The chapter also presents how validity and reliability for both the quantitative and qualitative parts of the study have been ensured. Finally, ethics considerations are elaborated.

3.2 RESEARCH QUESTIONS AND THE PURPOSE OF THE STUDY

This study involved a mixed methods approach to investigate how Physics teachers draw on the components of PCK to construct their classroom practices in a variety of secondary school contexts, taking note of the following research questions:

Primary question:

How do Physics teachers in Lesotho draw on the components of PCK to construct their classroom practices in a variety of secondary school contexts across the country?

The following secondary questions were asked to unpack the main research question.

1. What components of PCK do Physics teachers use to teach Physics?
2. How are the components of PCK manifested in Physics teachers' classroom practice?
3. How can the role of Physics teachers' PCK in classroom practices be understood and explained?

The aim of this study was to identify the PCK components that Physics teachers draw on to construct their classroom practices and to examine how classroom practices are constructed with respect to the PCK components that teachers possess. This was done to explain the role of PCK in the classroom practices of Physics teachers in Lesotho so as to better understand the relationship between the PCK components and classroom practices.

3.3 RESEARCH METHODOLOGY AND DESIGN

The methodology of the study gives details about the logical flow of the process of investigation, outlining methods of data collection, sample, instruments and data analysis to gain knowledge about the research problem (Kothari, 2004). According to Wahyuni (2012) the methodology describes the pattern followed in undertaking an investigation process in the context of a particular paradigm. The sections that follow give details of the research processes engaged in this study.

3.3.1 Research paradigm

Creswell and Creswell (2018) refer to paradigms as worldviews and define a worldview as the researcher's position about the understanding of the nature of the world and research that guide the researchers' choice as to how the study is conducted. Cohen, Manion and Morisson (2018) consider a paradigm to comprise how the world is interpreted, what counts as worthwhile knowledge in the process of studying the world, the suitable methodology used and the ways of validating the knowledge constructed. A paradigm is a way of thinking that informs the manner in which meaning is constructed in research and determines the research methods suitable for the study (Kivunja & Kuyini, 2017). According to Kivunja and Kuyini (2017) different paradigms may be employed by different researchers depending on the phenomenon studied. These paradigms include positivist, post positivist, interpretive and pragmatic paradigms. This study is situated in a pragmatic paradigm. The characteristics of a pragmatic paradigm are discussed to show why it is considered the best paradigm for this study.

3.3.1.1 *Pragmatic Paradigm*

Pragmatism involves the use of both quantitative and qualitative data collection and analysis methods to answer the research questions, focusing on what works best to address the research purpose (Cohen, Manion & Morisson, 2018). This implies that in this paradigm a researcher may employ both qualitative data and quantitative data to look at the needs of the study. Creswell and Creswell (2018) indicate that this paradigm allows the researcher to select the most suitable methods to best answer the research questions.

Creswell and Creswell (2018), referring to a paradigm as a worldview, argue that knowledge cannot solely be accessed through a single scientific method nor can it be accessed through interacting with the subject, but it can be constructed by engaging different methods to better understand the behaviour of participants (Kivunja & Kuyini, 2017). Kivunja and Kuyini contend that in this paradigm, researchers choose methods, which they deem appropriate to study the behaviour of participants. Mackenzie and Knipe (2006: 2) contend that it is the choice of paradigm that directs the researcher's choices of the "methodology, methods, literature and research design." According to Mackenzie and Knipe (2006), a pragmatic paradigm takes into consideration the research problem and employs all the approaches that can be used to understand the problem. A pragmatic paradigm enables the use of mixed methods and argues that no single scientific method can access reality about the world through a positivist paradigm or an interpretive paradigm (Kivunja & Kuyini, 2017). This paradigm allows the research of a phenomenon that has different aspects, allowing these aspects to be measured using quantitative and qualitative methods (Fielzer, 2010). Hanson *et al.* (2005) claim that pragmatism focuses on different approaches that work best to construct knowledge about the situation being studied and values both objective and subjective knowledge. This study sought to quantitatively measure Physics teachers' PCK and qualitatively track and illustrate the use of this PCK in a classroom context. The study required the use of mixed methods, which is supported by the pragmatic paradigm.

3.3.2 Research approaches

This study involved mixed methods approach. Mixed methods are a combination of quantitative and qualitative research methods (Kivunja & Kuyini, 2017). Hanson *et al.* (2005: 226) assert that "mixed methods investigations may be used to obtain statistical quantitative data and results from a sample of a population and uses them to identify individuals who may expand on the results through qualitative data and results". The use of mixed methods may be helpful in cases where one set of data can be used to explain the other set of data or in cases where different approaches are needed to explore different types of research questions when one set of data is not enough to answer all the research questions (Creswell & Creswell, 2018). In this study, the quantitative data was

used to answer the first research question while the second research question was investigated through qualitative data.

3.3.2.1 Mixed methods

Mixed methods enabled the researcher to quantitatively measure the PCK of Physics teachers using a statistical PCK test, which yielded the numbers that could shed light on the teachers' PCK. This method also portrayed the use of PCK in classroom practice, which required qualitative descriptions of practice to shed light on how the teachers' knowledge is used in classroom settings. A mixed methods approach best suited this study as Lodico *et al.* (2006: 282) contend that a mixed methods approach "combines strengths of both quantitative and qualitative data, providing both an in-depth look at a context, process and interactions and precise measurement of attitude and outcomes". This allowed the researcher to use data collection methods which helped to understand the participants' PCK using numbers and descriptions of the participants' PCK in classroom contexts, so as to yield "the presentation of results [that] can be convincing and powerful when both summary numbers and portraits of the setting are included" (Lodico *et al.*, 2006: 282). Although mixed methods research has advantages such as being straight forward and giving opportunities to examine quantitative results in more depth, the method also has disadvantages such as engaging in data collection and analysis for a long time and also it is possible that the resources needed to collect and analyse the data may not be feasible (Ivankova, Creswell & Stick, 2006).

This study used mixed methods to address the research questions stated in section 3.2. While quantitative methods were used to measure the PCK of Physics teachers, the data collected only provided knowledge about teaching, but not about how this knowledge is used in actual teaching. To probe beneath the surface of this knowledge, a combination of both quantitative and qualitative methods were engaged for data collection. The PCK test survey was used to gain information on the overall PCK of Physics teachers while interviews and classroom observations were used to explain how this PCK was used in teachers' classroom practices.

3.3.3 Research design

The study involved an explanatory sequential design. An explanatory sequential design comprises two phases of data collection: quantitative data collected first and qualitative data collected afterwards (Hanson *et al.*, 2005; Lodico *et al.*, 2006; Creswell & Creswell, 2018). Creswell and Creswell (2018) indicate that in explanatory sequential design quantitative data is collected first and analysed, then the qualitative data is collected and analysed to explain the quantitative results in more detail. Data is collected in phases; phase one followed by phase two and that is why the design is referred to as sequential. According to Lodico *et al.* (2006:284), quantitative data is collected and analysed to investigate “outlier scores or extreme cases in more depth” and the qualitative data is used to exemplify or to broaden the explanation of these quantitative findings.

In this study the PCK test was first given to Physics teachers and then analysed to examine both the teachers with the highest PCK test scores and those with the lowest PCK test scores. The teachers with the highest PCK test scores and the lowest PCK test scores were chosen as case teachers to see how these teachers use their PCK in a classroom context and to see if PCK plays a certain role in classroom practice. By engaging the explanatory sequential design, the qualitative data enabled the researcher to create a deeper understanding of the classroom practices of teachers with extreme scores in the PCK test. Table 3.1 summarises the sequential mixed method engaged with in this study, adapted from McCrudden & McTigue (2019).

TABLE 3.1: A DISPLAY OF EXPLANATORY SEQUENTIAL STUDY DESIGN METHOD

Phase	Procedure	Product
Quantitative data collection	PCK test administered to Physics teachers.	PCK test scores.
Quantitative data analysis	Extended Rasch Model and SPSS	Wright Map Descriptive statistics
Purposeful sampling	Four case teachers purposely selected using extreme-case sampling.	Two PCK test participants with high PCK test scores and two with low PCK test scores
Qualitative data collection	Individual interviews (pre and post observation interviews). Video-recorded classroom observations.	Interview transcripts Video record transcripts
Qualitative Data analysis	Coding, development of sub-themes and themes.	Codes, categories and themes. Similarities and differences in themes and categories. CoRes and narratives.
Integration of the quantitative and qualitative results	Interpretation and explanation of the PCK test results and qualitative results.	Interpretation of results

3.3.3.1 Quantitative research methods: Survey

Cohen, Manion and Morrison (2018) define a survey as a descriptive research method that is used to explain and interpret the conditions focusing on either individuals, groups or institutions with the aim of describing, comparing or classifying events in a particular field of enquiry. The purpose of the survey that is part in this study was to examine the

PCK components that Physics teachers draw on to teach Physics excluding the classroom context. The PCK components examined were: assessment knowledge, content knowledge, pedagogical knowledge, knowledge of students and curricular knowledge. The examination of these PCK components was important because it was hoped that it would shed light on what Physics teachers know in general about teaching Physics without being influenced by classroom contexts.

A survey in the form of a paper-and-pencil test that yielded numerical data was used to gather data with the intention of describing the components of Lesotho Physics teachers' PCK, looking at the knowledge bases the teachers possess. Creswell and Hirose (2019) point out that a survey is carried out to describe the characteristics of the sample. In this study, the test scores of Physics teachers were used to describe their PCK.

3.3.3.2 Qualitative research methods: Multiple Case studies

The study followed a sequential explanatory design that involved case studies drawing a sample from a larger sample. In this study multiple case studies were engaged to compare the PCK of Physics teachers who had extreme scores in the PCK test, comparing the construction of their classroom practice with respect to the components of PCK they used. The selection of the teachers who made up the cases came from those teachers with the highest PCK test scores and the lowest PCK test scores. These were the teachers who depicted a boundary for this study and therefore created a case (Creswell, 2015). Multiple case studies refer to any studies that result in more than one case being studied. The manifestations of PCK components in classroom practices that were investigated could be considered as the effects of the PCK components developed in the minds of the chosen teachers (cases), portrayed in their actions observed in the classroom.

The multiple-case study approach was chosen because it helped to study the phenomenon in its context. It allowed multiple data sources so that the phenomenon could be studied in different ways so as to acquire knowledge about the different features of the phenomenon from different perspectives and to answer the “how” questions of the

study (Baxter & Jack, 2008: 545). This multiple-case study approach enabled the researcher to analyse data within the context of the participant and across different contexts. This approach helped the researcher to better understand the similarities and differences of the PCK components used by teachers with extreme scores in the PCK test. Although a multiple case study approach collects strong and reliable data, it is very expensive to conduct and also time consuming.

3.4 SAMPLING PROCEDURE

There were about 339 registered secondary schools in 2014 according to the Bureau of Statistics (2015) in Lesotho, but not all of these schools have a senior secondary level. This means that the number of senior secondary schools was expected to be less than 339. The research participants in this study were originally supposed to have been one hundred and eighty qualified Physics teachers, teaching the last two years of the senior secondary level and preparing students for the LGCSE certification. They all have a different number of years of experience in the teaching of Physics. This sample was expected to be representative of Physics teachers in Lesotho, teaching at different locations, with different qualifications, gender and experience. The one hundred and eighty teachers were to be given a PCK test to yield quantitative results. In the end the final sample for this study was 87 qualified Physics teachers because many teachers did not respond to the call to do the PCK test. The second sample was a sub-sample of these 87 teachers, which were four case teachers with PCK test scores at the extremes, two teachers with the highest scores and two teachers with the lowest scores.

3.5 SAMPLING STRATEGY

A mixed method sampling strategy was employed, where the units of analysis were selected through both non-probability of convenience and purposive sampling (Cohen *et al.*, 2018). Among the mixed method sampling strategies, this study used a sequential mixed method sampling, which involves the sequential use of non-probability convenience sampling, and purposive sampling strategies in which the quantitative data from the first non-probability convenient sample was used to draw the second purposive

sample. This study was carried out in all Lesotho districts. The country is characterised by poor roads, which restrict access to some of the schools in the country. Non-probability convenience sampling was used in this study because this is the sampling type that allows a researcher to focus on a certain group within the population that is easily accessible. In this study the group of focus was qualified Physics teachers who are teaching in schools that can easily be reached by car. This study sought to find the components of pedagogical content knowledge amongst Lesotho Physics teachers. Not all Lesotho Physics teachers were going to be engaged in this study but a large number with different years of experience, different levels of qualifications, teaching in well-resourced and poorly resourced schools, which are some characteristics of Lesotho Physics teachers.

Quantitative data from the first non-probability sample was used to draw the second extreme case purposive sample (Teddlie & Yu, 2007; Teddlie & Tashakkori, 2009). Purposive sampling was used in this study. The type of purposive sampling that was engaged with is extreme case sampling, in which the participants represent the extreme (Lodico, *et al.*, 2006; Creswell & Creswell, 2018). The researcher selected Physics teachers based on their extreme scores in the PCK test. Two teachers with the highest scores and two teachers with the lowest scores were selected to find out how the teachers with extreme scores manifest their PCK in the classroom. The third objective of this study was to explain the role of PCK in Lesotho Physics teachers' classroom practices for the relationship of PCK components and classroom practices construction to be better understood. The chosen extreme case sample was used to look for variations between teachers with high PCK test scores and teachers with low PCK test scores, this comparison could not be achieved by also involving teachers with average PCK test scores.

3.6 DATA COLLECTION

Data was collected in phases. In phase one, data was collected through the administration of the PCK test and in phase two data was collected through interviews and video recorded classroom observations. The first data collection took place between January and March 2020, but it was cut by the COVID-19 lockdown. The second data

collection took place in December 2020. The third data collection began in March 2021 until August 2021. The two different methods of data collection were engaged with to study how PCK was used in the construction of classroom practice. The complementary combination of the two data collection methods helped to capture PCK in-action and provided more insights into the investigation through data triangulation. The PCK test used in this study is discussed below and also how it was administered. The interviews and observations, other methods of data collection are also discussed. The multiple methods were engaged due to the tacit nature of PCK that makes it difficult to articulate what the teacher knows (Park, Suh & Seo, 2018). In this study, the PCK test was used to measure what the teacher knows in relation to the teaching of Physics and the interviews and classroom observations were used to articulate what the teacher does in relation to what they know. The study also involved visual method by capturing pictures of classroom practices.

3.6.3 The PCK test

The PCK measured by the PCK test in this study was domain specific PCK. Domain specific PCK is defined by Veal and Makinster (1999) as PCK at the level of the sub-discipline, in this study Physics, which is a sub-discipline of Science. This is PCK about teaching Physics in general, as a subject. The PCK measured by Kischner *et al.* was defined narrowly as knowledge about experiments, concepts and students' preconceptions. Although this PCK seems to be narrowly defined, the items represent different aspects of the teachers' professional knowledge base from the Consensus Model of Gess-Newsome (2015), which are said to be measurable (Liepertz & Borwoski, 2019). For instance, the knowledge about experiments entails the teachers' knowledge of content, pedagogy and assessment, as the teacher would be expected to have content knowledge for the experiment to be carried out, know the procedure and the sequencing of activities to help learners learn through an experiment and have knowledge of what and how to assess the knowledge gained by students. The knowledge about concepts is represented by content knowledge in the Consensus Model. Knowledge about students' preconceptions appears under the knowledge of students in the Consensus Model.

This PCK test measured what teachers know from their responses in the test. The PCK test was adapted from Kirschner *et al.* (2016). The PCK from Kirschner *et al.* was made up of seventeen items, testing the knowledge of students' understanding and the knowledge of instructional strategies as facets of PCK. Unlike the PCK test of Kirschner *et al.*, the PCK test in this study was developed using the Consensus Model of Gess-Newsome (2015) that includes these knowledge bases that are transformed to comprise teachers' PCK.

The PCK test items were adopted and adapted to assess the knowledge bases referred to as PCK components possessed by Physics teachers and builds their PCK. The Consensus Model has five knowledge bases, which guided the development of the PCK test items. The items were divided into categories of knowledge bases from the Consensus Model being: assessment Knowledge (AK), pedagogical knowledge (PK), content knowledge (CK), knowledge of students (KS) and curricular knowledge (CuK) (see appendix A for the PCK test instrument). Refer to appendix C for a description of the PCK test items, showing which were adopted and adapted. Out of the seventeen items in Kirschner *et al.*, the items that were not used in the PCK test were either not in the syllabus of LGCSE, like items about projectile motion, or a repetition of the same knowledge base category. Some of the items were adapted to suit the knowledge base being tested. The questions on curricular knowledge were adopted and adapted from Ergönenç, Neumann and Fischer (2014) and Neumann and Fischer (2018) because there were no questions related to this knowledge base in the items developed by Kirschner *et al.* (2016). Most of the items of the PCK test cover topics in mechanics, as these take a larger portion of the LGCSE Physics syllabus and some cover electricity, which is the second largest topic in the syllabus. The PCK test was restricted to a few topics in both mechanics and electricity to avoid a long test. The topics covered in mechanics were: velocity/speed, relationship between force, energy and power. In electricity, the topics covered were: series and parallel circuits and resistance.

The PCK test of Kirschner *et al.* (2016) developed the items to test teachers' knowledge of students' understanding and instructional strategies, but in this study the same items

were assigned to different knowledge bases. Kirschner *et al.* propound that PCK is the integration of different knowledge bases and that it has many facets, so one item that can be viewed to represent one knowledge base can also represent a different knowledge base.

The PCK test in this study was made up of twelve open-ended questions, where some items had sub-questions yielding fifteen questions, testing the knowledge of different PCK components. Looking at the large number of characteristics each of the five components of PCK has the test required a large number of items and this led to limiting the number of characteristics to include a small number of items for the following reasons, namely that it would take a long time to complete and this test was to be administered to in-service teachers who do not have the time due to their work commitments to complete long tests. Instead of limiting the PCK components, a few items per component were used and a large number of Physics teachers were engaged in this study. Open-ended questions were used to gather as much information as possible from the teachers without any restrictions, so that the teachers could communicate their PCK, which is considered to be tacit (Rollnick *et al.*, 2008), as the Physics teachers could then communicate this hidden knowledge in their responses.

The engagement of the open-ended questions of the PCK test resulted in a variety of responses and accommodated the different responses anticipated; a rubric was used to score the test. The rubric was developed by the researcher and gave the responses that were expected for the PCK test items. Some of the expected responses were taken from Kirschner *et al.* (2016). The rubric was given to a Physics teacher trainer to validate the responses. The rubric was developed such that it had a four-point scoring scale to depict different levels of PCK. The scale consisted of the following: 1 = undeveloped, 2 = limited, 3 = intermediate and 4 = developed. The rubric was developed such that it had expectations of responses, but was also open for some relevant responses that were not written down in these expectations. The expectations provided were to ensure agreement between raters of the PCK test (refer to appendix B).

3.6.3.1 Administering the PCK test

The PCK test was administered in ten districts of Lesotho as the research problem was to be examined across the country. The test was given to individual teachers to work on in their spare time since they were in-service teachers with commitments. The test was expected to take one hour thirty minutes, even though it was not guaranteed that all teachers would have finished the items by that time. Table 3.2 shows the distribution of PCK test and the number of the responses collected.

TABLE 3.2: PCK TEST DISTRIBUTION AND COLLECTION

District	Number of schools where PCK Test was distributed	Number of PCK tests given	Number of PCK tests collected
Botha-Bothe	10	21	4
Leribe	16	36	20
Berea	18	46	13
Maseru	32	68	27
Mafeteng	10	34	7
Mohale's Hoek	6	15	2
Quthing	5	19	5
Qachas' Nek	4	10	3
Mokhotlong	4	8	1
Thabatseka	4	8	6
Total	109	265	88

Table 3.2 shows the large number of teachers who agreed to participate in the PCK test and the smaller number of the responses collected from the teachers. The reasons for the decreased number of responses differ. This data was collected during the time of COVID-19 and in some schools the teachers could not respond to the test due to COVID-19 infection that led to absenteeism from school. In some cases the teachers complained that they found the test too demanding since it was not a yes or no type and so they declined participation. In other schools some of the teachers complained about their workload and said they could not squeeze in time to respond to the test. Some teachers were my ex-classmates from university and they said they felt like I wanted to test their knowledge to compare it with mine and they did not want to be judged, so most of them withdrew from the study even though the purpose of the study was communicated with them. In some schools the principal gave consent for the study to be carried out but later asked that teachers withdraw from participation in the research, citing that the teachers have lots of work to do.

3.6.4 Interviews

Interviews were used to find out how Physics teachers used the components of PCK in a classroom context. An interview is defined as a flexible tool for data collection that allows data to be collected through a conversation between the researcher and the participant, with a discussion that involved interpretation of the contexts in which the participant lives and how the participants regard their situation in their own opinion (Cohen *et al.*, 2018). Cohen *et al.* add that interviews engage multi-sensory channels for data collection such as verbal, non-verbal, spoken and heard; helping to construct meaning about the world in which the participants live. Opie (2019) contends that interviews should give participants the opportunity to communicate their ideas, feelings, insights, expectations and attitudes with great spontaneity and richness. As much as interviews are good for data collection because they enable the researcher to examine the concept studied in depth, Cohen *et al.* (2018) indicate that interviews can be prone to subjectivity and bias from the interviewer's side. Opie (2019) adds that interviews have complexities associated with them such as considerable interpersonal skills, structuring the interview schedule so as to avoid short unexpected answers and the context in which the interview

is carried out. Opie (2019: 175) suggests that when preparing the interview, the following key points should be considered:

- That you chose the appropriate venue, which offers a degree of privacy and assured non-interruption.
- Seating arrangement
- If you have not made the interviewee aware of questions to be asked, then make sure you give a briefing and explanation of the interview, i.e. its purpose, how the data will be used, how confidentiality will be maintained.
- Negotiate the method of recording well in advance, e.g. whether just notes, using a voice recorder or video.
- That you round up the interview with thanks, detail of future contact and how you will give feedback.

There are different types of interviews that can be engaged with in studies. Examples of interviews include unstructured interviews, structured interviews, and semi-structured interviews. In this study, semi-structured interview were used.

3.6.4.1 *Semi-structured interviews*

These are interviews in which the interview schedule is prepared but the interviewer has the freedom to expand the questions and probe the interviewee where clarity is needed (Lodico *et al.*, 2006; Opie, 2019). Opie maintains that semi-structured interviews are more flexible than structured interviews since they allow the wording and order of questions to be changed. Although large amounts of data can be gathered through semi-structured interviews due to the interview flexibility, Opie (2019) indicates that in this interview type drawing conclusions from the questions asked is not a straightforward job because researcher bias may sneak in and the interviewee may understand the question in a different way from how the researcher understands it.

In this study semi-structured interviews were conducted. Semi-structured interviews were chosen because they allowed probing to get more insight about the knowledge for teaching that the teacher has, on the topic the teacher is intending to teach. Interviews were used to access teachers' PCK through verbal communication. Gess-Newsome (2015) contends that PCK is the application of teachers' professional knowledge found in

their instructional plans. In this study, lesson plans were not involved as data sources but the study investigated knowledge used in planning through interview questions so as to allow the teacher to talk about the knowledge they used in planning and to access the reasoning beyond the plan for instruction that could not be accessed through the lesson plans. Lesson plans could not be used because they show the plan without stating reasons beyond the decisions. This study was looking for actions in teaching and to understand this better, the communicated version of the plan for teaching done through the interviews gave more data than the data that could have been accessed through lesson plans.

The interview questions were taken from the CoRe prompts, which were designed by Loughran *et al.* (2004). The following table adapted from Rollnick (2017) shows the adapted CoRe prompts and the relevant PCK components investigated per prompt.

TABLE 3.3: CORE PROMPTS AND RELEVANT PCK COMPONENTS

CoRe prompt	Relevant PCK component
Which topic or subtopic are you going to teach today?	Curricular knowledge
What are the main concepts you are going to teach today?	Curricular knowledge, content knowledge
Why do you think it is important for students to know these concepts?	Knowledge of students, curricular knowledge, knowledge of assessment
What else do you know about these concepts that you do not intend students to know yet?	Content knowledge, curricular knowledge, knowledge of students.
What are the difficulties connected with teaching these concepts?	Knowledge of content, knowledge of students
What knowledge can you share about students' thinking that influences your teaching of these concepts?	Knowledge of students
Are there any other factors that would influence your teaching of these concepts?	Pedagogical knowledge, knowledge of students

What teaching procedures would you employ?	Pedagogical knowledge
Why would you use these procedures?	Pedagogical knowledge, knowledge of students
What aspects of Science learning are you going to assess in this topic?	Knowledge of assessment
What methods would you use to assess students' understanding of this topic?	Knowledge of assessment.

These prompts were used to capture and portray the teachers' PCK, covering different PCK components that teachers draw from when constructing their classroom practices. The prompts were adapted to suit the Consensus Model of Gess-Newsome (2015) used in this study to examine teachers' PCK. Some of the questions were left unchanged while others were changed to accommodate the areas interrogated. The prompts were adapted to result in semi-structured interviews, so that teachers could be probed where more information was required; the interview schedule is attached as appendix D.

3.6.4.2 Conducting the interviews

The pre-observation interviews were conducted at schools before the teacher could go to class to teach the topic for the day and they were designed to last for about twenty minutes. The interview schedule was given to the teacher the previous day before the interviews took place to familiarise themselves with the kind of questions that would be asked and to help the teachers relax during the interviews. The interviews were conducted to access knowledge that is spoken. Nilsson and Karlsson (2019) involved student teachers in CoRe design before the teaching episodes in a study that was aimed at professional knowledge development. This was done to help students teachers become aware of issues around the content they were going to teach so that they could engage in pedagogical reasoning and discuss how to enact their teaching of a particular content. In this study, the CoRes were not designed by the teachers but by the researcher guided by the responses of the teachers per interview question. The interview schedule was also given to the teacher before the interview commenced so as to stimulate the teacher's thinking about the content he/she was going to teach and the issues connected

with teaching that content. This was done so that teachers could engage in more thinking about their practice to yield data that had been thought through and reflected the teacher's knowledge about teaching a particular concept. The interviews were conducted at the schools before each lesson observation, to discuss the content related to the lesson about to be observed.

The interviews were audio-recorded and then later transcribed. The interviews were audio-recorded to maintain natural language, to capture every word and the way the participant communicated; the sighs, the pauses, the change of tone to stress certain points, so as to understand teachers better and to keep the data for later re-analysis (Opie, 2019). There are disadvantages associated with tape-recording interviews argued by (Opie, 2019) such as collecting too much data that may be irrelevant and is time consuming to transcribe.

3.6.5 Classroom Observations

Classroom observations were made to collect data, where the classroom was observed with the researcher being a non-participant observer, which means being in the classroom but not taking part in classroom activities (Lodico *et al.*, 2006). According to Lodico *et al.*, careful observation should include a description of the physical setting of the classroom, the activities taking place in the classroom, individual and group activities and interactions. The activities of the teachers were of interest in this study since it was through these activities that the PCK components were studied in a classroom setting, observing how teachers use their knowledge when confronted with issues arising in the classroom. Gess-Newsome (2015) argues that what the teacher does in the process of teaching is informed by the teachers' PCK, to carry out what has been planned for instruction but the plan may change during instruction to respond to students' needs. Since this study was aimed at investigating how the components of PCK are used in classroom practice, classroom observation helped the researcher to capture the moments when these PCK components were used to respond to the needs arising in the classroom, those that could not be accessed through an interview.

Classroom observations were video recorded. Opie (2019) contends that video recording helps researchers to make sense of captured non-verbal activities, but video recording also brings technical problems such as: setting up the equipment, ensuring good sound quality and also that the participants may change their behaviour due to the presence of the camera. Classroom observations are good for collecting first hand data and they require the researcher to spend more time observing to reduce a change in behaviour by the participants owing to the presence of the observer (Cohen *et al.*, 2018). More than one lesson was observed to minimise change in behaviour due to the observer presence and this was also done to collect more data. Loughran *et al.* (2004) contend that PCK needs to be captured in a number of lessons, as it may not yield enough data about the PCK of the teacher when observed through one teaching experience, since PCK unfolds in an extended period of studying the classroom context and interactions. This can be time consuming. Although the researcher was aware of the importance of prolonged classroom visitations for the collection of quality of data, the study took place in the time of COVID-19 restrictions. In some schools, the access was limited to only a few visits to protect learners and teachers from possible COVID-19 infection that could be brought in by visitors. The restrictions reduced the number of classroom observations to only a permitted number per school. Table 3.4 shows the number of observations per case teacher.

TABLE 3.4: CLASSROOM OBSERVATIONS PER TEACHER

<i>Teacher</i>	<i>Number of classroom observations</i>
<i>Jay</i>	2
<i>Gift</i>	3
<i>Jimmy</i>	2
<i>Joy</i>	3

Cohen *et al.* (2018) contend that observations are essential in the data collection process as they yield data occurring in the natural setting of the participant, giving the researcher first-hand information that is more authentic than relying on secondary data from other

methods of data collection. In this study, it was not enough for teachers to talk about their classroom practice and how they use their knowledge to teach effectively, but it was also necessary to see practice in the context of the teacher, to identify unspoken activities that illustrated their knowledge of teaching. This study focused on the components of PCK of Physics teachers and how these components were used to construct classroom practices of these teachers. Observations were necessary in this study to see the actions of the teacher in their classroom context, to see these components of PCK in action, to identify the knowledge that could be missed in an interview and the PCK test and to have access to a personal knowledge of the teacher as exhibited in practice (Cohen *et al.*, 2018).

3.6.6 Post Observation interviews

The type of post-observation interview that was used in this study is a video stimulated recall interview. Nguyen, McFadden, Tangen and Beutel (2013) define a video stimulated recall interview as a research technique that involves the participants in watching episodes of their own actions in a particular event and then they are requested to reflect on their actions recorded in the video. Before the post-observation interviews, the researcher watched the video records per observed lesson several times to capture episodes of interest that needed more clarification about the teachers' actions in the classroom. The episodes of interest were then watched with the case teacher. As the video played, the case teacher and the researcher watched. The case teacher was allowed to request a pause when they wanted to comment about their actions or to question their actions in the classroom. The post observation interviews were conducted while watching the episodes of interest where questions, which were not scheduled, were used to gather more data from the explanations or comments given by the teachers about their practices. This method was used to elucidate more information from there flections of the teachers' actions in the classroom. Studies, which successfully used this technique in education, include Malva, Leijen and Arcidiacono (2021) and Oztay and Boz (2022). This study also

successfully used this technique and the case teachers were able to give reasons for their actions, question their practice, identify their shortfalls and suggest things they would improve if they were to teach their lessons again.

3. 7 DATA ANALYSIS

3.7.1 Analysis of quantitative data

The analysis of the PCK test started with the marking of the test by the researcher using a rubric. The rubric was developed such that it had a four-point scoring scale to depict different levels of PCK from the responses. To reiterate, the rubric scale consisted of four levels of PCK: 1 = undeveloped, 2 = limited, 3 = intermediate and 4 = developed. The lowest level for the PCK test was awarded one point. The highest level was awarded four points. Two raters, the researcher and another, rated the PCK test. Two raters scored the PCK test because some responses were long sentences in which the meaning of the words might be differently interpreted by the researcher. This called for the need of another rater to give a score for the test to increase reliability.

The involvement of another rater in the rating process required expert judgement to be observed in this study. Expert judgement is defined by Escobar-Pérez and Cuervo-Martínez (2008) as an engagement of ‘knowledgeable others’ to give an opinion or to take part in assessment of a subject. Such experts are selected based on their experience in the subject and are qualified in the area of judgement. In this study, the following steps, as proposed by Escobar-Pérez and Cuervo-Martínez (2008) were followed in the process of getting expert judgement: the other rater was selected as someone who could be involved in this study for the following reasons:

(a) The expert had been a secondary school Physics teacher for more than ten years, had been a Physics teacher trainer at the college for more than ten years, had been a Physical science marker and a senior team leader at the Examination Council of Lesotho for more than ten years; implying she is conversant with assessment standards and the confidentiality required in assessment.

(b) I discussed the objectives of my study and the objectives of the PCK test with the expert. Our discussion included looking at each PCK test item and clarifying what it was

intended to test. The PCK test rubric was also discussed to verify that the responses proposed by the researcher were in line with what the items were testing.

(c) The Physics teacher trainer and the researcher rated the responses of the PCK test and agreement between the two raters was calculated as discussed in the following paragraphs.

The inter-rater agreement was calculated using [the irr package for R](#) version 0.84.1. (Gamer *et al.*, 2019). McHugh (2012) refers to inter-rater reliability as the measurement of the similarity of the scores assigned by data raters to the same variable. In this study the variable was the teachers' responses to the items of the PCK test. The inter-rater reliability assessment is essential as a way of quantifying the degree of agreement when two or more independent raters are involved in making independent ratings about the characteristics of a set of subjects (Hallgren, 2012). In addition, the inter-rater reliability entails the degree of agreement between two or more raters or the degree of consistency between the raters and it is expressed as a number between 0 and 1 where 0 indicates no agreement and 1 shows perfect agreement (ten Hove, Jorgensen & van de Ark, 2017).

The data reported in this study is the PCK of Physics teachers and therefore needs to minimise subjectivity by engaging a second rater. Inter-rater reliability was considered important as it reported the degree of agreement between the raters. McHugh (2012) emphasises the need for the training of the raters before they are engaged in rating the responses. In this study, this was met as the instrument for data collection had been discussed with the second rater; a Physics teacher trainer, as the rater also helped with validating the instrument. This implies that there was a shared understanding of the items in the PCK test. The rubric used for scoring was constructed by the researcher and discussed with the second rater so as to agree on what to look for in the responses. Although the two raters discussed the PCK test items and the responses expected, there were cases of disagreement on the scores allocated. In such cases the two raters discussed the reasons behind the scores allocated. In some cases, the two raters agreed to allocate the same score, but in other cases where there was disagreement the scores were left unchanged.

According to ten Hove, Jorgensen and van de Ark (2017) there are various coefficients that can be used to calculate inter-rater reliability and this makes the justification for why a certain coefficient was used to be difficult. The inter-rater liability is calculated using Cohen's Kappa; the Kappa is a form of correlation coefficient that ranges from -1 to 1. The negative values indicate no agreement at all; zero also shows no agreement while 1 represents perfect agreement (McHugh, 2012). Table 3.5 shows the interpretation of Cohen's Kappa. de Ruiter and Smid (2007) argue that Cohen's Kappa is equivalent to the coefficient *iota*. This implies that interpretation of the values of the two coefficients is similar. Coefficient *iota* is defined as a chance corrected reliability for multivariate data (de Ruiter & Smid, 2007). Coefficient *iota* was used to report the inter-rater reliability for this study.

TABLE 3.5: INTERPRETATION OF COHEN'S KAPPA

Value of Kappa	Level of agreement	% of data that are reliable
0 – 0.20	none	0 - 4
0.21 – 0.39	minimal	4 -15
0.40 – 0.59	weak	15 - 35
0.6 – 0.79	moderate	35 - 63
0.80 – 0.90	strong	64 - 81
Above 0.90	Almost perfect	82 - 100

3.7.1.1 PCK components inter-rater agreement

The PCK test was composed of five components which were categorised as: AK, PK, CK, KS and CuK and these categories had a different number of questions. The presentation of the inter-rater agreement for the two raters is shown in Table 3.6.

TABLE 3.6 INTER-RATER AGREEMENT

Item	Category	Percentage Agreement	Kappa
Q1	AK	88.5	0.9
Q2b	AK	83.9	0.8
Q3	PK	92.0	0.9
Q4	PK	97.7	1.0
Q5a	CK	96.6	1.0
Q6	CK	95.4	1.0
Q7a	CK	100.0	1.0
Q2a	KS	97.7	1.0
Q5b	KS	94.3	0.9
Q7b	KS	87.4	0.9

Q8	KS	94.3	1.0
Q9	KS	92.0	0.9
Q10	KS	95.4	1.0
Q11	CuK	95.4	1.0
Q12	CuK	94.3	0.9

iota for quantitative data (15 variables)

Subjects = 87

Raters = 2

iota = 0.967

Table 3.6 shows the inter-rater agreement for the 2 raters who rated the PCK test. Each item of the PCK was assigned a category in which it belonged. A category in this study is a PCK component which is also referred to as a knowledge base. The inter-rater agreement was calculated per item and then the overall agreement was found. The Kappa value was found to be 0.967. This suggests that the agreement was almost perfect, which suggests that the raters rated most of the items similarly (McHugh, 2012). This high level of agreement suggests minimal error introduced by the two independent raters and therefore the statistical power for succeeding in the analyses is not significantly affected. Kivunja and Kuyini (2017) suggest that the instrument should be constructed in such a way that it produces consistent results over time, so as to ensure reliability the PCK test was rated by two raters, the researcher and one Physics teacher trainer.

3.7.1.2 Extended Rasch Model

The scores obtained from the PCK test were analysed using the Extended Rasch Model. The points to be considered when administering Rasch analysis are outlined as ensuring that the instrument has been constructed considering the theory encompassing the construct being studied and that there should be items of the construct ranging from low to high levels. According to Boone and Noltemeyer (2017), the Rasch measurement model is guided by the following mathematical assumptions: when measuring a single trait, easy items are more likely to be answered than difficult items and that people with high ability are more likely to answer all items correctly than people with low ability. For

data types such as tests and rating scale surveys the Extended Rasch Model is engaged (Boone & Noltemeyer, 2017). The Rasch model is aligned with the idea of objective measurement. Boone and Noltemeyer (2017) assert that Rasch measurement is associated with an objective measurement, since it uses a common metric to express results irrespective of the construct being measured and the instrument being used. With the use of Rasch measurement, Boone and Noltemeyer (2017) argue that it is easier to confidently inform decisions, since the measures are expressed on an equal interval scale.

There are a variety of ways in which the Rasch measurement model has been used. Boone and Noltemeyer (2017) outline examples such as to develop, evaluate and improve surveys and tests, to enable the calculation of Rasch measures that direct data analysis and interpretation of greater confidence, since the Rasch measurement model uses equal interval data. Boone and Noltemeyer (2017) point out the advantage of using the Rasch measurement model as the possibility of the Rasch techniques allowing both person measures and the item measures to be expressed on a logit scale.

3.7.1.3 Importance of Rasch Model analysis

Rasch Model analysis has proved to be of great importance for this study that has focused on a comparison between teachers with a high level of PCK and those with a low level, since this type of analysis allows a comparison between PCK test respondents where the person measures were described using PCK test instrument items (Boone & Noltemeyer, 2017). Boone and Noltemeyer (2017) add that the Rasch technique is suitable for a small sample, since it provides reliable measures for a smaller number of items that the study has targeted. This was important to consider in this study since the instrument was constructed with just a small number of items in a small sample. The Rasch approach can enlighten researchers to target intervention or instruction because the anticipated performance of a test taker in an item can be inferred from each person's ability measure and the difficulty of the items that are illustrated on the same scale (Boone & Noltemeyer, 2017). This enables effective decisions about the next skill to teach a person or to help that person develop.

3.7.1.4 Fit assessment in Rasch Model

The Rasch Model considers ‘assessment of fit’, to work out how well the data obeys the Rasch Model (Boone & Noltemeyer, 2017). The ‘fit’ statistics determine the items or persons who may not be the best to keep for use in the instrument. When there is evidence of ‘misfitting’ items or persons, the causes of deviation from the Rasch Model should be considered and the ‘misfitting’ items or persons may or may not be removed. For data that deviates a lot from the Rasch model, Boone and Noltemeyer (2017) point out that these cases of deviation should be taken into account. The ‘misfitting’ item or person may or may not be removed depending on the causes of ‘misfit’, which may be several and need to be dealt with during the analysis. This analysis is deemed important, as it provides insight as to whether the items of an instrument involve a single trait and whether the responses of the respondents lead to confident computation and communication of person measures along one trait. Boone and Noltemeyer (2017) assert that the ‘infit’ and ‘outfit’ are used as statistics in ‘fit’ assessment and these are reported in two forms: mean squared (MNSQ) and z-standardized (ZSTD). MNSQ is sample independent while ZSTD is sample dependent. The acceptable values for outfit MNSQ are less than 1.4 for rating scale data and the misfitting values would be greater than 1.4 but Smith *et al.* (2008) argue that most of studies consider a range of 0.7 to 1.3. According Boone & Noltemeyer (2017) there are several causes for misfitting items or persons, but all the causes can be addressed in several ways failing which leads to the removal of such a person or item from the data and this leads to a new analysis. Smith *et al.* (2008) show that the infit and outfit MNSQ can be converted to t-statistics which are evaluated against +2 and -2, where values above +2 are interpreted as showing more variation than predicted.

3.7.1.5 Fit analysis of the Items and persons

It is important to evaluate how well the data fits in the Rasch Model (Boone & Noltemeyer, 2017; Planinic *et al.*, 2019). Although The PCK instrument used had items adapted and adopted from Kirschner *et al.* (2016, 2014) and Ergönenç, Neumann and Fischer (2018), it was quite important to illustrate how well both the items and the participants fit the Rasch

Model for the purposes of improvement of the instrument, for the future use and validity. The item fit statistics are demonstrated in Table 3.7 below.

TABLE 3.7: ITEM FIT STATISTICS

Item	OutfitMNSQ	infitMNSQ	Outfit t	Infit t
Q1	1.249	1.226	1.897	1.856
Q2a	0.618	0.594	-2.968	-3.718
Q2b	0.834	0.840	-1.410	-1.449
Q3	0.689	0.747	-1.808	-1.679
Q4	0.808	0.758	-1.663	-2.290
Q5a	1.001	1.030	0.051	0.290
Q5b	0.961	0.963	-0.245	-0.268
Q6	1.181	1.283	1.140	1.990
Q7a	2.203	2.035	6.037	6.235
Q7b	0.578	0.596	-3.677	-3.931
Q8	0.843	0.886	-1.183	-0.943
Q9	0.991	1.034	-0.017	0.317
Q10	0.624	0.607	-3.296	-3.862

Q11	0.865	0.833	-0.946	-1.382
Q12	1.124	1.144	0.795	1.028

The numbers in bold indicate misfitting items.

The analysis shows the overfitting items $MNSQ < 0.7$ or $t < -2$ to be Q2a, Q7b and Q10 while the underfitting item $MNSQ > 1.3$ or $t > 2$ is Q7a in bold. The misfitting items are 27% of the PCK test, which makes the test still valid since these items could not be removed from the analysis, as Boone and Noltemeyer (2017) argue that for data that deviates greatly from the Rasch Model, the cases of deviation should be taken into account and that the misfitting item or person may or may not be removed depending on the causes of misfit which may be several and dealt with during the analysis. Planinic *et al.* (2019) contend that the values of infit and outfit MNSQ between 0.5 and 1.5 can still be regarded as productive in measurement. This makes all the bold items fitting the Rasch model except item Q7 but the model did not exclude it from analysis. Although these items could not be removed during the analysis, there might be calls for revisiting them should this instrument be used again. Since the causes of misfit were dealt with during the analysis, as the Rasch model did not exclude these items, the PCK test items are considered to be measuring a single trait and leading to confident computation and communication of measures along a single trait. Table 3.8 illustrates the person fit statistics.

TABLE 3.8: PERSON FIT STATISTICS EXAMPLE

Person	OutfitMNSQ	InfitMNSQ	Infit t	Outfit t
1	1.082	1.120	0.37	0.53
2	1.135	1.281	0.45	0.83
3	0.955	0.969	-0.05	-0.01
4	1.787	1.531	1.66	1.33
5	1.574	1.316	1.31	0.88
6	0.939	0.919	-0.07	-0.15
7	0.798	0.807	-0.48	-0.57
8	2.098	1.990	1.91	1.98
9	1.339	1.081	0.93	0.35

10	1.080	1.061	0.37	0.32
11	1.267	1.211	0.95	0.80
50	0.241	0.223	-3.28	-3.57

The numbers in bold illustrate misfitting persons.

The table for person-fit statistics could not be wholly included because it shows the person fit for 87 participants which is a very long table. An example has been given in Table 3.7. The cases of overfitting persons with $MNSQ < 0.7$ are 21, which is 24% of the sample or with $t < -2$, which are 4 persons, which is 5%. The underfitting persons whose $MNSQ > 1.3$ are 6 persons which is about 7% or with $t > 2$, 3 persons, which is 3% of the sample. In this case, there are differences in recording fit for MNSQ and t-statistics with MNSQ recorded more misfitting items outside the range of (0.7-1.3) than the t-statistics. This might be due to the small sample size as Smith *et al.* (2008) argue that t-statistics are sample size dependent. In a similar manner with item-fit statistics, the misfitting persons were included in data analysis since the issues of misfit were resolved during data analysis, but one participant was excluded from the data set from the start. This respondent was a clear outlier whose inclusion would distort the results in an influential way, taking the focus off the nuance in the bulk of the data. The respondent had responded to only two items and left the rest unanswered causing a similar pattern of responses that led to a similar score in unanswered items. This resulted in a total of 87 participants whose data were included in this analysis.

3.7.1.6 The Wright Map

The Wright map presents the person-item measures and it is sometimes referred to as the person-item map (Boone & Noltemeyer, 2017). The Wright map assesses how well the instrument functions. The map illustrates person-item relationships displayed on equal logit scale. The person measures are presented in logits, which can be positive or negative. The more positive logits represent a more able person and the more negative logits represent a less able person. The item measures are also reported in logits. The more positive items are deemed to be more difficult and the more negative items are less

challenging. Boone and Noltemeyer (2017: 8) illustrate the importance of the Wright map: "... to assess an instrument's strengths and weaknesses, document the hierarchy of items, compare theory to the observed data, and provide clinical guidance to practitioners." According to Boone and Noltemeyer (2017) the Wright map displays the different levels of difficulty of the items, which makes it possible to assess whether the instrument assesses the same levels of difficulty. It is expected that the levels of difficulty were well spread through the construct. Some items may not match the theoretical construct and they may be located along the trait. Once this happens the causes should be established and this may lead to a need to collect more data or to remove the item to indicate that the item did not measure the trait. In this study, the Wright map was used to portray the levels of difficulty of the PCK test items, to give insights on the items that participants found difficult or easy. The map differentiates participants according to their ability, helping to identify participants with high or low scores for the test.

3.7.2 Descriptive statistics of the PCK test

The responses to the PCK test were marked and awarded numerical points according to the rubric that had a four-point Likert scale showing undeveloped, limited, intermediate and developed for the PCK test items. The item responses were each awarded a number 1 to 4 respectively in order to calculate the mean. The mean was calculated using SPSS. During data analysis, the means were used to state the level of PCK of the participants and per PCK component and to rank the PCK components according to the level of development. For a four point Likert scale Pimentel and Pimentel (2019) advise that a more uniform interval should be used to assign the mean values at a suitable level. A more uniform interval scale is suggested as follows: 1(1.00-1.75), 2(1.76 – 2.51), 3(2.52- 3.27) and 4(3.28-4.00). In this rating interval scale, the scale has a uniform difference of 0.75, the exception is for the last interval where the difference it is 0.72. Compared to other intervals that researchers assume in assigning means to different levels of the Likert scales, this is considered the most uniform.

3.7.3 Analysis of qualitative data

Lodico *et al.* (2006:301-302) assert that analysing qualitative data follows the following steps, not necessarily in a linear order:

1. Preparing and organizing the data
2. Reviewing and exploring the data
3. Coding data into categories
4. Constructing descriptions of people, places, and activities
5. Building themes and testing hypotheses
6. Reporting and interpreting data

Audio-recorded interviews were transcribed, where the exact words of the interviewees were written down, their nonverbal actions such as their sighs, pauses, emotions expressed through their tones and interruptions were also recorded (Lodico *et al.*, 2006). The interviews were qualitatively analysed and used to construct the CoRe and narratives for the case teachers to illustrate Physics teachers' PCK in classroom practice as developed by Loughran *et al.* (2004). Loughran *et al.* (2004) have developed a tool to capture, articulate and document professional knowledge in practice by detecting PCK in different areas of teaching such as laboratory work, demonstrations and other work by the teachers. As has been mentioned, an interview schedule was composed using prompts from the adapted CoRe developed by Loughran *et al.* (2004). This tool documented professional practice knowledge through discussion with teachers about their teaching and classroom observations. The CoRe was used to access Physics teachers' knowledge and to characterise their knowledge in practice. In this study the CoRe was used to tap into what the teacher knew about the content they were teaching with respect to the knowledge of: (a) the main concepts of the topic, (b) the importance of teaching the topic to students at a particular level of learning, (c) the teachers' deeper knowledge of the content that cannot be taught at the particular level of the students, (d) the difficulties around the concept being taught, (e) knowledge about students' thinking that could influence the teaching of the particular concept, (f) knowledge of other factors which could influence teaching, (g) knowledge of teaching procedures, (h) reasons for

choosing the particular teaching procedures to teach the concept, (i) knowledge of Science aspects needed to assess the topic and (j) methods used to assess students' understanding of the concept. As Loughran *et al.* (2004) indicated, the CoRe helped the researcher to codify the knowledge of content in a common way concerning how teachers characterise the content they were teaching in their classroom.

The rich narratives of the teachers' classroom practice associated with the content under consideration in the CoRe were also involved in this study. The narratives were used to shed more light on the professional knowledge in practice. The narratives were informed by the interviews, classroom observations and post observation interviews. They brought into life what was done in the classroom, considering teachers' actions, students' actions and voices, the response of the teacher towards different classroom experiences and the reasons for the teacher responding in a certain manner to different classroom activities. A diversity of narratives of four case teachers was documented to show the PCK of the teacher in action. CoRes and narratives helped to categorise knowledge of the teacher in action, to better understand the professional knowledge and the aspects of PCK for the teacher in their classroom practice and to make the unspoken knowledge of teachers explicit. The videos of classroom observations were transcribed picking the activities that depicted the use of knowledge bases in the classroom context and the video excerpts that were used to demonstrate examples of classroom activities showing the teachers' knowledge bases in practice. The transcripts of the video recordings were also used to construct CoRes when unspoken PCK was manifested in classroom practice.

3.7.4 Integrating quantitative and qualitative data

According to Terrell (2012: 263), a sequential explanatory method follows the following pattern of data collection and analysis:





Integration means connecting the quantitative and qualitative data together (Ivankova *et al.*, 2006). The integration in this study happened during the interpretation of the data (Terrell, 2012). Data were mixed to further explain the results of the quantitative study and to answer the research questions in full, looking at the outcomes of both the quantitative and qualitative studies, as Terrell (2012) argues that the focus in explanatory sequential design is to explain the results of the quantitative study by looking at the results of the qualitative study in more depth.

3.7 THE PILOT STUDY

Majid *et al.* (2017) point out the importance of piloting the study to prepare for the main study. The preparation is done in terms of modification of the instruments when the need arises. This study used a PCK test in the form of a questionnaire, an interview schedule and video recorded classroom observations to collect data. The questionnaire and the interview schedule were both piloted. The video camera that was used in this study had already been used to capture video records of the researcher teaching to test whether the voices would be audible and classroom actions visible. The purpose of piloting the research instruments was mainly pre-testing the instruments to find out if the instruments would yield the appropriate data (Malmqvist *et al.*, 2019).

The questionnaire was piloted with 12 qualified Physics teachers teaching grade 11 and grade 12, which were the qualities of the sample for this study. The pilot study respondents were excluded from the main study. The pilot was made to find out if there would be enough space for responses in the questionnaire, whether the wording of the questions was understandable for the respondents and to address any other challenges that might be communicated by the respondents. Some of the wording of the items was changed after the pilot study. An example of wording that was changed is provided below.

Before the pilot

Category A: Assessment knowledge

1. Imagine you are teaching a lab and students report their results graphically in a diagram using smoothing functions. Please provide a list of general criteria you would use to score students presentation of their results.

Criteria for scoring students presentation of graphical results ...
--

After the pilot

Question 1
Imagine you are teaching speed-time graph in a lab and students report their results graphically in a diagram using smoothing functions. Write at least three points of the general criteria you would use to score students presentation of their results.
Criteria for scoring students presentation of graphical results ...

After noticing that question 1 was not clear enough for some respondents, the wording of the question was modified to be more specific about the concept to be tested in the laboratory, rather than being general where the teacher would not know what to look for. The pilot was also conducted to include some of the expected responses, which the researcher could have left out in the rubric for scoring the PCK test.

For the pilot study the interview schedule was given to two physics teachers who had responded to the questionnaire. The interview schedule was also piloted to test whether the questions would yield appropriate data for the main study and to train the researcher to engage in probing questions so as to elicit more data from the participants, also to help the researcher develop skills that would make the participants feel comfortable in during the interview. These skills included being humble, flexible and learning to listen without interfering while the participants responded (Malmqvist *et al.*, 2019).

3.8 VALIDITY AND RELIABILITY

To reiterate, the PCK test instrument that was used in this study had questions adopted and adapted from Kirschner *et al.* (2016), Ergöner, Neumann and Fischer (2014) and Ergöner, Neumann and Fischer (2018). Refer to appendix C to see which questions were adopted and adapted. Sürücü and Maslakçı (2020) assert that when an instrument has been adapted to suit the characteristics of a new sample that it is going to be administered to, such as changing the wording, it is not necessary to develop a new scale but content validity and construct validity need to be ensured. Sürücü and Maslakçı (2020) define validity as a measure of how well an instrument measures what it is intended to measure. The validity that was tested in this study was the validity of the PCK test and the interview schedule. The following discussion illustrates how validity has been ensured in this study.

3.9.1 Content validity, expert judgment and construct validity

Sürücü and Maslakçı (2020) define content validity as a form of validity that evaluates whether each item comprising the test instrument served to test what was intended. The adapted items in the PCK test instrument needed to be validated by an expert. To reiterate, expert judgment is defined by Escobar-Pérez and Cuervo-Martínez (2008) as the engagement of knowledgeable others to give an opinion or to take part in assessment. Experts are selected based on their experience in the particular subject in question and are qualified in the area of judgment. In this study, two experts rated the PCK test and steps for expert selection proposed by Escobar-Pérez and Cuervo-Martínez (2008) were followed in the process of achieving expert judgment. Inter-rater reliability was calculated to be 0.967, being the agreement between the two raters.

Construct validity is the degree of how well an instrument “measures the concept, behaviour, idea or quality-that is the theoretical construct which it purports to measure” (Sürücü & Maslakçı, 2020: 2700). Construct validity was ensured by engaging the

Extended Rasch Model to provide validity indices through item and person-fit inferential statistics. Noltemeyer (2017) indicates that the use of the Rasch Model suggests whether the instrument measures a single trait and differentiates items in order of difficulty and well as participants according to their ability. The Extended Rasch model was used in this study to provide item and person-fit statistics that could determine which items to include or exclude from the instrument. After the item-fit analysis, none of the items were removed from the instrument, indicating that the instrument used was valid.

3.9.2 Legitimation

This study is a mixed methods research in which validity is referred to as legitimation. Legitimation encompasses credibility, dependability, plausibility, conformability, transferability and the trustworthiness of the results (Cohen *et al.*, 2018). Kivunja and Kuyini (2017:34) argue that the “findings of the study [should] align with reality as constructed by the researcher and the participants to guarantee credibility”. Credibility in this study was ascertained through member checking, by confirming the interpretations of interview transcripts with teachers in the case study so as to verify that data were authentic and trustworthy and by watching video episodes of interest together with the teacher, asking questions to verify that the classroom actions were what the teacher was aware of during their teaching of Physics (Baxter & Jack, 2008). Baxter and Jack argue that this enables the participants to discuss issues under study, explain more by giving the researcher more depth to the situation researched and contributing new understanding of different angles. Credibility was also ensured by providing evidence from data in the form of excerpts from interviews and pictures from classroom observations to provide legitimacy for and trustworthiness of the results. Using different data sources such as interviews and video recorded classroom observations ensured triangulation.

3.10 RESEARCH ETHICS

Erickson (2012) argues that researchers should predict what should be done when collecting data, analysing data and reporting in order to communicate with participants

about the ways they are going to be engaged with and why the methods used to collect data are chosen above others. Erickson further claims that the participants should be fully informed about how the study will be conducted and they should be allowed to talk about how the way chosen would be convenient for them and how safe they feel about the way the study is to be conducted, so that participants give their consent after being well informed.

The ethics clearance was applied for from the University of the Free State. The application was approved with ethical clearance number: UFS-HSD2019/1243, attached as appendix E. A letter seeking permission to conduct the study was sent to the CEO of secondary schools of the Ministry of Education and Training seeking permission to conduct the study in all ten districts of Lesotho and the permission was granted, refer to appendix F. Permission was also sought from the principals of the participating schools, see appendix G for principal consent letter. One aspect of ethical issues is to clarify how the participants would be treated in the study, considering the issues of informed consent, ensuring confidentiality, anonymity and addressing the question of respect (William, 2010). To address these issues, informed consent forms were filled out by the Physics teachers, showing the purpose of the study, stating that participation is voluntary and informing participants that they have the right to withdraw at any time and that the information given by the teachers would be kept confidential, attached as appendix H. The informed consent showing no obligation to participate in the study minimises the risk of social destruction and shows that the researcher respects the participants (Erickson, 2012). The faces of students were not used in any writing or report of the study. Similarly, no names of schools or participants were used in the reports and pseudonyms were generated.

3.11 CONCLUSION

This chapter articulated the methodology of this study. This sequential explanatory mixed method study was carried out with quantitative and qualitative methods for data collection. For the quantitative part, participants were selected through non-probability convenience sampling in schools in the ten districts of Lesotho while the qualitative sample was

purposely selected, by selecting the two teachers with highest scores on the PCK test and the two with the lowest PCK test scores. The quantitative data was analysed through the Extended Rasch Model and SPSS while the qualitative part was analysed through narratives and documentation of PCK through CoRes. Validity and reliability were discussed as well as ethical considerations. The next chapter presents the results of this study.

CHAPTER 4: ANALYSIS OF THE PCK COMPONENTS AND PHYSICS TEACHERS' CLASSROOM PRACTICES

4.1 INTRODUCTION

The aim of this study is to identify the PCK components that Physics teachers draw on to construct their classroom practices and to examine how classroom practices are constructed with respect to the PCK components that teachers possess. This study involved a mixed method approach, in which it is believed that there is no single way of knowing and truth can be accessed by involving more than one scientific method. It is in this regard that this chapter presents both quantitative and qualitative data. The results presented here have two sections. The first section is a representation of the quantitative part, which gives an account of the PCK test scores of all participants in the study; while the second section is the qualitative part that focuses on the four teacher case studies.

The data source for the quantitative part is the PCK test, whereas the qualitative section is informed by data from pre-observation interviews, classroom observations and post-observation interviews.

Although it has already been illustrated in chapter 2 that different researchers visualise PCK as having different components, the PCK components in this study are referred to as knowledge bases in the Consensus Model of PCK (Gess-Newsome, 2015). The PCK components that Physics teachers possess are examined in section 4.2 of this chapter, while section 4.3 looks at a qualitative analysis of the Physics teachers' classroom practices. Section 4.4 then examines the role of Physics teachers' PCK in their classroom practices.

4.2 ANALYSIS OF PCK COMPONENTS THAT PHYSICS TEACHERS POSSESS: QUANTITATIVE ANALYSIS

This section provides the answer to the research question:

What components of PCK do Physics teachers use to teach Physics?

To respond to this research question, a PCK test was administered to 265 teachers but only 88 teachers responded to this test. This shows a response rate of 33%. The reasons for a low response rate included absenteeism and heavy workload (see **section 3.6.1.1**). Among the 88, one respondent was excluded from the data set from the start. This respondent was a clear outlier whose inclusion would distort the results in an influential way, taking the focus off the nuance in the bulk of the data. The respondent had answered only two items and left the rest unanswered causing a similar pattern of responses, which led to a similar score in the unanswered items. This resulted in a total of 87 participants whose data were included in this analysis.

The PCK test analysis is presented in this chapter to illustrate the PCK components which the teachers possess to teach Physics.

4.2.1 Description of PCK test Participants

The PCK test responses were collected from 88 Physics teachers but one participant had to be excluded for being an outlier as mentioned previously. The participants were from all the ten districts of Lesotho. Refer to **Table 3.2** for PCK test distribution and collection. Figures 4.1, 4.2, 4.3 and 4.4 show demographic information for the PCK test respondents. Figure 4.1 shows the gender of the participants.

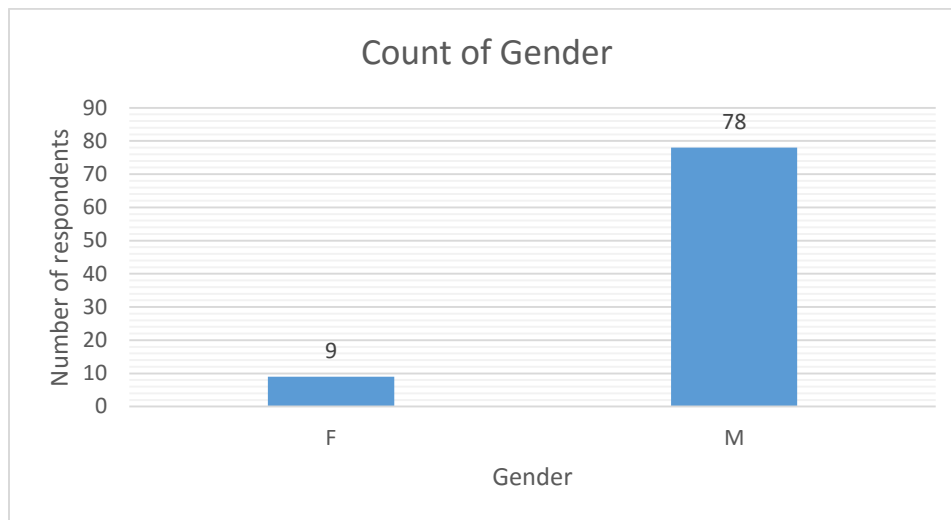


FIGURE 4.1: GENDER REPRESENTATION OF PARTICIPANTS

The PCK test was distributed to conveniently selected schools that were easy to reach. There were 78 males and 9 females who responded to the PCK test. This suggests that there were more male Physics teachers than female teachers in the selected schools. The gender imbalance may be the result of the choice of major subjects from the teachers training institutions where more males than females select Physics as their major subject. The Council on Higher Education (2012: 10) reported the male dominance of science related subjects calculated at “30.5% for males and 16.3% for females” observed in Lesotho institutions of higher learning. This may be the result of gender stereotypes where science is meant to be studied by males. A similar unequal proportion in gender of a sample of Physical Science teachers was reported by Qhobela and Moru (2014) whose survey sample was 66.7% of males and 23.3% of females.

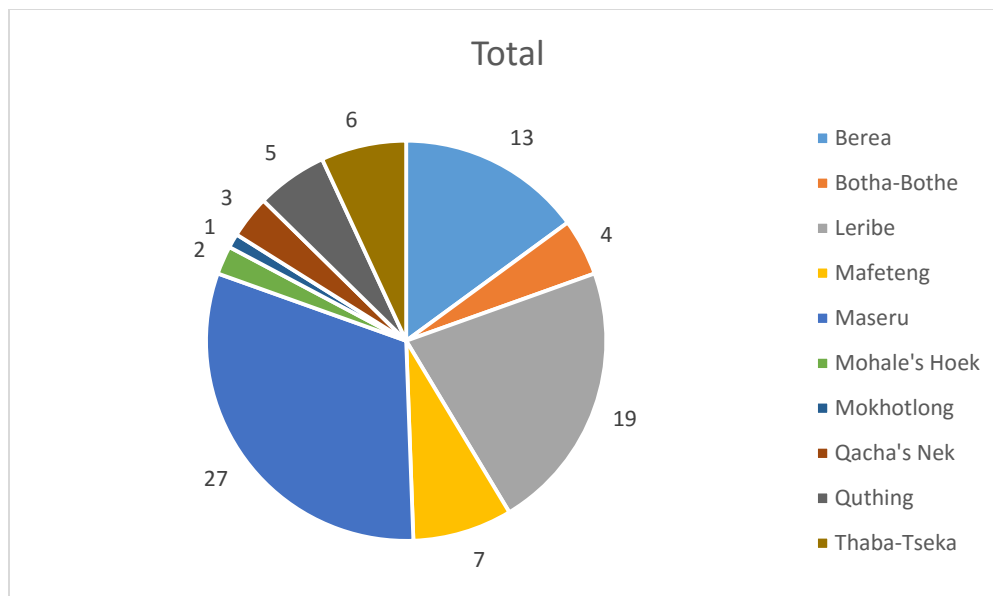


FIGURE 4.2: PCK TEST RESPONDENTS PER DISTRICT

Figure 4.2 shows the number of PCK test respondents per district. The greatest number are from Maseru with 27 respondents. The results could be expected, as there are more schools in Maseru than in other districts, with Maseru being the capital city of Lesotho, followed by Leribe with 19 respondents. The numbers are lower in Berea with 13, Mafeteng 7, Thaba-Tseka 6, Quthing 5, Botha-Bothe 4, Qacha's Nek 3, Mohale's Hoek 2 and lastly Mokhotlong 1. In all the districts, with the exception of Maseru and Leribe, the PCK test was distributed, but most of the teachers did not respond. Some of the reasons for the lack of response to the PCK test include teachers' absenteeism at the time of collection due to COVID-19 infection or the consequence of COVID-19. Some teachers stated that they could not find time to respond to the test because of their increased workloads during that period. Detailed reasons for the low response rate are discussed in **section 3.6.1.1**.

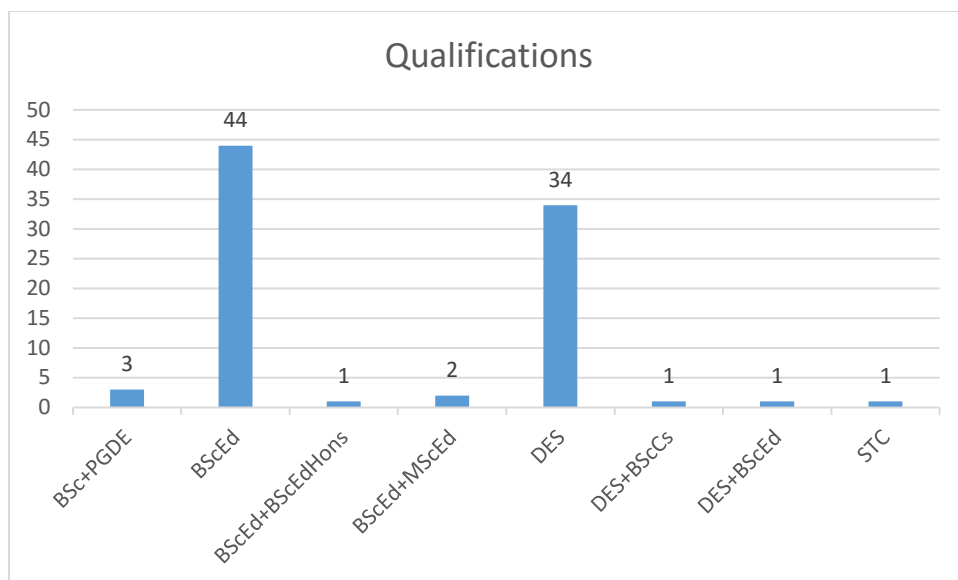


FIGURE 4.3: PCK TEST PARTICIPANTS' QUALIFICATIONS

The qualifications have been abbreviated in figure 4.3 and there is a brief description of what each abbreviation means in Table 4.1.

TABLE 4.1: PARTICIPANTS' QUALIFICATIONS MEANING

Qualification abbreviation	Meaning
BSc + PGDE	Bachelor of Science and Postgraduate Diploma in Education
BSc Ed	Bachelor of Science with Education

BSc Ed + BSc Ed Hons	Bachelor of Science with Education and Bachelor of Science with Education Honours
BSc Ed + MSc Ed	Bachelor of Science with Education and Master of Science with Education
DES	Diploma in Education Secondary
DES + BScCs	Diploma in Education Secondary and Bachelor of Science in Computer Science
DES +BSc Ed	Diploma in Education Secondary and Bachelor of Science with Education
STC	Secondary Teachers Certificate

The most common Qualifications were BSc Ed, a Bachelor of Science with Education with 44 respondents, followed by DES, a Diploma in Education Secondary with 34, BSc + PGDE had 3 respondents, BSc Ed + MSc Ed had 2 and the rest of the qualifications had 1 respondent each.

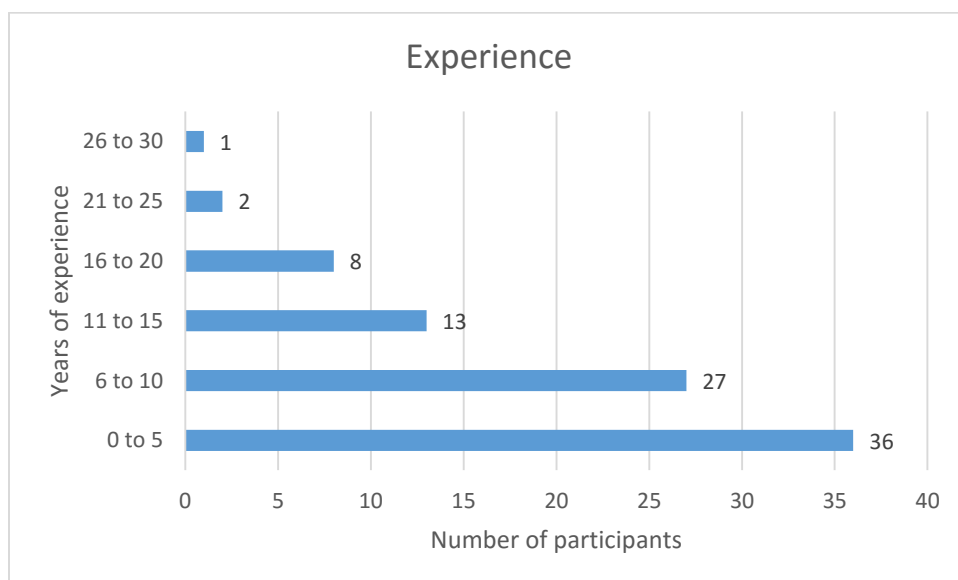


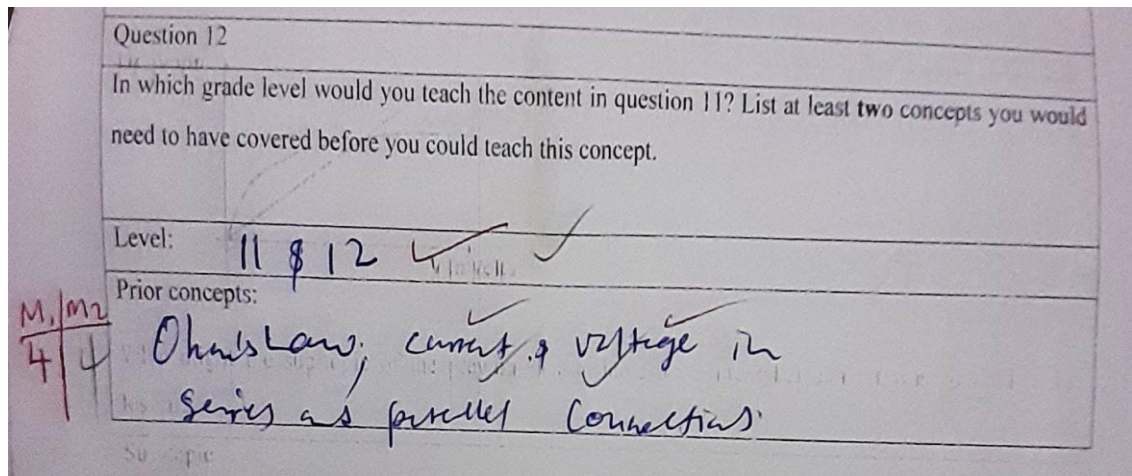
FIGURE 4.4: PCK TEST PARTICIPANTS' YEARS OF EXPERIENCE

Figure 4.4 shows that 0 to 5 years of experience is dominant with 36 respondents followed by 27 respondents with 6 to 10 years of experience. The numbers of respondents decreased from 13 to 8 to 2 and to 1 for respondents with 11 to 15, 16 to 20, 21 to 25 and 26 to 30 years of experience respectively. This indicates that the majority of the PCK

respondents were teachers with between zero and 10 years of experience; a relatively young cohort of Physics teachers.

4.2.2 Description of the PCK test analysis process

As discussed in **section 3.6.1**, the PCK test was composed of fifteen items exploring knowledge in five PCK components, viz., Assessment Knowledge (AK), Pedagogical Knowledge (PK), Content Knowledge (CK), Curricular knowledge (CuK) and Knowledge of Students (KS). The participants who responded to the PCK test items and their responses were rated by two people: The researcher and also a Physics educator; for reliability purposes. The inter-rater reliability score was 0.967 and thus considered “almost perfect”(McHugh, 2012: 279). Refer to **Section 3.7.1** for details on how scoring was resolved in cases where there were differences. An example illustrating how one PCK test item on content knowledge, was rated by the two raters, rater 1 with a red pen and rater 2 with a green pen is portrayed in figure 4.5.



Question 12

In which grade level would you teach the content in question 11? List at least two concepts you would need to have covered before you could teach this concept.

Level: 11 & 12 ✓ ✓

Prior concepts: Ohm's Law; current & voltage in series and parallel connections

M₁/M₂
4/4

Key:

M₁: Rater 1

M₂: Rater 2

4: PCK level

FIGURE 4.5: ILLUSTRATION OF THE RATING OF PCK TEST ITEMS

Figure 4.5 shows responses to Question 12 and how each of the raters rated it. M₁ and M₂ show rater1 and rater2 respectively and the numbers 4 and 4 indicate the PCK rating level from the rubric. Each item was rated on a four-point rating scale of: (1 =

undeveloped, 2 = limited, 3 = intermediate and 4 = developed). The PCK test rubric excerpt is given in Table 4.2.

TABLE 4.2: PCK TEST RUBRIC EXAMPLE

Question 12			
Expectations • Level: Grade 11 or 12 or 9 and 10 because of the new syllabus Prior concepts • Current • Emf, p.d or voltage • Resistance • Electric circuits • Measurement of current and voltage			
1 point: Undeveloped	2 points: Limited	3 points: Intermediate	4 points: Developed
No grade, no prior concepts or Wrong grade and wrong prior concepts	Correct grade and wrong prior concepts Or Wrong grade and one correct prior concept	Correct grade and one correct prior concept Or Wrong grade and two correct prior concepts	Correct grade and two or more correct prior concepts

Table 4.2 indicates an excerpt of a rubric for rating question 12 of the PCK test. The rubric shows the expected responses and the levels of PCK awarded per response given. The award of different PCK levels per item was based on the answers provided by the participants when looking at the rubric. The scores per participant were then recorded in Excel for analysis. Table 4.3 gives an example of how the scores were recorded.

TABLE 4.3: PCK TEST RAW SCORES

TID	Gender	1	2(a)	2(b)	3	4	5(a)	5(b)	6	7(a)	7(b)	8	9	10	11	12	Total PCK Score
001	F	4	1	4	4	1	2	4	1	1	2	3	4	3	3	4	41
002	M	4	3	4	4	4	1	4	4	1	4	4	3	3	2	4	49
003	M	1	2	2	3	2	3	4	1	1	1	3	1	2	3	4	33
004	M	1	1	1	4	1	3	3	1	4	1	1	1	1	1	2	26
005	F	1	1	2	4	1	1	3	1	4	1	1	2	1	1	2	26
006	F	2	1	3	4	2	1	1	2	1	1	4	3	1	2	2	30
007	M	4	3	4	4	2	4	2	2	1	4	3	3	3	4	3	46
008	F	4	1	2	1	1	2	1	1	4	2	1	1	1	1	1	24

Note: TID is teacher identity. 1 to 12 are the PCK items. The maximum score per item is 4 and the minimum score is 1. The maximum total PCK test score is 60.

Table 4.3 illustrates the raw scores from the PCK test. The items 1 to 12 represent different PCK components. There were fifteen items, each with a maximum score of 4 and the maximum raw score from the PCK test was 60. No participant achieved the maximum score. Since the scores were raw, it could not be inferred which PCK components were deemed undeveloped, limited, intermediate or developed. The data was analysed using the Extended Rasch Model as shown in section 4.2.3 and further analysed using SPSS as discussed in section 4.2.4.

4.2.3 Analysis of the PCK test using the Extended Rasch Model

In the Extended Rasch Model, the Rating Scale Model was used to analyse data. Smith, Rush, Fallowfield, Velikova and Sharpe (2008) assert that the Rating Scale Model analysis is used to analyse Likert-type data and portrays the probabilistic relationship between the item difficulty and the person's ability. The Rasch Model measures a single trait (Boone & Noltemeyer, 2017). In this study a single trait was the Physics teachers' PCK. The theory underlying the Rasch Model is discussed by Boone and Noltemeyer (2017: 2):

[W]hen attempting to measure a single trait, test-takers are more likely to correctly answer easy items than difficult items; furthermore, all items are more likely to be correctly answered by people with high ability on the construct being assessed than by those with low ability.

The data were processed using Extended Rasch Model version <https://cran.r-project.org/package=eRm>.

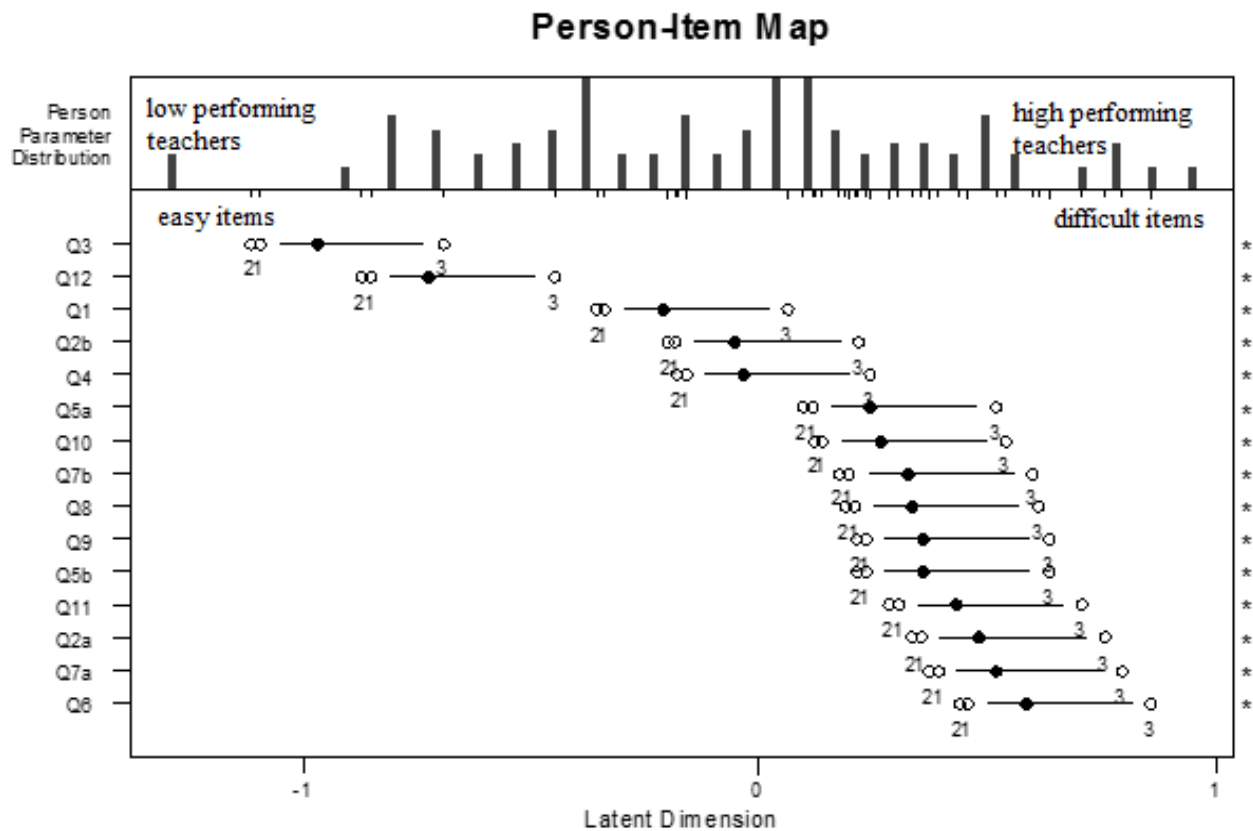


FIGURE 4.6: WRIGHT MAP

Note: Figure 4.6: The Wright Map for PCK test. N = 87. The Wright Map illustrates the location of person abilities and item difficulties along the same latent dimension. The solid circles describe locations of item difficulties while thresholds of adjacent category locations are indicated with open circles.

Figure 4.6 illustrates the distribution of Physics teachers' abilities and item difficulties on the same logit scale. The average item difficulty is set at zero. The more positive the value the more difficult the item and the more able the teacher. The more negative the value, the easier the item and the less able the teacher. The item difficulty is within the range of ± 1 logit intervals, meaning that the items were around an average level of difficulty. This average level of item difficulty is considered the most suitable level to evaluate the ability of the sample (Susac *et al.*, 2018). Figure 4.6 also shows that the relationship between the item locations and the person location on the latent scale. The easiest items are

shown on the left and the most difficult items are located on the right side of the latent scale. In a similar manner, the participants with the lowest scores are located on the left and those with the highest scores are on the right of the latent scale. From figure 4.6, the participant abilities ranged from -1.37 logits for the lowest scorer to 0.95 logits for the highest scorer. Teachers' ability has low positive values on the logit scale. Although Figure 4.6 shows that most of the items were roughly equal in level of difficulty, Q3 and Q12 stood out as easy. Q1, Q2b and Q4 were moderate while the rest of the items were difficult. Table 4.4 shows the level of difficulty of the PCK items in order from the easiest to the most difficult. The easiest are coloured orange; the moderate items are coloured blue, while the difficult items are in black.

TABLE 4.4: LEVEL OF DIFFICULTY OF PCK TEST ITEMS

Item	Difficulty (logits)	Threshold1	Threshold2	Threshold3
Q3	-0.968	-1.095	-1.115	-0.693
Q12	-0.724	-0.852	-0.872	-0.45
Q1	-0.212	-0.339	-0.359	0.063
Q2b	-0.057	-0.184	-0.204	0.218
Q4	-0.035	-0.162	-0.182	0.24
Q5a	0.243	0.116	0.096	0.518
Q10	0.266	0.139	0.119	0.541
Q7b	0.324	0.197	0.177	0.599
Q8	0.336	0.208	0.188	0.611
Q5b	0.359	0.232	0.212	0.634
Q9	0.359	0.232	0.212	0.634
Q11	0.432	0.304	0.284	0.706
Q2a	0.481	0.354	0.334	0.756
Q7a	0.519	0.392	0.372	0.794
Q6	0.584	0.457	0.437	0.859

Table 4.4 shows the items which participants found easy, moderate and difficult. The greater the magnitude of a negative score, the easier the Extended Rasch Model

considered the item. The items with a greater magnitude of positive scores were found to be difficult. For instance, Q3 was found easy as it had the difficulty level at -0.968 logits. Q6 was found most difficult with the difficulty at 0.584 logits. Table 4.5 shows the components in which the PCK test items belong and their level of difficulty.

TABLE 4.5: PCK COMPONENTS AND THE LEVEL OF DIFFICULTY OF THEIR COMPOSITE ITEMS

PCK component	Difficulty level of PCK test items		
	Difficult	Moderate	Easy
Assessment Knowledge	-	Q1, Q2b	-
Pedagogical Knowledge	-	Q4	Q3
Content Knowledge	Q5a, Q6, Q7a	-	-
Knowledge of Students	Q2a, Q5b, Q7b, Q8, Q9, Q10	-	-
Curriculum Knowledge	Q11	-	Q12

In Table 4.5, The PCK components and their composite items are arranged according to their levels of difficulty. The words difficult, moderate and easy have been used to differentiate between difficulty levels. The participants had moderately developed skills in the components of Assessment Knowledge and Pedagogical Knowledge since there are no items in these components which were classified as difficult items. The Assessment Knowledge component has items Q1 and Q2b which are both classified as moderate. These two items examined knowledge of dimensions of Science learning that are important to assess.

In the component of Pedagogical Knowledge, item Q4 tested a knowledge of instructional strategies and was classified as moderate while Q3 examined a knowledge of instructional strategies and their advantages. Item Q3 was classified as easy. The participants' skills show that they have better knowledge of instructional strategies. The component of content knowledge has items classified as difficult. The three items in this component, Q5a, Q6 and Q7a all examined the subject matter knowledge of the participants. Q5a explored a knowledge of the relationship between force, energy and

power. Q6 tested a knowledge of the distance-time graph in freefall. Q7a examined a knowledge of current behaviour in circuit branches of parallel circuits. Among these items, Q6 was the most difficult having 0.584 logits.

The other component in which all items were classified as difficult is the component of Knowledge of Students. The component has 6 items: Q2a, Q5b, Q7b, Q8, Q9 and Q10. Q2a explored knowledge of misconceptions and students' difficulties. Q5b explored knowledge of students' difficulties. Q7b, Q8 and Q9 tested participants' knowledge of misconceptions. Q10 examined knowledge of students' understanding of Science. The component of Curriculum Knowledge had one item, Q11 was classified as difficult and another, Q12 was classified as easy. Q11 tested the knowledge of the topics taught in the last two grades of secondary school, while Q12 tested a knowledge of the prior concepts needed for the topic being taught.

Although the Wright Map was able to show the item difficulty and to differentiate participants according to their abilities, the person measures and item measures were described in logits and could not easily be compared to the levels of PCK on the rating scale. The Extended Rasch Model provided information where the level of PCK was the underlying variable. This data could only be reported as a high, average or low PCK level (Planinic *et al.*, 2019). On the other hand it would not be enough to be informed about a high or low level of PCK, but to also describe how high or how low the PCK level is. It is in this regard that descriptive statistics were used to classify PCK components according to the levels of PCK on the rating scale.

4.2.4 Descriptive statistics of the PCK test

Descriptive statistics from SPSS were used to rate the PCK levels of the participants according to the levels portrayed on the rating scale. Table 4.6 shows the descriptive statistics of the PCK test looking at the PCK components.

TABLE 4.6: DESCRIPTIVE STATISTICS OF THE PCK COMPONENTS

PCK component	N	Minimum	Maximum	Mean	Std. Deviation
PK	87	1.00	4.00	2.91	0.83
AK	87	1.00	4.00	2.57	0.62
CK	87	1.00	4.00	2.00	0.89
KS	87	1.00	4.00	2.07	0.61
CuK	87	1.00	4.00	2.59	0.79
Valid N	87				

Note: N = the number of participants. Minimum = minimum score of the PCK test. Maximum = maximum scores of the PCK test. Mean = the mean score of the PCK components. Std. Deviation = the standard deviation of the PCK components.

4.2.4.1 The PCK components ranking order

Referring to **section 4.2.3**, the Wright Map in figure 4.6 illustrates the difficulty levels of the PCK test items. Table 4.4 portrays the arrangement of the items in their order of difficulty, involving the item difficulty measures in logits. Table 4.5 shows the classification of items and their levels of difficulty per PCK component, but does not show exactly which PCK component was found more difficult than others. The Extended Rasch Model could not classify the PCK components in order of difficulty, according to the level of difficulty engaged with on the rating scale. Descriptive statistics were used to rank the PCK components according to their means, which made it possible to rank the PCK components according to their level of difficulty and shows the general PCK development of the participants. The difficulty of the PCK components is described according to the PCK test rating scales. To reiterate, the PCK levels of development range from 1 undeveloped, 2 limited, 3 intermediate to 4 developed. The interval used to place each of the PCK components is proposed by Pimentel and Pimentel (2019) who describe the following intervals for a unified interval four point Likert scale: 1(1.00 - 1.75), 2(1.76 – 2.51), 3(2.52 - 3.27) and 4(3.28 - 4.00). On this rating scale interval, the scale has a uniform difference of 0.75, except for the last interval where it is 0.72. Table 4.7 shows the PCK components and their ranks in order of their difficulty level.

TABLE 4.7: PCK COMPONENTS RANKING ORDER AND LEVELS

PCK Component	Pedagogical Knowledge	Curricular Knowledge	Assessment Knowledge	Knowledge of Students	Content Knowledge
Mean	2.91	2.59	2.57	2.07	2.00
PCK level	Intermediate	Intermediate	Intermediate	Limited	Limited

Table 4.7 shows three PCK components at intermediate level with the order of development according to their means as PK, CuK and AS respectively. This also illustrates two PCK components at Limited level in their respective order as KS and CK. There are no PCK components in the developed level and undeveloped level. Section 4.2 has explored the components of PCK that the participants possessed. PCK components are the building blocks of teachers' classroom practices (Gess-Newsome, 2015). The next section discusses the manifestation of PCK in classroom practices.

4.3 MANIFESTATIONS OF PCK COMPONENTS IN CLASSROOM PRACTICES: QUALITATIVE ANALYSIS

This section presents the manifestations of the PCK components in classroom practices and thereby responding to research question 2:

How are the components of PCK manifested in Physics teachers' classroom practice?

To respond to this question, data collected from the pre-observation interviews, classroom observations and post-observation interviews were analysed. Four teachers were selected as case studies from the survey sample, two of which had the highest PCK test scores while the other two had the lowest PCK test scores. The four teachers were selected based on their contrasting level of PCK, as measured through the questionnaire, so as to test the results through qualitative data collection and analysis. In this section, I present narratives on how the participants articulated their PCK, both as verbalised PCK

through interviews and enacted PCK seen through their practice in the classroom. In these narratives, the real names of schools and participants are not used and instead pseudonyms are adopted to maintain confidentiality.

I present the narratives of the teachers' practices as they were teaching the topic on 'effects of force'. The pseudonyms Jay, Gift, Jimmy and Joy are used to name and to illustrate by means of extracts of the practice of each of the four teachers. The letter S with a number shows the actions of the students in each teacher's classroom. The words in italics show when the national language, namely Sesotho, is used in class instead of English (the language of instruction). The excerpts are quoted verbatim and the translations of meaning are given either in brackets (for short translations) or below the excerpts for longer translations. It was not uncommon for students and teachers to code-switch to Sesotho during a lesson.

4.3.1 Case1: Jay's narrative on the teaching of 'turning effects of force'

4.3.1.1 Jay's Profile

Jay is a male teacher who teaches Physics in a mixed-gender church school that was established in the late 1970s. The school has about eight hundred students. There is an average of sixty students per class but due to COVID-19 restrictions, the classes were halved and students came to class on alternate days. In Jay's school there are twenty-five teachers including four Physics teachers. All the students in senior secondary level (grades 11 to 12) study Physical Science as a subject. The school has very old buildings, including the laboratory. Although the laboratory is available and has some equipment, Jay indicated that he would not consider it adequate for his teaching. He welcomed me into his office and arranged for the classroom observations that would allow me to observe him teaching the same group of students over time, given that the students were attending school on alternate days due to the COVID-19 restrictions. Jay is the head of department of Science and holds an MSc Ed in Mathematics education. His major subjects are Mathematics and Physics. He has a total of twenty eight (forty minute) periods per week

where he teaches either Physics or Mathematics to senior secondary level students. He has taught Physics for sixteen years at the same school. He appeared so busy, going up and down and his office frequently had visitors, either teachers or students. He could not concentrate for long during the pre-observation interview, which he preferred to schedule in his office despite the frequent interruptions. In class he exhibited so much energy and friendship between himself and his students. He code-switched between Sesotho and English to teach his Physics class.

4.3.1.2 Jay's Classroom practices on the teaching of 'turning effects of force' for grade 11

Jay was observed teaching two grade 11 lessons on the 'turning effects of force'. In one lesson Jay was teaching about torque being the moment of a force while in the other he was teaching about the principle of moments. Jay was teaching in a class that had about thirty students seated in rows and columns, sitting very quietly, and waiting for Jay to start the lesson. In teaching the principle of moments, Jay had placed a sheet of paper with a table of apparatus for verifying the principle of moments on the desk in front of the students. There was only one workstation in front of the class.

He mentioned during the interview:

Yes, in most cases, when I introduce this topic, I introduce this topic using the relevant materials which students use in their real-life activities, but where they are not aware. For instance, when opening the door, opening the window ... that's how I normally introduce these concepts.

He wanted to start with some concepts known from students' daily life experiences to develop the concept. To show how he was keen in starting with the known to develop the unknown, in his second lesson Jay introduced the principle of moments by referring to a seesaw. He discussed the effect of different positions taken from the pivot and occupied by people of different weights so as to develop the concept of the principle of moments. This was demonstrated in front of the class. Magnusson *et al.* (1999) consider the knowledge of linking students' prior knowledge to the new concept to be taught, as one

of the elements indicating the teacher's developed knowledge of the students - this is one of the PCK components. The activities articulated below were involved when teaching torque.

Activities

There were several activities that Jay planned to use in the lesson. He mentioned during the pre-observation interview that he had planned to use experimentation and discovery to teach both torque and the principle of moments. He gave reasons for his choice, arguing that these teaching strategies help students retain information for a longer time and also deepen their understanding. Although he had planned to conduct his lesson by engaging the said teaching methods, he had no worksheet prepared to guide students towards discovering the concepts he was going to teach. The set-up in his classroom had only one table with apparatus in front of the class, which suggested that only this demonstration was possible as a teaching strategy in this classroom and not experimentation as Jay had stated in the pre-observation interview. When interviewed later, after observing lesson 1 about why he did not engage the strategies he intended to use in his actual classroom practice, Jay pointed out that:

Discovery and experimentation could be very good to use for students to observe what happens when forces are moved, recording their observations of increasing torque as distance is increased or decreasing torque as distance is decreased. *Bothata ke lisebelisoa, joalo ka liforce metre, ha li eo* (the problem is the apparatus, like the force metres, they are not there). The problem is that some would see while others would not see because we have limited apparatus to use. Again, these things take a long time and I wanted to spend less time to cover many concepts.

This excerpt shows that Jay was conversant with appropriate teaching strategies that he could use to develop the concept of torque, but he was hindered by the limited availability of resources and a shortage of time. In his actual teaching, the dominant activities I observed were demonstrations where he would involve one or two students to illustrate the concepts.

Demonstrations

Jay started his lesson by inviting one student to open the door from outside while he was closing the door from the inside, changing the positions from where the door was pushed from the hinge. While they were pushing the door from the different positions, other students were observing while a student was trying to open the door when Jay was trying to close it. Jay asked questions about the demonstration he did with the student.

Jay: Eh! I think you have observed what has happened. I was trying to close the door but what he did...eh! Even myself, I didn't come here... (Pointing at the hinge) As he was trying to push the door, I didn't push it here (pointing at the hinge) but I decided to come at the end of the door (pointing near the lock)...why? Why couldn't I push it here? Pointing at the hinge. There are three positions, one, two and three (pointing at the position near the hinge, the middle and near the lock) ... which position would you choose? Just raise your hand and tell me why you would choose position 2 instead of position 3?

Position 1



Position 2



Position3



FIGURE 4.7: JAY PUSHING THE DOOR AT DIFFERENT POSITIONS

S1: From position 1, position 1 is near the hinge.

Jay: So why would you choose position 1? Why not position 3 [...] Yes.

Jay demonstrated what happens when a force is applied at different positions to introduce torque being the moment of a force. During this introduction, he asked students some questions to develop the concept of moments referring to what they had seen in the demonstration. Students answered questions in both Sesotho and English. In their answers they held the view that the force increased as the distance from the hinge

increased, but this was said in Sesotho with the use of the word “matla” appearing to mean force.

S2: *Hobane ha a ne pusha a le position 2 o ne a tlo mo hlola ka matla.*

Jay: *Hmm! Kea utloa hore u ne u tlo hloka ho hlola motho ea kantle. Joale ke re na why position 3 not position 1? When you go to position 3, you increase your... and what is matla?*

Students in chorus: force

Translation

S2: Because if he pushed from position 2, he would overcome his force.

Jay: Hmm! I understand that you needed to defeat the person outside, so I am asking, why position 3 not position 1? When you go to position 3, you increase your... and what is *matla*?

This shows that students thought force was increased as the distance from the turning point was increased while it was the moment of the force increasing. Being aware of the misconception that his student had, Jay resorted to using another way of illustrating what it is that increases as the distance increased. To improve students' understanding of this concept, Jay demonstrated using the set-up on the table in front of the class to show how the moment of a spanner increases as the force is applied at different positions from the turning point, as shown in figure 4.8 below.



FIGURE 4.8: JAY IMITATING A SPANNER

Jay: when you unscrew a nut using a spanner, you see a nut, now *e tii-tiile ha kere! Hore e tle e fasollohe ke tlameha ho etsa joang? U e fasolla kang? Ka spanner u fasolla mona e ea hana U chechella kae?*

Students in chorus: *morao*

Translation

Jay: when you unscrew a nut using a spanner, you see a nut, now it is tight, isn't it, and for it to be loose, what do I have to do? What do you use to loosen it? You untie it with a spanner trying to loosen it from this position (pointing at the position near the fulcrum), it doesn't loosen up, where do you move?

Students in chorus: backwards

In this extract, Jay illustrated the importance of the applied force's position from the fulcrum. He illustrated that when the force is applied near the fulcrum, it is difficult to untie the nut but when the distance is increased, the nut becomes easy to untie. He demonstrated this using a meter ruler clamped on to the retort stand. Nilsson and Vikström (2015) situate the knowledge of selecting appropriate teaching aids and suitable activities to develop a concept as curricular knowledge. The selection of various activities was evident in Jay's teaching, using one demonstration and then supplementing it with another to help students develop the concept of torque.

When interviewed about the importance of the topic he was teaching in the curriculum, Jay mentioned that this topic is important since the concepts that are introduced are applied in daily life. In his introduction, Jay used the daily life experiences of students to illuminate the concepts. The demonstrations included opening the door and using a spanner to untie the nut.

Consistent with his choice of beginning his lessons with familiar experiences, Jay began his second lesson by showing a diagram of a seesaw, where he placed people of different weights on either side of the pivot. He challenged his students by asking questions to develop the concept of the principle of moments.

Jay: [...] *Joale batho bana ba babeli, ka nqe ka moo ho leng ho khuts'oanyane ho tla palama ea joang?* (So there are two people, who is going to occupy the shorter side?)

S in chorus: *ea motenya* (the fat one).

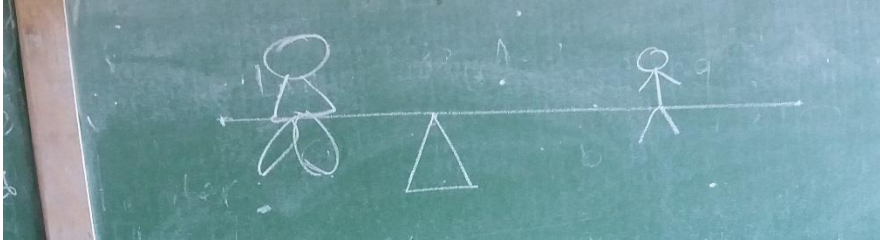


FIGURE 4.9: REPRESENTATION OF A SEESAW

Jay: *ea motenya, ebile o chechella kae?* (The fat one, where does s/he move to?)

S in chorus: *Morao* (backwards).

Jay: So you have played this seesaw, were you even aware why this person goes back? What is this person trying to increase here?

S in chorus: moment

Jay: moment. Is it ok? Suppose we don't want this seesaw to go either side. What do you think should happen?

S6: *ea mosesane o tlameha a atamele pele* (The thin one should go forward).

Jay: *o tlameha a atamele pele?* (Should s/he move forward?)

S in chorus: *o tlameha a ee morao* (s/he should move backwards).

It was evident from the students' responses that there was some confusion about how the big person should be positioned for the seesaw to be in equilibrium. The confusion could have been brought about by students' failure to infer from a diagram the effects of force, since the diagram does not portray the effects of different forces at different distances from either side of the pivot. This shows the limitations of using a 2-dimensional diagram to demonstrate the effects of a force. On noticing the confusion, Jay decided to use a different representation to help students understand better. To address the apparent confusion as to how the fat person on the seesaw should move to get equilibrium, Jay involved one student in a demonstration to move unequal weights hung with a string on a meter stick clamped on to a retort stand.

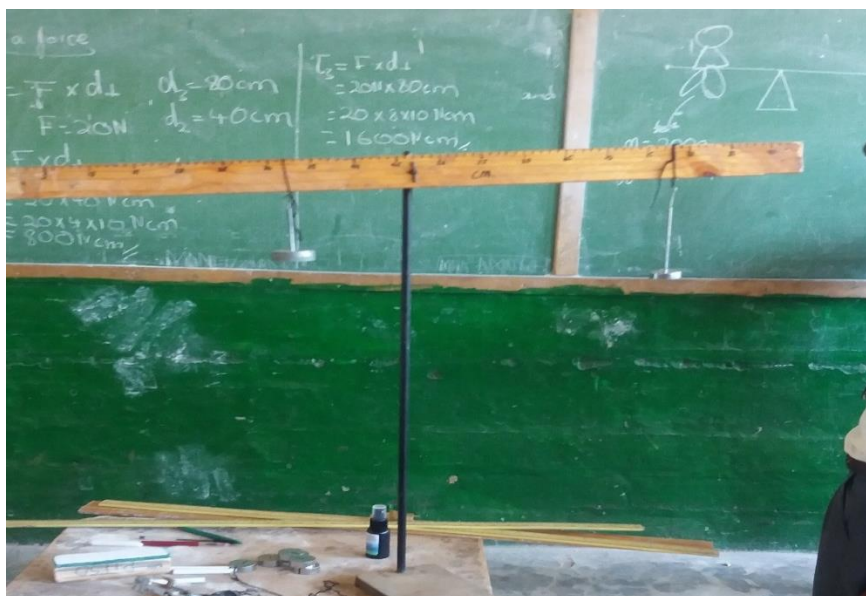


FIGURE: 4.10: WEIGHTS REPRESENTING PEOPLE ON THE SEESAW

With this, Jay illustrated the principle of moments where he represented the people on the seesaw by different weights. The student moved the weights until the meter stick balanced. Although Jay was trying to help students understand the principle of moments from this demonstration, there were challenges emerging from the apparatus he had used. He then used strings to hang weights; strings of different lengths, because there were no weight hangers. In the process of moving the weights a string broke, leading to more time taken to demonstrate the concept. With the two representations involved, Jay developed the concept involving not just one representation but using different representations. Ball, Thames and Phelps (2008) and Chabongora and Jita (2013) expound that to transform content knowledge effectively, it is important for the teacher to use different representations and registers while also dealing with problems arising during the teaching of the concept. Here Jay did not stop when a string broke but found better ways to hang the weights to continue with the representation he wanted to engage with for concept development. Jay aroused his students' thinking by using a diagram of two people of different weights on a seesaw. He also used apparatus that helped students to do the resulting calculations. This illustrates Jays' developed knowledge on how to engage different strategies of representing content, which Shulman (1986) considers to

be evidence of developed PCK - when the teacher is adept at using different techniques to present the same content to students.

Explanations

Jay told his students that they were going to learn about torque, circling the word 'torque' among other words on the board, together referred to as "matla" in Sesotho. He explained that what they have considered as increasing was the torque and not force, as they had thought when he changed positions on closing and opening the door. The following extract illustrates how Jay explained torque to his students.

Jay: ... *Nthoena entse eketseha mona* (this thing that is increasing here) we call it torque. Is it clear? It is torque. This torque is the product, you know in Mathematics product means multiplication. Yes, it is the product of the force I am applying here, multiplied by the distance from the turning point. In other words we have a Greek letter like this τ (writing on the board), it is equal to force multiplied by a perpendicular distance.

In this case, Jay was correcting a misconception that some of his students had about torque - they thought that as the distance increased from the turning point, the force was increasing and that was why it was easy to open the door. To illustrate this, Jay used calculations of the torque that was applied to open the door from different positions. Distances from the two different positions were measured and recorded. Using the definition of torque, the one position had its torque equal to zero because the distance was zero since position 1 was on the hinge. In his pre-observation interview, Jay had mentioned that the main idea he wanted his students to learn was to calculate torque. When fulfilling this objective in his classroom practice, Jay calculated the torque to compare the torque exerted from the two positions on the door. The calculations used are shown in figure 4.11.

Effects of a force

$$\tau = F \times d_{\perp}$$

$$F = 20\text{N}$$

$$\tau_2 = F \times d_{\perp}$$

$$= 20\text{N} \times 40\text{cm}$$

$$= 20 \times 40\text{Ncm}$$

$$= 20 \times 4 \times 10\text{Ncm}$$

$$= 800\text{Ncm}$$

$$\tau_3 = F \times d_{\perp}$$

$$= 20\text{N} \times 80\text{cm}$$

$$= 20 \times 8 \times 10\text{Ncm}$$

$$= 1600\text{Ncm}$$

FIGURE 4.11: CALCULATIONS OF TORQUE

In these calculations of torque Jay used the assumption that the force was kept constant so that his students could understand the role played by an increase in the distance from the turning point. Comparing the two calculations, Jay and his students agreed that torque increased as the distance from the door-hinge increased, making it easier to close or open the door. Jay emphasized that torque, which is sometimes called the moment of a force, increases as the distance from the turning point increases. In his own words he said:

Jay: Now, are you aware that... let us compare, the two torques, this is 1600Ncm and this is 800Ncm. *E le hore ntho eo re ileng ra e eketsa ha re chechella mo keng?* What do we call it? *Ke torque, ka nako enngoe re e bitsa* moment of a force about a turning point. In other words are you aware that we didn't increase the force, force e ntse setse ele 20N, *ho eketsehilengke torque*. Yes, even when you unscrew the nut e hana ho fasolloha, then u chechella morao, you are increasing what?

Translation

Jay: Now, are you aware that... let us compare, the two torques, this is 1600Ncm and this is 800 Ncm. What did we increase when we moved to this position? What do we call it? It is torque, at times we call it moment of a force about a turning point. In other words are you aware that we didn't increase the force, force is still 20N, what has increased is torque. Yes, even when you unscrew the nut (demonstrating using a rod fastened on a stand, from a shorter distance from the turning point) it can't be loosened, (moving hands to a longer distance from the turning point) then you move backwards, you are increasing what?

In this excerpt, Jay illustrated the importance of increasing the distance when torque was to be increased and force kept constant. In explaining torque, Jay used verbal

explanations and mathematical explanations (Shulman, 1986), while also using the apparatus to portray the difficulty of turning a clamped ruler to different positions so as to illustrate that increasing the distance of the applied force from the turning point increases the torque. He also used a verbal explanation to differentiate between force and torque because his students thought force was increasing as the distance from the turning point was increasing. Jay used different teaching strategies simultaneously to deepen his students' understanding.

Examples

In the pre-observation interview, Jay had situated the importance of this topic in the curriculum in daily life applications. The examples he used to help his students understand were daily life examples. These are the examples illustrating applications of torque in daily life. He used these examples at the end of teaching the concept 'moment of a force' or 'torque'.

Jay: [...] torque, which is a moment of a force. *Ke ntse ke soka papa mehla ena, lesokoana lena ke le ts'oarelloa morao ka nako enngoe ke lets'oarella pele. Re bula litlhapi malapeng mona, ntho eo e bulang is a lever, e hana ho buleha u chechellisetsa letsoho ho kae?*

S in chorus: *Morao*

Translation

Jay: [...] torque, which is a moment of a force. I always stir the pap; I hold the stirring rod at the end or at times near the beginning. We open a fish tin at home that which we open with is a lever, when it cannot be opened, where do you move your hand?

S in chorus: Backwards

Using examples that students are familiar with from their experience at home to wrap up the topic, Jay added more examples such as lifting big stones with a crowbar, opening a bottle of canned fruits using a spoon, showing how a longer distance is important to multiply force to produce a greater moment with less application of force to do more work. From the students' responses, it could be concluded that they were aware from their experience how the distance should be increased to increase torque.

Knowledge of what makes a particular concept ‘difficult’

In explaining what was happening to the door when it was opened and closed by Jay and one student, students kept on using the word ‘matla’ to refer to an increased moment of a force while others referred to the force as ‘matla’. Jay had earlier in the interview identified language as one factor that brings learning difficulties to the learning of Physics. Jay came to class already anticipating that there would be this kind of confusion brought about by language as he had mentioned in the interview that students fail to differentiate between energy, pressure, power and the moment of a force. To show his awareness of this, Jay differentiated all technical words, which are referred to as ‘matla’ in Sesotho to reduce the possible confusion brought about by the use of one word in Sesotho to mean different scientific words. This is illustrated in the following excerpt.

Jay: My dear students, normally in Physics we have what is called force. We also have what is called pressure, we also have what is called energy, and we also have what is called power. Is that ok? We need to differentiate all these. They are not the same (emphasizing). Is that clear? But if in Sesotho you talk of *matla*, but our language, our scientific language helps us to differentiate all these... Pressure is defined as force per unit area. Is that clear? [...] You see, the smaller the area the larger the pressure. We also have what we call energy. I am able to walk because I have eaten food therefore I have energy. We also have what is called power, ok, and power, what is power? [...] *Emong o tla re matla ano ke power emong o tla re matla ano ke force*. (It might be some of you refer to this *matla* as power; one might say *matla* is power while another one might say *matla* is force). But what is power? But power is the rate at which you do the work. Is that clear?

Although other technical terms were not used in this particular topic, to Jay it seemed important that he defined them so that his students could understand the type of ‘matla’ they were referring to in this particular lesson; namely force.

The other difficulty that Jay was aware of was the units of the moment of a force, which he indicated in the interview as being one challenge when teaching this topic. In his words he said:

Jay: More especially, the challenges which I refer to as difficulties, more especially students have a problem of completing units when calculating torque, you will realise that eh... they have a problem with units.

To show his awareness of students leaving out units in calculations, Jay included units in all his calculations of torque in class, communicating with his students every time he

added units about the physical quantities involved in calculations with the end product of the calculations being torque. Figure 4.12 shows his attachment of units to the calculations.

The image shows a chalkboard with handwritten calculations for torque. On the left side, under the heading 'moments of a force', there are two calculations. The first one is $T = F \times d_{\perp}$ with $F = 20N$ and $d_2 = 40cm$, leading to $T_2 = 20N \times 40cm = 20 \times 40 Ncm = 800 Ncm$. The second one is $T_3 = F \times d_{\perp}$ with $F = 20N$ and $d_3 = 80cm$, leading to $T_3 = 20N \times 80cm = 20 \times 8 \times 10 Ncm = 1600 Ncm$. On the right side, there is a similar calculation for T_3 with $F = 20N$ and $d_3 = 80cm$, leading to $T_3 = 20N \times 80cm = 20 \times 8 \times 10 Ncm = 1600 Ncm$.

FIGURE 4.12: UNITS IN CALCULATIONS

Having anticipated the challenge faced by students in writing the units of the topic being taught, Jay had mentioned that he would involve the conversion of units. He said:

Jay: Normally eh...what I have planned, I have planned to introduce them to the conversion of units and the appropriate use of those units, more especially in calculations of moments.

Physical quantities are often expressed in SI units, it might have been expected that Jay, as he had mentioned in the interview that he would demonstrate the conversion of units from Ncm to Nm so as to appreciate the use of SI units - but conversion of units was not evident in his teaching in his first lesson. In the second lesson, Jay had remembered that he had forgotten to emphasise the SI units of the moment of a force, and that led him to include this even though he pointed out that they would still use Ncm as the units of the moment. Leading his students to the conversion of units, he said:

Jay: [...] now there is something that I didn't emphasize here. The SI units of torque are Nm, is it ok? But this time around, I would like us to use Ncm. Even here I would like us

to use Ncm. *Ha li le tjena mass ona re tlameha re o convertele ho eng?* (When they are like this, we have to convert this mass to?)

S in chorus: force

Jay: And what do we call that force? What do we call this force *eo ntho ee e theohang ha ke e tsoere tjena*, (that which makes this go downwards when I hold it like this) it is pulled by?

S in chorus: Gravitational force.

Jay wanted his students to be able to use units appropriately, as he had identified this as one challenge faced by students when learning this topic. He focused his teaching on the conversion of units where he led his students to easy ways of conversion using leading questions. This is indicative of him focusing his instruction to develop knowledge of the appropriate use of units in Physics (Gess-Newsome, 2015). Having said this, Jay reminded his students of the relationship between mass and weight, writing it as an equation on the board and then addressed the unit conversion from grams to kilograms and then from kilograms to Newtons, which was the required force to calculate the moment of a force. Figure 4.13 shows what was done in class.

$W = mg$

$1000g = 1kg$

$200g = ?$

$\frac{200g \times 1kg}{1000g} = 0.2kg$

$W_{ANT} = 0.2 \times 10 = 2.0N$

$g = 10N/kg$

$0.1 \times 10 = 1.0N$

FIGURE 4.13: CONVERSION OF MASS TO WEIGHT

From the relationship of mass to weight, Jay reminded his students of the value of gravitational field strength and wrote it on the board then he used it in unit conversions. Having approached the units' conversion this way, the students did not appear to struggle

to convert the units, as they were responding in chorus while Jay was writing on the board, as to what the answers should be.

Misconceptions

Jay was aware of misconceptions students have with this topic, knowing that the moment of a force is calculated as a product of force and perpendicular distance from the turning point they at times use any distance. He states:

...The other problem that learners used to encounter from my experience is when they calculate moments, normally they ignore that they are supposed to consider the distance from the turning point. They may take a longer distance, which is the distance that is not required, that is the difficulty that students normally come across.

This shows that students might fail to appreciate the importance of the perpendicular distance from the turning point. Having this in mind Jay engaged in activities to help students use the appropriate distance in their calculations as illustrated by the demonstrations in the classroom.

Knowledge of dimensions of Science that are important to assess

Jay intended to focus on assessing calculations. Referring to the LGCSE Physical Science syllabus (NCDC, 2019: 5). Among the three objectives of assessment, Jay's focus on assessing calculations falls under objective B, which is "[h]andling information and problem solving".

Knowledge of methods by which learning can be assessed

While teaching Jay used oral questions to ascertain students' understanding, as he had intended and had mentioned in the interview. He had also said that he would test students' knowledge of the calculations. This was observed in his teaching and in the two questions he posed; one was testing knowledge of the calculations needed to find the distance and in the other question he asked students to find the weight in questions that involved the principle of moments.

Jay: Em le tle le nchekele mona. (Writing on the board) Re tle re etse liweight tsa rona neh! Ebe kere ena weight ea teng ke se ke e calculatile le mass, ebe li tharo hle ke cho ha kere! Li re etsetsa 3N. Ebe kere from here to here, it is 20cm. Ebe weight ea ena ke

1N. Hantle weight ee ea clockwise moment, difference ea ho tloha mo ho tla mo e tla tlameha ebe bokae hore this system e qetelle ele in equilibrium?

Yes (pointing at the student)

Translation

Jay: Em check this for me. Let us do our weights, let me say I have already calculated the weight and mass, let us say they are three ... they make 3N. And say from here to here it is 20cm and the weight for this one is 1N. For this system to be in equilibrium, what should the distance from here to here be? Yes (pointing at the student)

S12: 4cm

Jay: 4cm?

S13: 10cm

Jay: 10cm?

S14: 60cm

Jay: 60cm? Why 60? Can you tell us why 60?

S14: is to balance

From the students' responses, it could be heard that some were still a bit confused about the concept that had been developed since there were several different responses given, but Jay concentrated only on the one that was correct and ignored the rest. One would think Jay would find out more from the students who gave incorrect answers to help them understand as Gess-Newsome (2015) point out that knowledge of assessment entails the teacher's use of a designed assessment to direct a modification of instruction to help concept development, but Jay was more interested in the correct answer and went on to explain how the 60cm was appropriate. He explained solving the question on the board as shown:

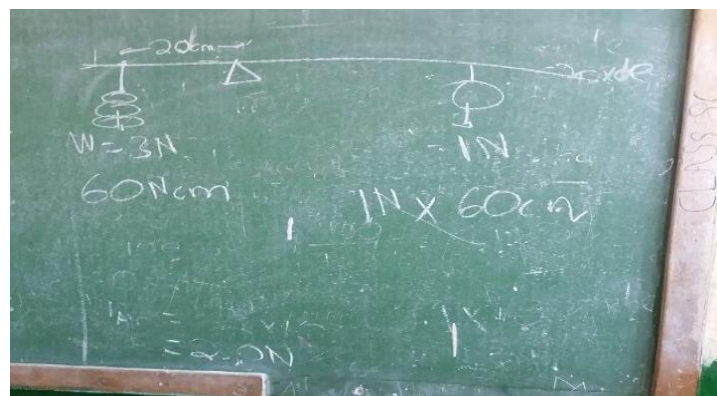


FIGURE 4.14: JAY'S ASSESSMENT QUESTION 1 SOLUTION

In another problem, Jay wanted his students to find the weight of an object using the principle of moments.

Jay: *Ere ke teste ea ho qetela.* (Writing another question on the board) *Hore system ea rona ebe at equilibrium, weight ea rona e tla tlameha ebe bokae? Weight W?*

Translation

Jay: Let me test the last one (Writing another question on the board). For our system to be at equilibrium, how much should our weight be? Weight W?

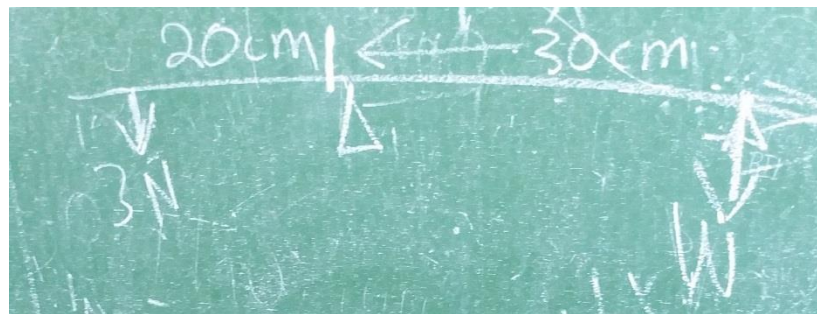


FIGURE 4.15: JAY'S ASSESSMENT QUESTION 2

S15: 2N

Jay: oh 2N, good.

In this part of the lesson, one would expect Jay to follow up on the correct answers and for students to explain how they got the answers they did, but there was no such action in this class. This is the part that ascertains students' understanding and it might have been helpful to listen to students' explanations. Although Jay had articulated his PCK of teaching the concept of the principle of moments and had selected appropriate questions to ascertain students' understanding, there is some concern about his response to students who still revealed confusion about the development of the concept. He seemed to have very little interest to find out more about what the underlying cause may be for their incorrect answers. Some of the students were left with little understanding of the concept taught, as Jay moved forward with the students who had the answers correct.

4.3.2 Case 2: Gift's narrative on the teaching of the 'turning effects of force' for Grade-11

4.3.2.1 Gift's Profile

Gift is a female teacher with three years of teaching experience and was in her second year at the current school. She holds a diploma in Education with Mathematics and Physics as major subjects. She has twenty three (hour-long) periods per week and has taught Physics for two years at the same school. She code-switches between Sesotho and English to teach her Physics lessons. She appears energetic even though her classroom movement is limited by the rather small spaces in-between the rows of desks in her class. Even though the class has many students, Gift seems to know all her students by name. Although she is a small woman and a young teacher, she has a very commanding voice.

Gift teaches Physics in a mixed gender government school that was established in 2007. The school has sixteen classrooms with an average of about eighty-five students per classroom and about one thousand five hundred students. In Gift's class, the teacher does not have a table because the classroom is so full, leaving a very small space in front where the teacher can barely move. In this school there are thirty-five teachers and five of them are Physics teachers. All students in the senior secondary levels studied Physical Science. The school has very new and beautiful buildings including a laboratory. Gift claims that there is not enough laboratory equipment. The school is known to have a consistent record of good grades. Although Gift complained that the class she was teaching was not as responsible with learning as the class she had had in the previous year, her students appear to be involved except for a few who slept. Gift is quick to identify the passive students and calls them by names to capture their attention.

4.3.2.2 Gift's Classroom practices on the teaching 'effects of force on shape' in grade 11

Restricted use of some instructional strategies

Gift considered Physics to be a practical subject, which should involve experiments even though her teaching conditions did not allow for that, she opted for other ways of teaching Hooke's law. She had previously shown that the apparatus she would be using did not fully illustrate what she wanted to teach, meaning that she had tried the apparatus before going to class and had seen that it would not work effectively. She indicated:

Gift: There are factors that are going to affect the learning, because Physics itself is a practical subject. And among any other topics, this one should have experiments, but we are not going to manage to do the experiments because I tried to find the materials which we could use but the masses we found in the lab, *ha ke tsebe na nkare li joang, eka re li bobebe*, even if *e ngotsoe 1000g* but *ha li corresponde le* the written value. So I could not even try using them. I tried using a spring balance, *ne kere* I would demonstrate to them *re sebelisa se le seng feela* so that they see that a spring when you hang the mass is going to stretch, *ebe ke bona* the masses *li hloloa ho etsa* spring balance stretch, *li hloloa ho etsa* spring stretch because a 1000g mass, I was expecting that it was going to give me a 10N force, but *e be ha e etse joalo ebe ke bona ekare e tlo re bakela* inconvenience, *ke hore lipalo tseo re li sebelisang ha li tlo corresponda le liresults tseo re li lebelletseng*. So I thought in that case, I should leave the materials aside, and try to discuss the topic in the absence of the materials.

Translation

Gift: There are factors that are going to affect their learning, because Physics itself is a practical subject. And among any other topics, this one should have experiments, but we are not going to manage to do the experiments because I tried to find the materials which we could use but the masses we found in the lab, I do not know how I can describe them, it's like they are light, even if it is written 1000g but they do not correspond with the written value. So I could not even try using them. I tried using a spring balance, I was thinking I would demonstrate to them using just one so that they see that a spring when you hang the mass is going to stretch, and I saw the masses failing to make a spring balance stretch, failing to make a spring stretch because a 1000g mass, I was expecting that it was going to give me a 10N force, but it wasn't giving me that and I noticed it would cause inconvenience, meaning the numbers we used did not correspond with the expected results. So I thought in that case, I should leave the materials aside, and try to discuss the topic in the absence of the materials.

This excerpt shows that Gift knew of the best teaching strategies for teaching this topic, but she was hindered by the apparatus she had in the laboratory where the labelling of the weights was incorrect. She had in her mind that she could teach the concept better if

she could do experiments or make demonstrations, but the ineffective apparatus led her to make use of discussion. In her previous lesson she had mentioned that one of the factors leading to her choosing methods other than experimentation was the overcrowded classroom. She stated:

Gift: [...] this is a practical topic, topic *ena* is practical. The expectation would be I would use the springs or rubber bands with the masses *re etsa liexperiment* but we have a challenge *ea bana bana ba ba ngata, ke hore le ha ho se hothoe u rata ho e etsa ntho eo*, it takes a very long time because *le ha u kaba arola ka ligroup, u attenda ligroup tse nyanenyana ebe* its time up. So the idea *ea bana ba rona baba ngata* in class *ere u tlameha ho ba ruta le sa etse liexperiment. Hobane le ha u ka re e bonolo, mohlala, pendulum, hore re etse pendulum ke ntho e bonolo*, but attending each group *nako e ea u fella ka mono u so qete ntho eno. So se re bile re le used to teaching them ka ... ha u ba etsetsa demonstration, u etsa e nyane feela e etsuoang ke uena. Because ba ba ngata haholo.*

Translation

Gift: [...] this is a practical topic ... this topic is practical. The expectation would be I would use the springs or rubber bands with the masses doing experiments, but we have a challenge of so many students, even if you may want to do experiments, it takes a very long time because even if you divide them into smaller groups, you just attend a few groups then the time is up. So, the idea of many students in class suggests that you should teach them without doing experiments, because even if it may be simple, for example, to make a pendulum is easy, but attending each group then the time becomes used up without you having finished the experiment. So we are used to teaching them through...when you do demonstration, you do a small one that is done by you ... because they are too many.

Gift seemed to be restricted when choosing the best teaching methods for her class, mainly because of the overcrowded classroom. Her teaching conditions restricted her choice of teaching methods to just a few; such as doing a demonstration that she thought would cover the content in a short time. Although she indicated in her first lesson interview that she would involve discussion and demonstrations by herself, she involved a few students in the demonstrations in class, arguing in her lesson two interview that her students needed to have a feel to develop the concept better.

I chose them because I thought manipulating would help them see things better than if I just come and tell them a story, but if I employed the idea of manipulation, *e kanna ea skaba le nna motho ea etsang liexperiment ka ba fa tsona* (it might not even be me doing experiments, I can let them do them) so that they could have some feel.

With this in mind, Gift involved her students in the demonstrations that were done by one or two students in front of the class, while a discussion about the concepts were going on in the classroom. As much as she tried to involve her students to help demonstrate the concepts, only a few could see what was being done. The students involved did hold the apparatus high so that others could see what was done. The following example shows how Gift used available materials to demonstrate the effect of force on shape, involving students in a demonstration.

Example

To demonstrate the behaviour of elastic materials - Gift did not have springs - she drew a spring on the board just to mention it as an elastic material but used the available elastic bands from facemasks. She wanted to show that elastic materials stretch when force is applied to them and then return to their original length after the force is removed. In the absence of the necessary laboratory materials, Gift did not choose to only talk about the behaviour of the elastic materials when force is applied but opted to improvise, using the available material that could exhibit the same behaviour as the spring.



FIGURE 4.16: GIFT SHOWING A MASK THREAD

Gift: now I want to use it not necessarily as a spring but let us use it to identify the original length. We are going to talk about the stretching of a spring and the spring here is used for any other stretching material. So we are going to identify the lengths, so we say when you apply, *ha kere lea bona na length ee e kae* (you see this length)? Now when I apply the force, what happens to the length?

S in chorus: it increases.

Gift: The length extends. Such that we say we have the original length and the stretched length. *Re na le* (we have) original length. *Hana re e hlalosa joang* (how do we explain it)? The original length of this thread?

S11: the length at which an object returns to when a stretching force is released.

S12: the length of an object without a mass

After students had defined the original length, Gift used one student to demonstrate what happens when a force is applied to an elastic material using the thread of a mask as an elastic material. The student measured the original length and the new length after stretching the elastic band. The extension of the stretched elastic band was calculated after recording the measurements on the board.

Original length



New length after stretching



Recorded lengths

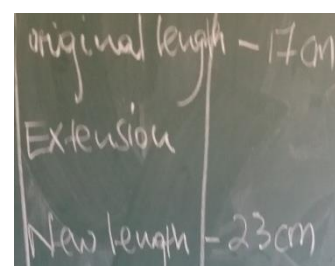


FIGURE 4.17: STUDENT MEASURING LENGTHS OF AN ELASTIC MATERIAL

After recording the lengths, Gift asked students how the extension is found.

Gift: How do we get the extension?

S13: we subtract the original length from the extended length.

Gift: she says she subtracts the original length from the new length to get the extension.

So the extension was found to be? 23 minus 17, which is 6 cm.

Gift engaged a student in the demonstration. Although the demonstration was presented in front of the class, most of students could only hear what Gift was saying but could not see what was actually happening because the classroom was too full. Some students were standing, trying to look at what was happening on the desk of a student in front of the class. This might of course lead to some students developing the concept better while others would not, as they could not see what was happening.

Prerequisite knowledge

Gift began her first lesson by reviewing the content that was studied in the previous lesson, asking the class what they had covered. Students mentioned that they had been dealing with inertia. Gift reminded her students that the topic they were dealing with is 'the effects of force'. She asked questions to find out how her students defined elastic and plastic materials. The following excerpt shows Gift reminding her students about the effects of force on plastic and elastic objects.

Gift: *re tle re hopole hore re itse* (let us remember that we said) force can affect objects in many ways. We talked of changing shape, changing size. And many others *ha kere*! Now we are going to talk about today, the effects of force on objects that we say are elastic and some we say they are plastic objects. Now let me ask you how we define elastic objects. How do we define an elastic object? E... (Pointing at a student)

S3: we can say elastic objects are stretching objects.

Gift: Ok we can say they are stretching objects. Ok you said they are stretching objects, any other opinion? Yes sir (pointing at another student).

S4: madam they are objects that return to their original length.

After the students had defined the elastic materials, Gift moved on to investigate how they define plastic materials.

Gift: Ok. What about plastic materials? [...] Plastic materials? [...] What materials are said to be plastic? E... (Pointing at a student)

S5: eh! Madam, I think they are materials which when stretched; they are stretched such that they do not return to their original sizes.

Gift: so they stretch?

S5: yes mam, over their elastic limit.

Gift: over their elastic limit... (Moving to the board, writing elastic limit on the board). You think they are the ones that stretch beyond their elastic limit and then get deformed?

In her introduction, Gift interrogated her students' prior knowledge about the differences between elastic and plastic materials. From the excerpt it could be deduced that students consider both plastic and elastic materials to be stretching but plastic not returning to the original size. She intended to build the students' knowledge from what they already knew. After listening to the students' definitions, Gift incorporated the definitions to develop the concept of elastic and plastic materials. This indicated that Gift viewed the link between prior knowledge of certain concepts to the new concepts to be learned as vital in her

teaching and this is considered one of the indicators of a developed PCK of the knowledge of students (Magnusson *et al.*, 1999).

Knowledge of students' difficulties

Gift had earlier in the interview mentioned one of the learning difficulties as being the daily language use of words which differ in meaning to Physics technical terms and she gave the example of the word 'plastic'. Although she had anticipated these language-learning difficulties that she had talked about, some difficulties emerged during the teaching of this topic. The following excerpt shows two students, one referring to 'load' as the force applied while the other referred to the load as the mass applied to an elastic material.

Gift: Our business for today, *re itse rena le* load. *Na re hlalositse* load? (We said we have load. Did we explain load?)

S14: the force applied to the elastic material.

Gift: ok, you are saying it's the force applied to the elastic material.

S15: I can say it's the mass applied to the elastic material.

Here Gift had just told her students that they were going to study Hooke's law the following day and that this law looks at the behaviour of elastic materials when a load is applied. She allowed her students to define 'load'. This is where a language difficulty emerged. The students seemed to use both force and mass as the quantity applied to the elastic material. Gift explained the difference as follows:

Gift: [...] but the definition of the load is the force that is applied because when you hang the mass, *re tlo ba le* a force there. You hang the mass but the results *ke* stretching force. Force *ke* mass times... *ke* mass *thaemese* acceleration or mass *thaemese* gravity.

Translation

Gift: [...] but the definition of the load is the force that is applied because when you hang the mass, we are going to have a force there. You hang the mass but the result is stretching force. Force is mass times... is mass multiplied by acceleration or mass multiplied by gravity.

This explanation was used to show that mass and force are different concepts in Physics. Gift did not specify the force that she was talking about when a mass was hung and why this hanging mass would result in a force. In her explanation, she described 'force' as "mass multiplied by acceleration or mass multiplied by gravity". She was referring to

gravitational field strength and calling it gravity in a way that may also lead students to call it similarly, which might also lead to increasing language difficulties in the Physics classroom. Having explained this, Gift wanted her students to use the formula $W = m \times g$ to convert the load given as mass in grams seen on the table she had drawn on the board. Students took a long time to convert this, coming up with different answers with different units. The following excerpt shows the different answers provided:

Gift: How much will be the load? Pointing at 1000 g.
 S in chorus: 100 N
 Gift: *le e fumana joang 100 ee?* (How did you get that 100?)
 S in chorus: force is equal to mass...mass over...mass (a lot of murmuring)
 Gift: *hana re ne re re weight re e calculata joang?* (How did we say weight is calculated?)
 S16: $mg = \text{weight}$
 Gift: *le sebelise formula eo ea* (use that formula for) weight to find the load for 1000 g, 2000 g, 3000 g, 4000 g
 S: working out the load in their exercise books
 Gift: ke 400 N? (Asking after going around to see how students work out the load).
 S17: 400 N/kg...400 N/g
 Gift: *hana load ke force na liunits tsa force li na le bo per kg?* (Weight is a force... do the units for force have per kg?)
 S in chorus: no

Although Gift mentioned in the post-observation interview that her students had already been taught about the relationship between weight and mass, there was evidence of a struggle, both in calculating the weight and in choosing the units attached to weight. The problem was observed in converting mass in grams to mass in kilograms before using the relationship of weight and mass to find weight. Having reflected on her teaching during the post-observation interview, Gift suggested that if she was going to teach this concept again, she would include the weight calculation in her introduction, she said:

Gift: I think the idea of calculating the force could be using this formula for weight. They have already been taught about that. So, I think it can be one of the prior knowledge which I think before I start teaching I can ask them so that they can recall *le ha eba ba e lebetse* (even if they have forgotten) I can try to remind them in my introduction.

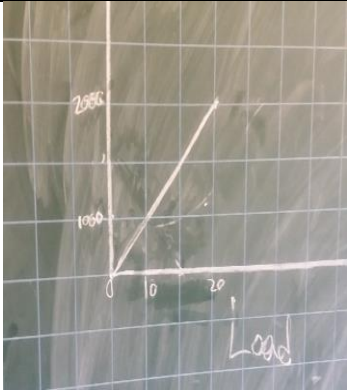
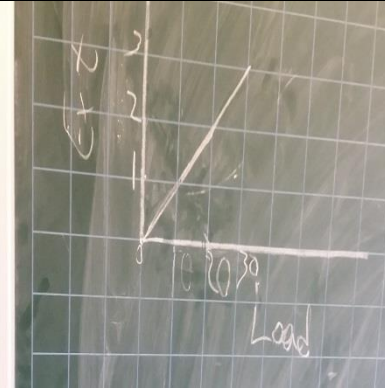
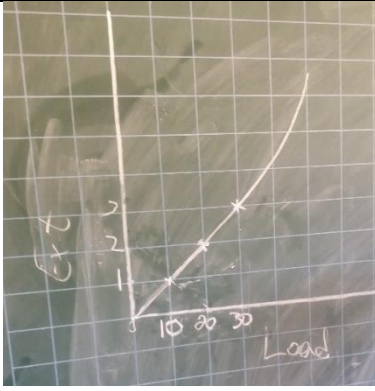
From her statement, it shows that Gift did not anticipate this to be a learning difficulty because she knew that her students had already been taught this idea. This knowledge of converting mass to weight was used in plotting the extension-load graph. In the pre-

observation interview, Gift had only indicated that her students might have a problem plotting the graph since the graph involves Mathematics which some struggle with, but she had not specified the area of struggle as she said:

Gift: The difficulties may be, we are going to draw some graphs [...] so graphs are some kind of mathematical ... and some students can find it a problem working with Mathematics, so I think the problem will be trying to plot some graphs ... it's not going to be just as easy as that. I think it's some kind of a challenge. Because plotting a graph means you are going to identify the x and y values.

Although the specific challenges with the mathematics involved in plotting the graphs were not stated, these challenges were seen in Gift's teaching as non-uniform scale when plotting the graph and some which she did not mention included unlabelled axes, writing numbers in the squares instead of on the lines when plotting the graph, leaving out the units of the quantities involved. These are shown in Table 4.8.

TABLE 4.8: HOOKE'S LAW GRAPHS

		
Drawn by S21: non-uniform scale, no units, unlabelled y-axis, numbers used on the y-axis are mass in grams not extension.	Drawn by S22: no units on labelled quantities, numbers are placed in squares on the load axis.	Corrected by Gift but still left out units of quantities.

When asked in the post observation interview about what might be the impact of leaving out the units in her teaching of this concept in class, Gift indicated:

the impact could be ... eh ... that could lead *hore le bona* (to them) in the future *ba siee* (leave out) units and not just being unaware just because I did it in class *e be* (and) they think there is no problem there.

This meant that Gift was acknowledging that some of her actions during the lesson might have led students not to be careful enough about the units, having seen the teacher leaving them out and also not commenting about them when they were left out.

Knowledge of dimensions of ‘science’ that are important to assess

Gift believed that her assessment should be guided by the syllabus. In her two pre-observation interviews, Gift indicated that she would assess their knowledge more than any other objectives described in the syllabus. She said:

Gift: [...] I thought of knowledge because I think even if I could manage to ask them some questions, I think it could be based more on knowledge. *Kea kholoa* (I believe) basing myself again on the syllabus.

Gift: Eh...I think it's the knowledge, because I base myself on the syllabus, *hore na ere re asseesse part e feng*. (What it says about which part to assess).

Gift intended to concentrate on assessing knowledge of the content that she taught. Knowledge falls under objective A in the LGCSE Physical Science syllabus (NCDC, 2019). This objective involves recall and explanation questions and she pointed out that she was guided by the syllabus to assess knowledge of this topic.

Knowledge of the methods through which learning can be assessed

When asked about the methods of assessment she would employ in her teaching, Gift indicated that she was going to assess her students orally. Giving the reasons in her day two interview, Gift mentioned that:

Gift: I am going to employ oral questioning ... the main reason behind this is if I could say everyone should have an exercise, it's going to be a long time process to finish the marking, I could mark but *ke se ke le kantie ho* (when I am outside the) class.

Looking at her overcrowded class, Gift chose oral questions as most effective so that she could take a shorter time assessing, rather than involving written work which would require marking. During the classroom observation, Gift used oral questions to ascertain

students' understanding. Examples of the questions and answers involved are illustrated as follows:

Gift: ... *Re bona* (we see) the load *e/e* (being) directly proportional to the extension. Can we have someone to state Hooke's law?

S28: Hooke's law states that the force is directly proportional to the change in length.

Gift: Ok when do we know that the object obeys Hooke's law? Yes sir (pointing at the student)

S29: if it does not have a straight line

Gift: what causes a straight line?

S30: direct proportionality

Although this topic could involve other assessment objectives, Gift intended to assess only knowledge in her class. Like she had shown in the pre-observation interview, Gift asked questions which involved recall and explanations orally, which she believed would save her time. This implies that Gift had restricted her assessment methods to methods which would save her time and avoid marking because of the overcrowded classroom.

4.3.3 Case 3: Jimmy's narrative on the teaching of the 'turning effects of force' for Grade-11

4.3.3.1 Jimmy's Profile

Jimmy is a head of the department of Science and holds a BSc Ed degree. His major subjects are Physics and Geography. He teaches eighteen periods (40-minutes long) and has taught Physics for sixteen years. He also code-switches between Sesotho and English to teach Physics. Jimmy seems to be a friend to his students, passing jokes during his teaching and his lessons are characterised by fun and laughter.

Jimmy teaches Physics in a mixed gender government school that was established in 2007. The school has fifteen classrooms with about eight hundred students. There are an average of fifty students per classroom. In this school there are thirty-three teachers and six of them are Physics teachers. All students in the senior secondary enrol for Physical Science. Although the school has a laboratory, Jimmy stated that there is not enough equipment in the laboratory.

4.3.3.2 Jimmy's Classroom practices when teaching the 'turning effects of force' in Grade-11

Jimmy had neither any apparatus nor a workstation for doing demonstrations in his class. He taught the required concepts having engaged with only one illustration of clockwise and anticlockwise directions using a stick placed on his head. To teach the principle of moments, he used 2-dimensional diagrams drawn on the board. When I asked why he could not do this practical topic in the laboratory so that his students would be able to answer the practical examination, he indicated that he was very satisfied with his teaching technique. He made this claim in the post-observation interview:

Jimmy: [...] when I teach, in most of my teachings, I teach this bearing in mind that my students write what we call alternative to practical, and that is to say I know that there is not any point where they are going to be engaged in the lab in the exam where it will be said put this thing here and then measure the distance but all those things are going to appear as theories. So I engage them in much of the theories such that even if they are not going to be hands on, they master the theory [...] I knew that I could do it in the lab but knowing the fact that they are doing an alternative to practical I said let me do it this way, remembering that they are not going to be exposed to saying do this in the exam practically. [...] I imparted knowledge to them in the absence of practical, the knowledge was imparted in the absence of practical (emphasising). [...] Believe you me; I would not take them to the lab, for reasons of time and other reasons of course because I believe in myself. I believe that things that I say with my mouth, they make students understand fully what I am driving them towards, so I believe that what I am doing in class is sufficient for them to face the exam of either kind.

When Jimmy reflected on his teaching, there was a contradiction with what he had said earlier in the pre-observation interview and that was that he would engage his students in the laboratory, provided the laboratory equipment was sufficient and if he was not limited by time constraints. In this instance he emphasised that he was not willing to do experiments in the laboratory because of the nature of the exams that his students would write. This indicates that Jimmy had appropriately selected teaching strategies, according to his understanding, that were the best for teaching according to examination requirements. Realising that Jimmy thinks he is teaching in the best way he could ever teach; the following discussion portrays his activities in the classroom.

Illustrations

Having indicated that students confuse clockwise and anticlockwise directions in his pre-observation interview, Jimmy began his first lesson by illustrating the directions with a

stick on his head, referring to how the clock hands rotate to show the difference between clockwise and anticlockwise directions.

Jimmy: *Naka la watch kaofela le tsamaea clockwise.* (Demonstrating clockwise rotation by pushing the stick placed on his head). This is the clockwise direction. *So ha u sa etse ntho tseo watch e li etsang, u ea the anticlockwise.*

Translation

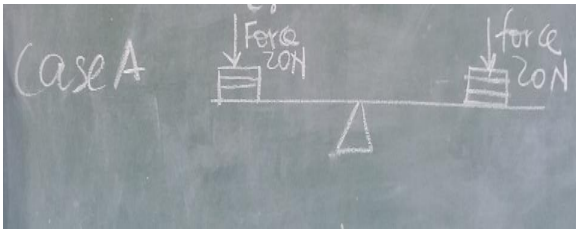
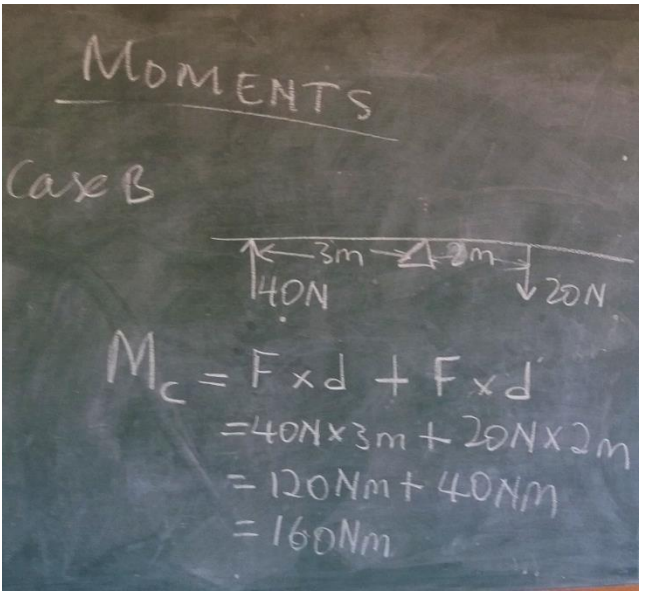
Jimmy: The clock hand rotates clockwise. (Demonstrating clockwise rotation by pushing the stick placed on his head). This is the clockwise direction. If you do not do what the clock does, then you are rotating anticlockwise.

With this illustration, Jimmy emphasized the difference between clockwise and anticlockwise directions, showing how the bar turns when a force is applied so that his students could identify forces which turn the bar clockwise or anticlockwise as they apply the principle of moments.

Examples

Shulman (1986) argues that to make a subject more comprehensible to students the most powerful forms of representation should be engaged. Representations include examples used to develop the concepts. Looking at the examples used by Jimmy to develop the concept of the principle of moments they were limited, with only case A demonstrating the principle of moments while case B not addressing the conditions of equilibrium. The examples used are illustrated in table 4. 9.

TABLE 4.9: EXAMPLES USED FOR TEACHING PRINCIPLE OF MOMENTS

Case A	Case B
 Case A $f = \text{force in Newton (N)}$ $d = \text{distance in meters (m)}$ $M = f \times d$ $= 20\text{N} \times 2\text{m}$ $= 40\text{Nm}$ Even on the other side the Moment would still be 40Nm	 MOMENTS Case B $M_c = F \times d + F \times d$ $= 40\text{N} \times 3\text{m} + 20\text{N} \times 2\text{m}$ $= 120\text{Nm} + 40\text{Nm}$ $= 160\text{Nm}$

The principle of moments states that when the system is in equilibrium, the sum of clockwise moments is equal to the sum of anticlockwise moments. In case A, the conditions of equilibrium hold while case B could never be in equilibrium and so the principle of moments could not be applied but Jimmy chose to use this example. This brings into question Jimmy's PCK because of his choice of examples. While Cochran *et al.* (1993) contend that PCK grows with experience, one would expect that Jimmy might have gathered more useful examples to teach this concept because of his experience, but this was not the case in this classroom. When asked about his choice of examples in the post-observation interview, Jimmy argued that his choice of examples was appropriate since it helped students to see that the system cannot always be at equilibrium and, according to him, the inclusion of examples not obeying the principle of moments was one way of developing the concept of moment of a force. This is how he responded to the question he was asked:

I: In general, how do you select the examples that you use in your teaching of this topic?

Jimmy: Look at it from this perspective, I started with those that are balanced, then you derive from something that is known to something that is unknown, try to be a little complex, you are trying to be smart by saying let me try to bring something that is a little

challenging there. [...] This time they are going to see that there is going to be some toppling on only one side, with that example, it was to open their eyes that it is not going to always be the case that the system balances.

Although Jimmy's example did not obey the principle of moments, he was contending that this example was still helpful in developing the concept of the principle of moments since it would make his students see that the principle is violated. He believed that it was an indicator that his students understood the principle if they could tell that the principle of moments had been violated. In his classroom unfortunately, no student noticed this; they just looked at Jimmy working out the clockwise moment as shown in Table 4.9.

Advantages and disadvantages of particularly-chosen teaching strategies

In his pre-observation interview, Jimmy had shown that he would use illustrations and discussion as his teaching strategies, because he believed that they help to bring reality into the classroom and to address the abstract nature of the concepts he was dealing with. In our conversation, he indicated that:

I: What are the teaching procedures or methods are you going to use?

Jimmy: Illustrations, discussions

I: Why would you choose to use such procedures?

Jimmy: To try to bring it to reality, to make these abstract things come to life.

The choice of teaching strategies was based on knowledge of the nature of the concept taught, but in Jimmy's classroom there was no apparatus used to develop the concept, contradicting what was said earlier. He had indicated that if he had a laboratory, he would teach this concept differently. He also showed that he was aware that in the absence of resources he had to use improvisation and that would help, but due to time constraints he could not improvise. He said:

Jimmy: *Lilab, ha ke ne kena le lab, ke ne ke tla li etsa labong re li behe hantle re sebelise li ruler, but mokhoa oa ho improviser o ntse o le teng re ka li etsa, empa feela ele hore taba ke nako, re tlameha ho covera a lot.*

Translation

Jimmy: Laboratories, if I had laboratories, I would treat these concepts in the laboratory using rulers, but there are still ways to improvise, we can do that, but there is no time, we have to cover a lot.

Jimmy seemed to know the best ways of teaching this concept and the teaching aids he would require to develop the concept but factors such as a lack of laboratories (George, 2017) limited his utilisation of known teaching strategies and he resorted to choosing other methods which are often deemed inappropriate to teach Physics (Qhobela & Moru, 2009). Although in our discussion he mentioned that the laboratory was there, he considered it not helpful as there was not enough equipment and that is why he referred to it as non-existent. This is contrary to what he had said in the post-observation interview where he reveals that he was not going to the laboratory on purpose, to rather teach the theory so that his students might be able to face the alternative to a practical examination.

Prerequisite knowledge

Jimmy stated in his interview that one of the challenges he had when teaching this topic is the lack of prior knowledge amongst the students of the concepts involved. He indicated 'direction' as one important concept needed when learning this topic, but students do not always understand this concept. He said:

Jimmy: One would think they know the clockwise and anticlockwise direction, but the moment you teach, you find that they do not understand these.

This is the prerequisite knowledge that Jimmy was expecting from students before teaching this concept. Being aware of this Jimmy engaged in an illustration to show these directions at the beginning of the lesson.

Misconceptions

Jimmy was aware of the misconceptions that students have on this topic, which were revealed in his pre-observation interview:

Ba na le ho etsa clockwise ebe anticlockwise, ba etse (they have a tendency of treating clockwise as anticlockwise and write) and N/m instead of Nm.

In his teaching Jimmy tried to address these misconceptions when he illustrated the clockwise and anticlockwise directions using a stick on his head and explained why the units for moment should be Nm not N/m, he said:

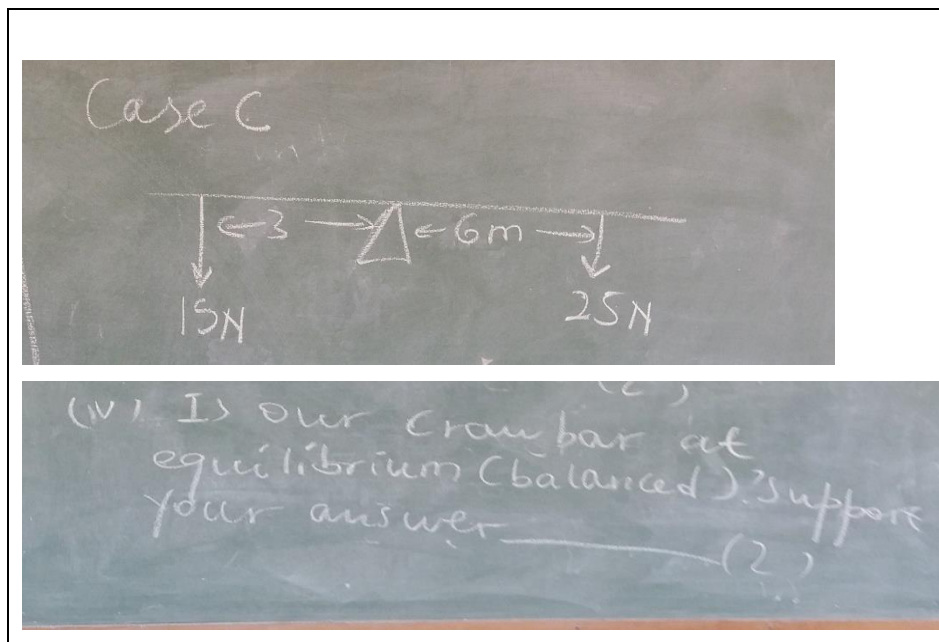
Jimmy: So our moment here is N *thaemese* metres. So *u tla bona motho e mong a sa itse* N/m. *Feela re sena per. Empa re itse ke* force in Newtons multiplied by distance in metres. So it should be Nm not N/m. So our force F is in Newtons, N, and our distance d is in metres m. So that is why we come up with these units because we multiply force by distance, so we have Nm like we said.

Translation

Jimmy: So our moment here, is N multiplied by metres. So you will see one having written N/m. While we do not have 'per'. But we said it is force in Newtons multiplied by distance in metres. So it should be Nm not N/m. So our force F is in Newtons, N, and our distance d is in metres m. So that is why we come up with these units because we multiply force by distance, so we have Nm like we said.

With this Jimmy was emphasizing the origin of the units for the moment of a force to try to prevent students expressing these units as N/m. Although Jimmy was aware of some of the possible misconceptions, others came up during his teaching; where some students thought the forces have to be equal on either side of the pivot for the crowbar to be at equilibrium. This might have been the result of Jimmy stating the principle of moments without emphasizing the conditions needed for equilibrium. Jimmy used the example below (table 4.10) to ascertain students' understanding.

TABLE 4.10: CASE C AS AN EXAMPLE



From the students' responses, it could be deduced that some students did not understand the conditions needed for equilibrium.

Jimmy: Is our crowbar at equilibrium? That means is it balanced or not?

S5: yes sir.

Jimmy: oh it is at equilibrium? Support.

S6: no, because the clockwise is 25N and anticlockwise is 15N

In the responses there was a student who thought the crowbar was at equilibrium and had not been given a chance to state the reasons for thinking like that. Giving this learner a chance to explain his answer might have led Jimmy to clarify the student's problem so that he could help the student understand what was being taught. There was also a student who thought the crowbar was not at equilibrium because the forces were not equal on either side of the pivot. This might have emerged because of the use of only one example where equilibrium was achieved when forces were equal on either side of the pivot. This suggests a need for a variety of examples catering for different occasions where the system is in equilibrium, to develop the concept - not just one example.

Content knowledge

In his classroom Jimmy seemed confused about how direction is implied in the calculation of moments when applying the principle of moments. The excerpt that follows shows how he viewed the direction of the action of forces and their relationship with the resulting moment:

The moment of this force M1 is equal to this force multiplied by the distance that is the moment. Now because you said the forces are going to balance, there is no clockwise moment or anticlockwise moment but the moment is there. The moment is the force multiplied by the distance. [...] So in the absence of clockwise or anticlockwise moments, there is no direction.

With this explanation involving moments and direction Jimmy was referring to the diagram he used as one of the examples.



FIGURE 4.18: A CROWBAR WITH EQUAL LOADS

Explaining the direction of the action of force needed to cause a moment in a certain direction, Jimmy seemed to have a misconception about when the forces are equal on either side of the pivot, there are no clockwise and anticlockwise moments and there is no direction. With him having shown that to his students who often do not have much prior knowledge of clockwise and anticlockwise directions, it would be expected that he would prepare more examples to deal with this in his teaching and show how it is implied in the particular example that he chose. So here, Jimmy's lack of clarity might lead to some confusion for the students when it comes to direction in calculating moments and when the system is at equilibrium. The statements he made might have been due to limited content knowledge of the topic he was teaching, which could cause misconceptions for the students since the balancing is caused by equal clockwise and anticlockwise moments while he explained that when forces balance there is no direction. This shows a lack of clarity emerging from the teacher's explanation.

Knowledge of dimensions of science that are important to assess

In his pre-observation interview, Jimmy indicated that he intended to assess knowledge of theories and calculations in this topic. In the LGCSE syllabus, NCND (2019), the assessment of understanding and knowledge of theories appears in objective A: Knowledge and understanding while the assessment of calculations is under objective B: Handling information and problem solving. This indicates that Jimmy's assessment goals were in line with the LGCSE syllabus assessment objectives.

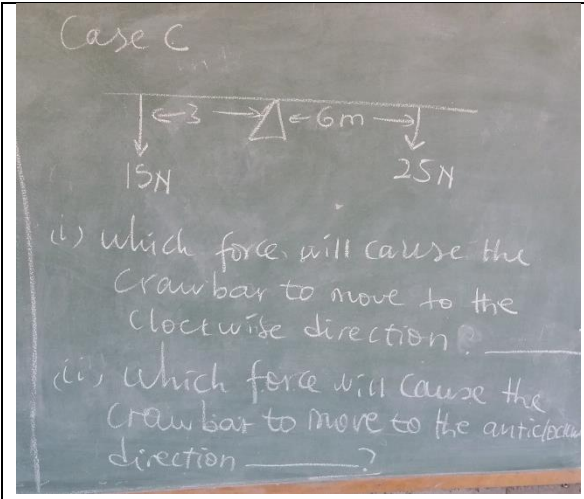
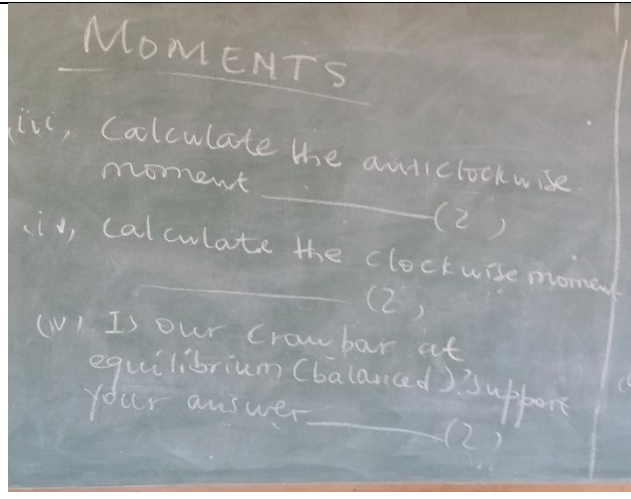
Knowledge of methods by which learning can be assessed

Jimmy intended to engage in oral questions and written classwork to ascertain students' understanding, as stated in his interview and the intended methods of assessment were engaged with in his classroom. He dedicated the whole of the second lesson to assessment, marking in the class and then discussing the students' responses to the questions. When I asked in his post-observation interview about why he assessed what he had taught in the previous lesson for the whole of the second lesson, he argued:

Jimmy: Assessment gives information about what students understand, the misconceptions they still have in the topic and the gaps that need to be filled in their understanding. *Le hanka ba ka hloloa ho ruta hantle, ka assessment ke bona hantle moo bana ba nang le bothata ebe ha ke ntse ke ba ts'oaea ke ruta ka liphoso tsa bona.* (Even if I may fail to teach effectively, with assessment, I am able to see where students have problems, and while I am marking, I teach based on the problems I identified).

Jimmy showed that he valued the assessment stage, as it directs and channels his teaching to the identified points of misunderstanding. The time spent on assessment was indeed characterised by marking and going around the classroom, calling students' attention to talk about challenges he had observed, as he marked and addressed these challenges. The questions Jimmy included in his assessment are shown in Table 4. 11.

TABLE 4.11: ASSESSMENT QUESTIONS FOR CASE C

 Case C Diagram showing a crowbar with a fulcrum in the middle. A downward force of 15N is applied at a distance of 3m to the left of the fulcrum. A downward force of 25N is applied at a distance of 6m to the right of the fulcrum. (i) Which force will cause the crowbar to move to the clockwise direction? (ii) Which force will cause the crowbar to move to the anticlockwise direction?	 <u>MOMENTS</u> (iii) Calculate the anticlockwise moment _____ (2) (iv) Calculate the clockwise moment _____ (2) (v) Is our crowbar at equilibrium (balanced)? Support your answer _____ (2)
--	--

Jimmy used the students' answers to address learning difficulties. He spent most of his time explaining the concepts after every question was revised. Some of the learning difficulties Jimmy mentioned in the interview were that of leaving out units in calculations or writing units for the moment of a force as N/m, but there were further difficulties observed in students' responses such as writing the Newton(s) with a small letter. Also, they often failed to differentiate between clockwise and anticlockwise moments. This was seen when a student answered the same question in two different ways, first adding both clockwise and anticlockwise moments to find the anticlockwise moments and then calculating the anticlockwise moment using one anticlockwise force. The same student had been able to identify the force causing a clockwise moment and also the force causing an anticlockwise moment correctly. An example of an exercise that the teacher had marked is given in figure 4.19:

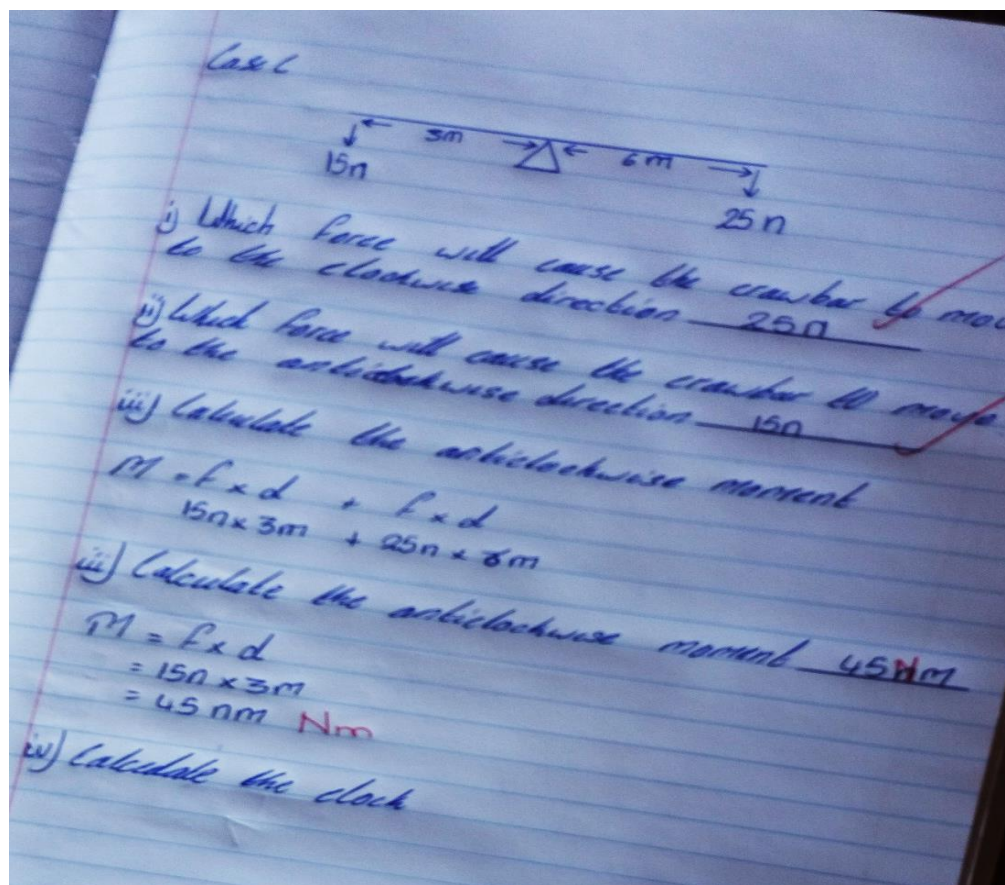


FIGURE 4.19: MARKED EXERCISE

In the same script, the answers involving units as Newtons are seen written with a small n instead of a capital N. Jimmy seemed to have realised that his students made errors when writing units; either writing the units incorrectly or leaving them out. Jimmy seemed to be quite particular about both writing units and writing them correctly. He was heard on two occasions saying:

Jimmy: *Le tseba hantle hore ha hona ntho eo ke ee e ngole ka classeng ka mona without units joale lona le ea kae?* (You know very well that I never write anything in this class without units, what is it that you are doing?) (Complaining as marking).
That is 25 N. Now which force moved the crowbar to the anticlockwise direction? Not which distance not which direction but which force, answer the question. *Ke batla Newtons mona u kampa oa fosa tse ling eseng li units.* (I want Newtons here; you may get other things incorrect but not units).

With these statements, Jimmy wanted his students to take an example from him, namely that he never left out the units in his calculations. That implies that he had noticed that some students left out the units in their calculations. He also emphasised that he was not expecting his students to write incorrect units at all. This implies that Jimmy was taking the issue of 'correct units' seriously in his teaching and he did not expect any student to write physical quantities without units.

The other learning difficulty that emerged was that of students thinking that when the forces are not equal on either side of the fulcrum, the system would not be in equilibrium. This was evident when one student argued that the crowbar was not balanced because of unequal clockwise and anticlockwise forces; answering the question as follows:

Jimmy: ... Is it at equilibrium?
S5: yes sir.
Jimmy: Oh it is at equilibrium? Support.
S6: No, because the clockwise is 25N and anticlockwise is 15N
Jimmy: *Ele hore ho ea ka uena* (so according to you) this 25N stands for clockwise, this force stands for clockwise. So we all say no, it is not balanced. Sir, we have others who are going to give their answers, *uena u mamele likarabo tsa bona.* (You listen to their answers).

While student 6 thought that the crowbar would not be in equilibrium because the anticlockwise and the clockwise forces are not equal, student 5 thought that the crowbar would be in equilibrium. Although Jimmy did not follow up on student 5's thinking, this might have been the result of the diagram which shows the crowbar balanced while the

moments were not equal. In addressing this, Jimmy asked one more student to give the answer and also to support his answer. The student stated:

S7: The crowbar is not in equilibrium because clockwise moment is not equal to anticlockwise moment.

Unlike other students, student 7 gives the reason for the crowbar not being in equilibrium, looking at the equality of moments in both clockwise and anticlockwise directions. After commenting on the response given by S7, Jimmy supported S7 with more explanations why his answer was correct, while he was also emphasizing the concepts of the principle of moments. He said:

Jimmy: [...] how do we calculate the right side, how do we calculate the left side? Where is your Physics there? The Physics is in the moments where we know the moment is the force multiplied by distance so that the force multiplied by the distance this side is not equal to the force multiplied by the distance that side. You can't just say this side is 25N and that side is 15N, no, who said that? What matters is the distance. *Mona re sheba* moment, *ha re shebe* distance *ha reshebe* force, *re sheba* moment *re sheba* force multiplied by the distance. *Se ka sheba* distance *feela*, *se ka sheba* force *feela*. *Li shebe li le peli*. (Emphasizing) I multiply, force by distance, *eleng* moment. So in your reasoning *re bue ka taba ea moments feela*, *hore* anticlockwise moment *ha e lekanele* clockwise moment, *eleng* force *thaemese* distance. So the answer is no.

Translation

Jimmy: [...] how do we calculate the right side, how do we calculate the left side? Where is your Physics there? The Physics is in the moments where we know the moment is the force multiplied by distance so that the force multiplied by the distance this side is not equal to the force multiplied by the distance that side. You can't just say this side is 25N and that side is 15N, no, who said that? What matters is the distance. Here we look at the moment, we do not look at distance we do not look at force, we look at the moment, and we look at force multiplied by the distance. Do not just look at distance only. Do not only look at force. Look at both of them (emphasising). I multiply, force by distance, which is moment. So in your reasoning let us talk about moments only, that anticlockwise moment is not equal to clockwise moment, which is force multiplied by distance. So the answer is no.

Jimmy seemed to have noticed the challenges faced by his students as they answered the question. Unlike in the first lesson where Jimmy seemed to have explained only a little in the development of the concept of the principle of moments, in his second lesson Jimmy was more direct with explanations targeting the challenges that emerged during

his assessment. Identified in his assessment were more misconceptions, such as students treating force and distance as separate entities when determining the equilibrium of the system, while their product is what is important. Jimmy was able to emphasise important concepts emerging from his assessment, directed by the learning difficulties.

4.3.4 Case 4: Joy's narrative on the teaching of the 'turning effects of force'

4.3.4.1 Joy's Profile

Joy is a male teacher who teaches Physics and Mathematics. He holds a Diploma in Education Secondary. His major subjects are Mathematics and Physics. He teaches thirty five (40 minutes) periods per week. He had been teaching Physics for four years at the same school. It is a mixed gender government school that was established in 2010. The school has twelve classrooms with about seven hundred students. There are an average of sixty students per class. In this school there are sixteen teachers with two Physics teachers. All students in senior secondary enrol for Physical Science. The school has a laboratory with not enough equipment. Joy conducts his classes in the laboratory where there is one front desk where he puts his teaching aids. He uses both Sesotho and English to teach Physics. Joy's class is very interactive, with students having arguments with each other and questioning the teacher for clarification. Joy seemed to know his students quite well since he calls them by names during discussions.

4.3.4.2 Joy's Classroom practices on the teaching of 'turning effects of force' in grade 11

At the end of each lesson, Joy asked his students to come to the next lesson having read the content that was to be covered. He was heard saying this at the end of each of the three lessons observed. This was also evident in the introductory questions that he asked the class and often his students were familiar with the content that they were going to learn.

Activities

Joy's first lesson was very interactive. Before Joy could begin engaging with the activities he planned to use to develop the concepts, there was a discussion where students exchanged ideas around the principle of moments and related concepts. Joy asked students to mention the concepts they were going to learn in the turning effects of force and while they mentioned them, Joy wrote them on the board.

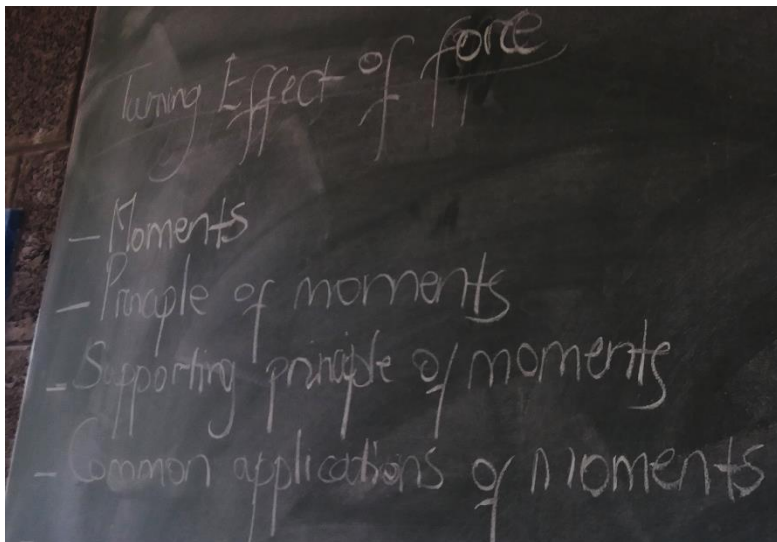


FIGURE 4.20: TOPICS TO BE COVERED

The students seemed to have come to class having knowledge of what they were going to deal with since they were able to list the concepts under the subtopic. This was followed by a discussion where Joy asked questions orally around the concepts related to the principle of moments. An example of such interactions:

Joy: We define moments as the turning effect of force about a fixed point. The moment of force is defined as the turning effect of force about a fixed point. The fixed point, *ke hore re bolelang*? (What do we mean)? Yes?

S14: the pivot

Joy: the pivot. What is this pivot?

S in chorus: the turning point.

S15: the fulcrum.

Joy: the fulcrum? *Hothoe keng* (what is it) yes sir?

S16: I think the fixed point is the point where moments are taken from.

Joy: the point where the moments are taken from. [...] Is there anywhere where you have come across this concept?

S17: yes sir I think it's the seesaw.

Joy: *ka language ea motseng e bitsoang?* (What do you call it in home language)?

S in chorus: *koche*

Joy: [...] how is the application of the moments there?

In this discussion, Joy wanted the students to define a pivot and used their daily life experience of the principle of moments to understand a pivot where they have seen it in action as they play on a seesaw. By discussing this experience, Joy then bridged what the students know about the principle of moments to the concept learnt in the classroom by involving a demonstration. Before this demonstration, Joy asked questions about how to calculate a moment.

Joy: How can we find these moments? *Ho itsoe* moments are the turning effect of force. *Joale ha u bua ka principle u bua ka hore* the clockwise and the anticlockwise moments have to balance. *Joale the clockwise re tlo e thola joang hore re tle rere hona ke clockwise?*

Translation

Joy: How can we find the moments? It was said that moments are the turning effect of force. So when you talk about this principle, you say that the clockwise and the anticlockwise moments have to balance. So the clockwise, how are we going to identify that now this is clockwise)?

S20: To find the clockwise moments, we multiply the force exerted by the distance from the pivot to the force.

Joy: Donny

S21: We calculate the moments by multiplying the force by the distance from the pivot.

Without commenting on the responses given by a student, Joy moved on to select another student to explain how the clockwise moment is found. Both students gave a general way of calculating the moment, but not specifically the clockwise 'moment' as Joy demanded. Without helping the students to identify the clockwise moment, Joy moved on to a demonstration. In the interview Joy had indicated that students confuse clockwise and anticlockwise directions; with this having been said before the class started it could have been expected that Joy would then address this point of confusion, especially after hearing that the students were not sure about direction when explaining how to calculate clockwise moments. This implies that there might be students who do not understand what a clockwise direction is and what the meaning of a clockwise moment is.

Demonstrations

Joy used two demonstrations to develop the principle of moments. Table 4.12 shows the demonstrations used by Joy.

TABLE 4.12: DEMONSTRATIONS USED BY JOY

 A 50cm ruler on a retort stand without the load	 A 50cm ruler on a retort stand with load
--	--

The first demonstration that Joy began with to develop the concept of the principle of moments involved a ruler supported on a retort stand without any load and left to balance on the pivot. A student who proceeded to communicate his observations to the whole class presented the second demonstration.

Joy: Ok. We have the materials here, we have the retort stand though incomplete, we have a metre rule, ebe re ba le half a metre here it is 50 centimetres. We also have the loads here, the 10g loads. From there we have these (holding two triangular prisms). [...] We said there is the centre of mass. At the centre of mass *eo re buileng ka eona ha re ne re qala ka mane ka* (that we talked about when we began) the centre of mass of the plane lamina. We said that if we can support the object at the centre of mass, the plane lamina was balancing; it was at equilibrium, *ho joalo?* (Is that so)? Now you have got the rulers here, can we have someone to try to support it on the retort stand? *Re tsebe ho bona na e balensa ha e fihlile ho kae.* (So that we can see where it balances). May be that can help us to see where the centre of mass of this is. Any volunteer? Yes ntate (pointing at the student). Tell us what you are looking for?

S21: the centre of mass of...

Joy: Where is it? Is it marked one way or the other?

S21: No it is not. Because it is 50cm, I will just show that may be the centre of mass is at 25cm. (putting the 50cm ruler on the retort stand so that it balances).

Joy: What can we say about this? Ntate tell us where it is balancing?

S21: at 25cm

Joy: Its length is 50cm. So what can we say about this? *Eea ntate* (pointing at another student)

S22: I think it supports that anticlockwise moments are equal to clockwise moments because there is the same perpendicular distance from our turning point. The load is the same.

With this demonstration, Joy wanted the 50cm ruler to be placed on the retort stand so that it attained equilibrium. Having reviewed prior knowledge about the centre of mass at the beginning of the lesson, Joy linked this knowledge with the balancing of the half-metre ruler on the retort stand to develop the concept of the principle of moments (Magnusson *et al.*, 1999). The second demonstration involved a ruler with hanging loads on either side of the pivot. The demonstration was still made by the student, explaining his observations to the other students.

S25: demonstrates the principle of moments but hangs weights on either side of the pivot so that the ruler balances.

Joy: what are your marks?

S25: 49 and 1

Joy: so it's 49, 1 now.

S25: yes

Joy: and the loads?

S25: 10g

Joy: *hona le ntho eo re tlo e etsa, ho itsoe li moments re li calculate joang?* (There is something that we are going to do, writing on the board as students answer, how are the moments calculated?).

S in chorus: force times perpendicular distance from the pivot.

The demonstration was followed by an explanation of how to calculate the moment and Joy emphasized the distance used as the perpendicular distance from the turning point to the force and said “[h]a re nke feela (we do not just take) the distance, re nka (we take) the distance from the pivot e perpendicular to the direction of the action of the force.” Since Joy had pointed out the distance used in the calculation as one challenge in the teaching of this topic, the emphasis he made was meant to address this challenge.

Wrapping up his first lesson, Joy summarized the important points he wanted the students to learn through the demonstration. These concerned what he had identified as learning difficulties and also the important concepts to be taught in his lesson. He said:

Joy: [...] that means to calculate the clockwise moment, you are going to take this direction (showing with his fingers), distance from here to here (pointing at the pivot, to the force) multiplied by the load here, then that gives us the clockwise moment. And the distance from the direction of this force (pointing at the other load) multiplied by this load gives us the anticlockwise moment. [...] The principle of moments states that clockwise moments are equal to anticlockwise moments so that our object is in equilibrium.

The second demonstration was meant to develop the concept of the direction of action of a force to incorporate this into the principle of moments. Joy's choice of demonstration showed that he was developing a concept from something simple to something more complex, since he started with a ruler without any load and moved to a ruler with hanging loads. This implies that he had knowledge about sequencing the concepts to help students understand (Gess-Newsome, 2015).

Knowledge of representations

Demonstration

The demonstrations were meant to illustrate the principle of moments. In the first demonstration, there were no loads hanging on the ruler and therefore there were no moments calculated, but Joy used this illustration to explain that there are forces balanced upward and downward acting on the ruler, and that because the forces are on the pivot there are no moments of forces. The second demonstration involved two loads hanging on either side of the pivoted ruler. This was the demonstration that was used to explain the conditions of equilibrium. In his words Joy explained:

Joy: [...] the two moments, the clockwise and the anticlockwise moments, the moment about this point of the force and the moment about this point of the other force, should always balance then you are saying that the beam has attained equilibrium. *Eaba ho tsoeloa pele hape hothoe* (then we moved on to say) then if this is the case, then the forces, the sum of the forces acting vertically downwards ... we have got two forces, the force on my left and the force on my right. The sum of the two forces, *haeba rere nthoena* (if we say this) has attained equilibrium ... must be equal to the force acting in opposite direction of the two forces. We have got two forces acting now downwards, and another force acting in the opposite direction where does another force act?

S in chorus: at the pivot, the turning point.

Joy: the force acts at the turning point, so these are the conditions that support equilibrium.

After the explanation about the conditions of equilibrium, Joy used another demonstration illustrating the effect of changing the load on the two distances from the pivot. This was used to verify the principle of moments. The student balanced the increased load on the ruler pivoted on the retort stand, which led to changing the distance from the pivot. Besides showing the balanced ruler on the pivot, the student also verified the principle of moments mathematically. This was illustrated in a diagram:

Handwritten text on a chalkboard:

$$\text{Anticlockwise} = \text{clockwise}$$

$$20g \times l_d = 240g \times 10g$$

$$l_d = 12cm \quad \frac{20g \times l_d}{20g} = \frac{2400cmg}{20g}$$

FIGURE 4.21: MATHEMATICAL VERIFICATION OF THE PRINCIPLE OF MOMENTS

The distance calculated shows that when the load is doubled on the anticlockwise moment, the distance is halved while the clockwise load and distance are kept the same. The same demonstration was used to illustrate how the units are converted from mass in grams to force in Newtons and from centimetres to metres so that the units for moments are given as SI units. The following excerpt illustrates what was done:

Joy: Good people this is mass, *mass ha se force hohang. Joale ho batla force re etsa joang?* (Mass is not force at all. So what do we do to find force)?

S14: We multiply by the gravitational field strength.

Joy: We have to multiply this by the gravitational field strength ... which is? We are going to use the formula weight equals mass multiplied by gravity to get the weight, and the weight is a force. When we have the weight in Newtons, *ke hona re tla sebetsa ntho ena ea rona ebe in metres.* (We will then work out this to be in metres). This is the mass in grams; we have to convert it to kg then to get weight by multiplying by gravitational strength *eleng* (which is) 10N/kg, *ebe re ba le* (so that we have) weight.

In his explanation, Joy wanted the students to understand that it will not always be the case that they will use units during moment calculations, but they will need to use the SI units at the end of the calculation. Being aware of this, Joy explained to the students how the conversions are done to get to the SI units.

Prerequisite knowledge

In his second lesson, Joy started the lesson by identifying one student who was absent in the previous lesson. He welcomed this student and asked other students to share with her all the concepts that were covered in the previous lesson. He stated that he was doing

this so that this student could be at the same level as the others before the lesson began. He said:

I see a new face today. Good people, can we have someone who can put Leslie where we are, *re mo late, u oa bona rea u tsotella?* (Bring her to us ... do you notice that we care about you)? Whatever a person can say that can help her to be where we are.

To Joy it seemed important not just to begin the day's activities but to help a student who had missed the teaching of the concepts gain the knowledge that had been taught in the previous lesson. This indicated that Joy cared that all her students had the prerequisite knowledge for the second lesson. In making the request about sharing the knowledge, Joy was asking students to share what was learned in the previous lesson. They responded as follows:

S1: we said a moment is the turning effect of force from a fixed point.

Joy: aha!

S2: we said a moment is equal to force multiplied by a perpendicular distance from the pivot.

Joy: (points at another student)

S3: we have clockwise and anticlockwise moments. We can calculate the anticlockwise moments by multiplying force and the perpendicular distance from the pivot. And our units are the Nm. We said the clockwise moments... going in front of the class to write on the board. We said these are the anticlockwise moments and these are the clockwise moments demonstrating with a diagram.

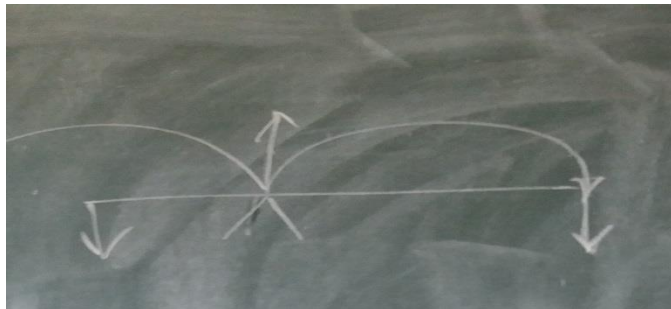


FIGURE 4.22: CLOCKWISE AND ANTICLOCKWISE DIRECTIONS

S4: the clockwise moments and the anticlockwise moments have to be equal.

Joy: any other thing?

S5: the forces for anticlockwise moments and clockwise moments must be equal.

Joy wanted the concepts to be revised before beginning the new lesson. He wanted to link what had been learned in the previous lesson to the new concepts about to be

covered so that there could be a bridge between already known concepts and the new concepts. He seemed to be developing the concept of the principle of moments spirally.

Knowledge of what makes a particular concept 'difficult'

Among the difficulties connected with the teaching of the principle of moments, Joy did not at first talk about the writing of correct units, but this emerged in his teaching when the students were calculating the moment of a force.

S13: Yes. We are going to multiply 10g with a distance, we are going to say, this 24 as our distance, and so we are going to say 10 times 24 for this side.

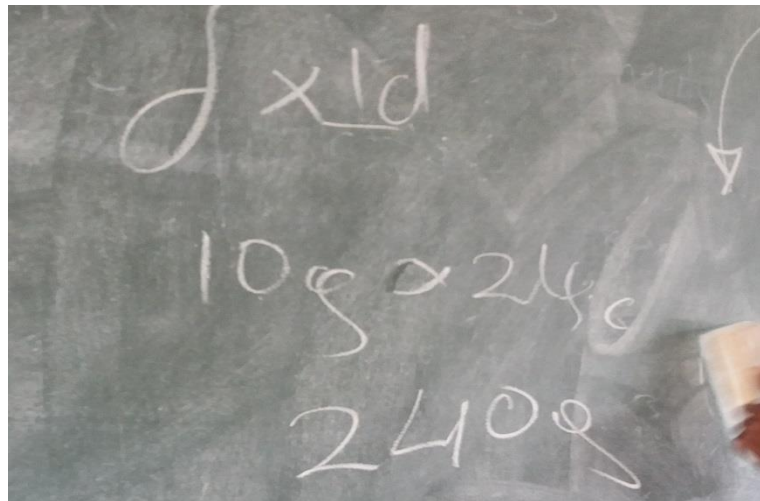


FIGURE 4.23: CALCULATION OF MOMENT

Joy: so the units will be?

S in chorus: Nm, Ncm, grams

Joy: *hela lona ha kere le multiplaile grams ka centimetres, joale units tse li tsoa kae?*
(Hey you, you have multiplied grams by centimetres, so where do these units come from?)

S in chorus: 240 gcm

While S13 seemed to be writing and rubbing out the units on the board, there were different units shouted out by the students. This indicated that they did not seem to know the correct units for the answer. They corrected the units after Joy had guided them to the quantities that had been multiplied.

Misconceptions

In the demonstration that was carried out in this class, students seemed to have a misconception that when the ruler has no load hanging from it while balancing on the pivot, then there is no load at all on the ruler. Joy had anticipated this, as he had illustrated in his pre-observation interview:

Joy: At times we say the beam ... its mass is negligible ... it is weightless ... when you are expecting to show the forces acting there, they do not consider the weight of the beam because at times it's considered negligible sometimes it is not negligible, they always leave it out when looking at the forces acting.

As Joy had mentioned - this emerged in the discussion following the demonstration, - some students thought, because the ruler was balancing on its own without loads hanging from it, then there was no load involved at all in the balancing.

S22: I think it supports that anticlockwise moments are equal to clockwise moments because there is the same perpendicular distance from our turning point. The load is the same.

S23: there is no load there.

Joy: There is no weight here, oh!

S22: the ruler itself is the load.

Joy: oh the ruler itself is the load. *Hothoe* (it is said that) the ruler itself is the load.

S in chorus: No

The majority of students were against the idea that the ruler itself was a load. This emerged as a learning challenge that Joy was aware of. In addressing this challenge, Joy asked questions aimed at directing students towards understand that the ruler has a load; namely its weight. Instead of being the one explaining, Joy let the students talk about their views until there was a point of agreement that the ruler is a load.

Joy: the ruler itself has its own load. And how much is that load? The load? Is that the weight?

S in chorus: yes sir.

Joy: is it?

S in chorus: yes

Joy: what makes it to balance?

S22: sir what if I say the gravity is pulling the ruler down on both sides?

S24: sir I am saying the ruler itself is a load because there at the stand where it stands, the force that is going up is the same as the force that is exerted by the ruler downwards.

Joy: I see people nodding, what are you agreeing with?

S25: the downward force exerted by the ruler is equal to the upward force exerted by the stand.

Although students came to an agreement that the ruler is balancing because of the balanced forces exerted by the ruler and the retort stand, there was one student whose idea was neglected who thought that the ruler is balancing because of the force of gravity pulling the ruler on either side of the pivot. This student had an idea of the centre of mass of the ruler and how it is responsible for the balancing of an object.

Knowledge of dimensions of science that are important to assess

In the pre-observation interview, Joy had said that he was going to focus on assessing knowledge, the application of moments in daily life, practical and analytical skills covered in this topic. Knowledge falls in objective A while practical and analytical skills appear under objective C of the LGCSE syllabus (NCDC, 2019). When I asked about which aspects of science knowledge he was going to assess, he mentioned:

Joy: Their knowledge, I am not just going to look at the examination questions, the applications of these in daily life ... can they use this in daily life? ... Can they use this and come up with solutions at home ... tomorrow in their lives ... can they use this and come up with solutions at home, at work or wherever they can be.

I: so what methods are you going to use to assess students' understanding of this topic?

Joy: for the class purposes, I just think it will be questions; guiding questions and we will have some sort of the quiz. But I am still thinking about that, because I said I want them to find the solutions on the other outside life ... I think I will find a way to assess that they look at the current situation ... we are having the tip-taps, *moo re hlapang matsoho teng* (where we wash our hands) and I will just think of the project they can do at school, *moo re ka sebelisang tip taps moo se re ka applya* (where we can use tip-taps to apply) the principle of moments.

Knowledge of methods by which learning can be assessed

Joy used oral questions as a method of assessment during his teaching, where students gave short answers or long explanations depending on the question asked. Examples of questions asked are:

Joy: *Joale* (so) the principle of moments *moo re bua kang*? (What are we talking about)?

The principle of moments, what is it?

S18: I think we talk of the clockwise moments and anticlockwise moments.

Joy: what about them?

S18: Because the principle includes clockwise moments and anticlockwise moments.

Oral questions were used during the development of the concept to direct students towards learning the concept. Joy asked these questions to individual students or to the class as a whole and responses were given by either an individual or in chorus. Another method of assessment evident in Joy's class was written classwork, where students worked out the answer on the board. An example:

Joy: Someone come and calculate the clockwise moments and anticlockwise moments.

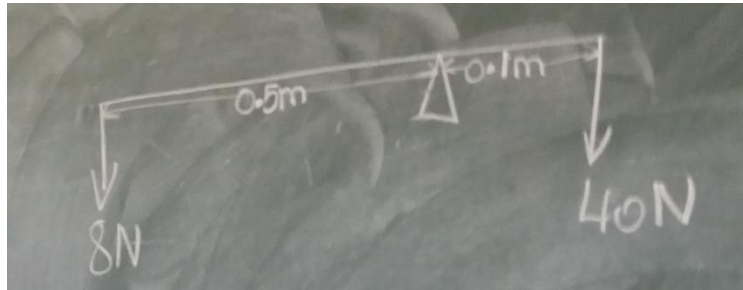


FIGURE 4.24: ASSESSMENT QUESTION ON MOMENTS

S17: calculates moments as follows

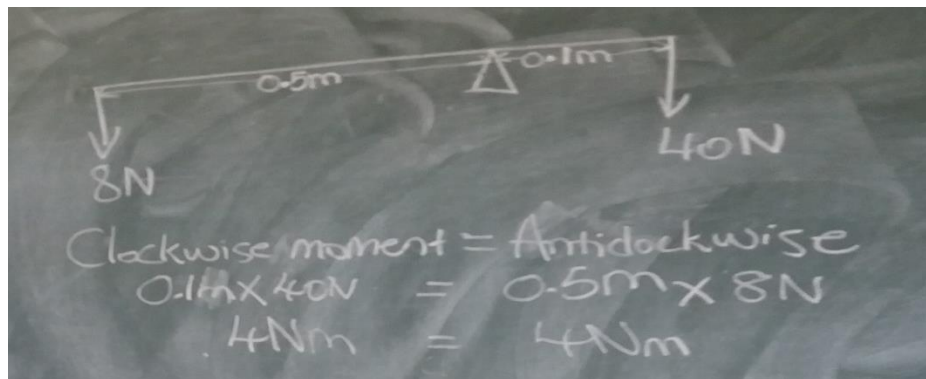


FIGURE 4.25: RESPONSE TO ASSESSMENT QUESTION

Joy also gave an assignment as one other method of assessment where students were to write the work and submit before they go home after school.

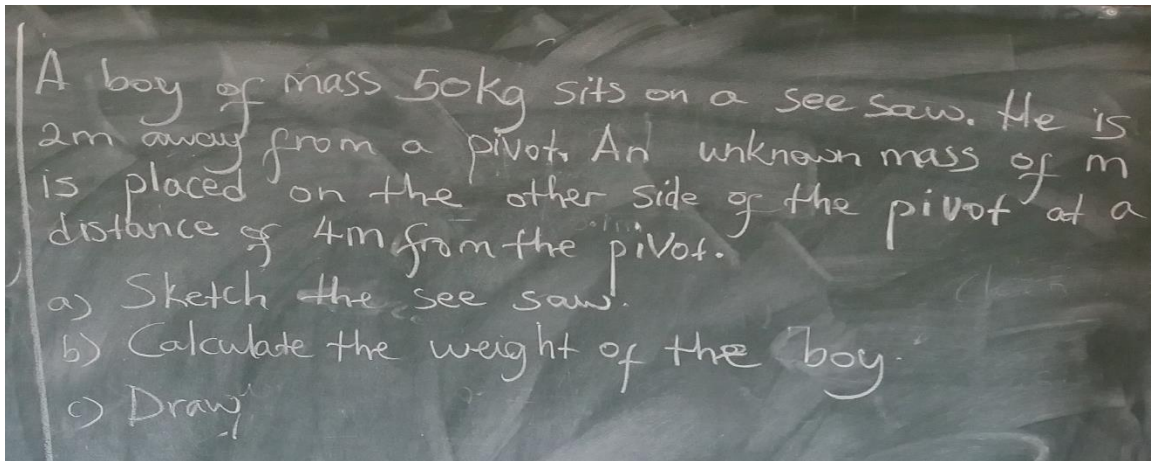


FIGURE 4.26: ASSESSMENT QUESTION 2 ON MOMENTS

Joy: *Potso ea boraro mona ere* (the third question here says) draw the two downwards forces, *kae*, (where) sketching *sane seo u se entseng sa seesaw*. (On the sketch you have done for the seesaw). That's c.

All the assessment questions were based on calculations even though Joy had planned to assess different aspects of Science. This implies that what the teacher plans may be quite different from what they practice in class.

4.4: THE ROLE OF PHYSICS TEACHERS' PCK IN CLASSROOM PRACTICES: A COMPARISON BETWEEN THE FOUR TEACHERS

This section responds to the third research question:

How can the role of Physics teachers' PCK in classroom practices be understood and explained?

To respond to this question, a sequential explanatory strategy has been used where the quantitative data was first collected, followed by the qualitative data that involved the four teachers selected as cases for study (Cresswell, 2014). The analysis of the qualitative data was used to explain the results of the quantitative data. The reported data is a mixture of both quantitative and the qualitative data. Five knowledge bases outlined by Gess-Newsome (2015) are used to explain the role of PCK in classroom practices. To reiterate, the knowledge bases are defined as PCK components in this study. The PCK test scores of the teachers have been displayed in Table 4.13. In this section, the quantitative results reported are the results of the whole sample involved, while the qualitative data results are only for the four teachers selected as cases, of whom two had the highest PCK test scores (Jay and Gift) and the other two had the lowest PCK test scores (Jimmy and Joy). The discussion that followed depicts the PCK components and the levels of difficulty and how they were manifested in their classroom practice. Firstly, the CoRes for these four teachers have been constructed so as to capture and portray their PCK. For three of the teachers (Jay, Jimmy and Joy) who had taught the same subtopic; the principle of moments, their CoRes have been documented in one table, Table 4.14. As for Gift who taught a different subtopic, her CoRe has been constructed apart in Table 4.15.

TABLE 4.13: DESCRIPTIONS OF THE FOUR TEACHERS

Teacher Identity and pseudonym	Years of experience	Gender	Highest Qualifications	PCK skill (logits)	Number of lessons observed	Content taught
				PCK mean and level		
002 Jay	16	M	MSc Ed	0.95	2	Effects of force: • Torque • Principle of moments
				3.30 Developed		
026 Gift	3	F	DES	0.78	3	Effects of force: • Hooke's Law
				3.10 Intermediate		
029 Jimmy	16	M	BSc Ed	-0.80	2	Effects of force: • Moment of a force • Principle of moments
				1.93 Limited		
087 Joy	4	M	DES	-0.8	3	Effects of force: • Moment of a force • Principle of moments.
				1.97 Limited		

Although Loughran *et al.* (2004) advocate for capturing PCK in several observed lessons as they unfold over an extended period of time, it was quite a challenge to visit and revisit schools due to COVID-19 restrictions where some principals refused access to the classrooms, while others restricted access to a limited number of visits. This led to a

reduced number of observed lessons as indicated in Table 4.13. The consolation in this case, however, is that I was able to follow-up lessons on a single topic to get a better sense of aspects relating to the topic-specific PCK.

4.4.1 CoRes (Content Representations) for the four teachers

The combined CoRe for individual teachers is illustrated in this section. The CoRe prompts investigate the PCK components of classroom practices as illustrated in Table 3.3.

In this study I have designed the CoRes using the interview data as well as the classroom observations data. As Rollnick *et al.* (2008) and Gess-Newsome (2015) assert that PCK is tacit, I have used classroom observations to identify characteristics of the content representations that teachers could not communicate during the interviews, to document and portray their classroom practices. Classroom observation data has been used to complement the interview data.

TABLE 4. 14: JAY, JIMMY AND JOY'S CORE FOR TEACHING PRINCIPLE OF MOMENTS

CoRe prompt/ Questions	Big Idea 1 Torque as the multiplication of force applied	Big Idea 2 Principle of moments considers the distance from the turning point
Which topic or subtopic are you going to teach today?	Effects of force: torque or moment of a force. Jay, Jimmy, Joy	Principle of moments. Jay, Jimmy, Joy
What are the main concepts you are going to teach today?	Torque calculations. Jay, Joy Clockwise moments and anticlockwise moments. Jimmy	Verifying the principle of moments. Jay, Joy Calculations of moments and the application of moments in daily life. Jimmy
Why do you think it is important for students to know these concepts?	For students to answer questions in the classroom. Jay To apply the concepts in daily life (VRT) Jay, Jimmy, Joy To know concepts for further studies. Joy For examination purposes. Jimmy	
What else do you know about these concepts that you do not intend students to know yet?	Mechanical advantage. Jay Velocity ratio. Jay	
What are the difficulties connected with teaching these concepts?	Incomplete units in torque calculation. Jay Using other distance instead of a distance from the turning point in calculations. Jay, Joy Lack of background knowledge, the concept is abstract (POI) Jimmy Students get confused as to when the weight of the beam becomes negligible. Joy	

What knowledge can you share about students' thinking that influences your teaching of these concepts?	Leaners confuse energy, pressure and power with moments. Jay Considering clockwise moment as anticlockwise and vice versa. Jimmy, Joy Writing units as N/m instead of Nm. Jimmy Left side force and distance should be equal to right side force and distance for the system to be at equilibrium. (VRT) Jimmy, Joy For a beam that is numbered, they fail to do the mathematical calculations of the distance from the pivot. Joy
Are there any other factors that would influence your teaching of these concepts?	Our language, where one word means several different technical terms. POI Jay Absence of laboratories, overburdened syllabus. Jimmy
What teaching procedures would you employ?	Experimentation, discovery, demonstration (VRT), discussion (VRT) Jay Demonstration, discussion. Jimmy Demonstration. Joy
Why would you use these procedures?	Retention of information, for students to understand better. Jay To make abstract concepts come to life. Jimmy To eradicate misconceptions. Joy
What aspects of Science learning are you going to assess in this topic?	Calculations. Jay, Jimmy Knowledge of theories. Jimmy, Joy Applications in daily life, practical skills and analytical skills. Joy
What methods would you use to assess students' understanding of this topic?	Written classwork, oral questions (VRT) Jay, Jimmy. Joy Quiz, project. Joy

NOTE: POI: Post observation interview, VRT: video record transcript, unlabelled: pre-observation interview

TABLE 4. 15: GIFT'S CORE FOR TEACHING EFFECTS OF FORCE ON SHAPE

CoRe prompt/ Questions	Big Idea 1 Differences between plastic and elastic materials	Big Idea 2 Elastic materials obey Hooke's Law
Which topic or subtopic are you going to teach today?	Hooke's Law	Hooke's Law
What are the main concepts you are going to teach today?	Plastic and elastic materials, their comparison, elastic materials and Hooke's law.	The graph produced when a force is applied to an elastic material.
Why do you think it is important for students to know these concepts?	The concepts are used in everyday life, knowing how to handle the materials is important.	
What else do you know about these concepts that you do not intend students to know yet?	-	
What are the difficulties connected with teaching these concepts?	Textbooks bringing in misconceptions. Using the word plastic from daily language and expecting that all things made from plastic are plastic materials while others are elastic.	Graphs are mathematical and students find it difficult to work with Mathematics. Students fail to express themselves when English used; Sesotho loses meaning when used to explain. (POI) Relationship of mass and weight. (POI)

		Engaging non-uniform scale when drawing the graph. (POI) Leaving out units when labelling the graph and in solutions during calculations. (VRT)
What knowledge can you share about students' thinking that influences your teaching of these concepts?	Students think that plastic stretches from their daily language use.	Students think all stretching materials obey Hooke's Law.
Are there any other factors that would influence your teaching of these concepts?	Overcrowded classroom leads to choosing not to engage experiments.	Lack of resources lead to not engaging experiments.
What teaching procedures would you employ?	Lecturing, discussion, demonstration	Discussion, experimentation
Why would you use these procedures?	For students to learn by seeing, to explain some words through doing.	To have a hands-on experience and feel the differences between materials.
What aspects of Science learning are you going to assess in this topic?	Knowledge	
What methods would you use to assess students' understanding of this topic?	Oral questions	

POI: Post observation interview, VRT: video record transcript, unlabelled: Pre-observation interview

4.4.2 Comparison of four teachers' PCK components

The CoRes illustrated the PCK of the four teachers, since they capture the PCK from what is intended to be taught to the actual teaching process (Loughran *et al.*, 2004). The narratives articulated the teaching process in the classroom context. This section presents a comparison between the four teachers; Jay and Gift with high scores in the PCK test and Jimmy and Joy with low scores. The comparison is focused on the PCK components, looking at how each teacher articulated PCK in a particular content being taught, referring to both the CoRes and the narratives of the four teachers. Table 4.16 shows the average raw score of the four teachers for the PCK components.

TABLE 4.16: TEACHERS' PCK COMPONENT RAW SCORES AVERAGE

Teacher	AK	PK	CK	KS	CuK	Average	Level of PCK	KEY:
002Jay	4.00	4.00	2.00	3.50	3.00	3.30	Developed	AK: Assessment knowledge
026 Gift	3.00	4.00	2.00	2.50	4.00	3.10	Intermediate	PK: Pedagogical knowledge
029 Jimmy	2.50	3.50	1.00	1.17	1.5	1.93	Limited	CK: Content Knowledge
087 Joy	1.50	3.50	1.00	1.33	2.50	1.97	Limited	KS: Knowledge of students
								CuK: Curriculum Knowledge

Note: The maximum raw score is 4.00 per PCK component and the minimum raw score is 1.00.

Content knowledge

Content knowledge is envisioned as one important ingredient of a teacher's PCK (Rollnick, 2017). The PCK test had three items Q5a, Q6 and Q7a which examined the content knowledge of the participants. All the items which tested the participants' content knowledge were classified as difficult. This is different from what was portrayed by the results of the PCK test, where the teachers scored a maximum of 2.00 and a minimum of 1.00, being limited and undeveloped levels respectively. The content knowledge that was exhibited in the cases of the four teachers' classroom practices showed that they had developed content in the subtopic they were teaching. As much as the four teachers

showed that they had developed content knowledge of the concepts they were teaching, Jimmy showed less content knowledge portrayed in the examples he chose, as some did not illustrate conditions of equilibrium which is one important concept to be learned in the 'turning effects of force'. Since Jimmy had taught the topic for so many years, it would be expected that he had gained the ability of selecting suitable examples, which could develop the concept better as it is argued that PCK grows with experience (Cochran *et al.*, 1993).

The inconsistent results between the examined component of CK and CK exhibited in the classroom lead to two suggestions for this study. On the one hand, the results may suggest that the examined CK through the PCK test; being the CK of the domain, does not ensure the CK in a specific topic taught in class. On the other hand, this may imply that teachers do not readily have CK when outside the classroom but know the relevant CK for what they are going to teach. This means that CK may not be considered an always readily available PCK component but the component available when used.

Pedagogical Knowledge

In this study, pedagogical knowledge was limited to the knowledge of instructional strategies and their advantages. Since there were no items that were classified as difficult in this PCK component, it shows that participants had a developed pedagogical knowledge.

In their interviews, the four teachers indicated that they were going to engage in demonstration, experimentation, and discussion as effective teaching strategies in their classrooms. These strategies are also considered appropriate for teaching Science according to Magnusson *et al.* (1999). In their actual classroom practices, none of the teachers used experimentation, but they all had indicated that they would engage students in experiments if resources were available. This indicates that they were aware of effective teaching strategies that they could use to help their students understand the content, but they were limited by the absence of lab equipment. Different from Gift, Jimmy and Joy, Jay also considered discovery as one teaching strategy he would engage. Unlike

others, Gift pointed out lecturing as one method she would use. While Qhobela and Moru (2014) assert that Physics teachers opt to use teacher-centred methods when their PCK is envisioned as undeveloped, these teachers intended to use mostly learner-centred strategies to teach the selected topics. Gift included lecturing as one teaching method she would engage. Her choice of using lecturing may also be attributed to the overcrowded classroom. The intentions as to which teaching methods to use often differed from what was observed in the classroom. The three teachers, Joy, Jay and Gift used mainly demonstrations instead of experiments. Jimmy on the other hand did not use demonstrations but rather discussion and lecturing.

There were different reasons for the selection and use of the teaching strategies mentioned. Jay pointed out the language of the students as one factor that influences his teaching, as their language uses one word (e.g. matla) to mean different technical Physics terms. Jay illustrated how language may bring in misconceptions, as it results in students failing to distinguish between the technical terms. The methods he selected were meant to help students understand better and also to help them retain information for a longer time. In agreement with Jay, Joy pointed out that the methods he selected were helpful to eradicate misconceptions that students have. On the other hand, Gift mentioned the overcrowded classroom and lack of resources restricting her choice of teaching strategies, showing that she was limited by the overcrowded classroom when it came to using experiments. The characteristics of the classroom context described by Gift are like those outlined by Qhobela and Moru (2014) who argued that Physics teachers in Lesotho end up choosing teaching strategies they deem not that appropriate for teaching due to the poor working environment, such as a lack of resources and overcrowded classrooms. Irrespective of the intention to use demonstrations in class, Jimmy opted to engage in discussion and lecturing in class, stating that if he had enough laboratory equipment (George, 2017) he could have taught the topic better.

Jay and Gift had high PCK test scores and have both scored 4.00 while Joy and Jimmy had low PCK test scores and have both scored 3.50, but these scores are all in the developed level of PK. The pedagogical knowledge that was manifested in their classroom practices portrayed that Jimmy had a limited pedagogical knowledge since he

mostly engaged in discussion, lecturing and in one episode of demonstration, even though he had shown a broader knowledge of teaching strategies in the interviews. The classroom practice observations revealed that an experienced teacher may show limited pedagogical knowledge in actual classroom practice. This contradicts Cochran *et al.* (1993) who argue that PCK develops with experience in teaching.

Curricular knowledge

The three teachers Gift, Jimmy and Joy exhibited that they were aware of the topics from the lower levels to the level at which they were teaching since they included prior concepts to develop the topics. Different from the three, Jay had the highest PCK test score and did not only show knowledge of the topics at the lower levels, but also showed that he was aware of the topics at the higher level beyond LGCSE, which he said he would not include in his teaching. Gift had the highest score for curricular knowledge - she had scored 4.00; a developed CuK, Jay 3.00; intermediate CuK, Joy 2.50; Limited CuK and Jimmy 1.50; undeveloped.

The choice of what to teach is guided by the curriculum that teachers implement. Jay, Joy and Jimmy intended to teach torque and the principle of moments while Gift taught the differences between plastic and elastic materials with a focus on elastic materials and Hooke's Law. Since all of these teachers chose topics in the LGCSE syllabus in the general Physics part P1 under P1.5 Forces (NCDC, 2019), it shows that they were aware that their selection of topics should be guided by the syllabus.

The knowledge of what to place central in their lesson when teaching a certain topic is considered vital in the teaching profession (Ergönenç *et al.*, 2014). The four case teachers were aware of the main concepts to look at in teaching the topics they selected. Jay, Joy and Jimmy mainly focused on calculating torque and verifying the principle of moments while Gift opted to mainly discuss the characteristics of plastic and elastic materials and the graph associated with Hooke's Law, produced when a force is applied to an elastic material. Being able to select the main concepts and sequencing the topics is one attribute

that shows curriculum knowledge (Coetzee *et al.*, 2020). All teachers indicated knowledge of the curriculum guiding their teaching.

According to Magnusson *et al.* (1999) and Gess-Newsome (2015) knowledge of curriculum entails the teachers' knowledge of goals and the objectives of the curriculum. Looking at the LGCSE Physical Science syllabus (NCDC, 2019), aim number 3 focuses in part on developing abilities and skills that are useful in daily life. The four teachers valued the relevance of the topics they taught to the students' daily life applications, emphasizing that students need to know the concepts to be able to handle materials at home and to apply the knowledge gained in class when doing work at home. Jay attributed the importance of the knowledge of concepts to the ability of students to answer questions in class while Jimmy indicated that he was teaching for examination purposes. This indicates that these teachers' goals of teaching the content were aligned with the goals of the curriculum they were implementing in their classes.

Knowledge of Students

The PCK test scores for the teachers are shown in Table 4.16 as follows: Jay 3.50; developed, Gift 2.50; limited, Jimmy 1.17; undeveloped and Joy 1.33; undeveloped. All items in this component were classified as difficult. With the low PCK test scores, it could be expected that three of the teachers would manifest low PCK levels in their teaching of Physics, but the opposite was observed, there appeared no difference between Jay and the others.

The four teachers were familiar when it came to difficulties associated with teaching the concepts. Jay, Jimmy and Joy identified one of the difficulties being incomplete units when calculating torque and the other as students using the distance of their choice instead of the distance from the turning point when calculating the moment of a force. The difficulties identified by Gift included misconceptions coming from the textbook coverage of the topic, the mathematics associated with plotting the graphs and the confusion coming from language use when it came to technical terms in Physics. Language is used in explanations by both teachers and learners in the classroom. That means when both

have a challenge in the language used, there could be compromised understanding of the concepts taught. This also contributes to the low PCK manifested by the teacher who has a challenge in explaining physics due to language restriction as explanations are considered important in PCK (Shulman, 1986). The four teachers showed that they have knowledge about the students since they were able to identify students' difficulties in the topics they taught (Magnusson, 1999). As Rollnick *et al.* (2008) indicate that PCK is tacit; the other difficulties documented in the CoRe for Gift were sourced from the video transcript and the post-observation interview transcript - Gift did not communicate them, but they were observable in her practice. These difficulties include students' failure to express themselves in English while the use of Sesotho often loses the Physics meaning, challenge in calculating weight given the mass, non-uniform scale in drawing the graph and leaving out the units on graph labels. The knowledge of students' difficulties prior to teaching informs the teacher about the ways to treat the content so as to address difficulties in class and to use appropriate teaching strategies that could be useful to change misconceptions about the scientific knowledge that is deemed appropriate (Shulam, 1986; Ergönerç *et al.*, 2014).

Jay identified some of the ideas that students come to class with - they confused the moment of a force with energy, pressure and power. In her sharing what students think around this topic, Gift mentioned that students think that plastic materials stretch, maybe coming from their daily encounters and that all stretching materials obey Hooke's Law. Joy portrayed that he understood the importance of prior knowledge in the development of concepts since he was able to revise what had been done in the previous lesson so as to help one student who missed the lesson to come to the same level of knowledge before the next lesson began. Jimmy had anticipated that the students would write units incorrectly and he was able to identify this in his teaching. The misconceptions that were identified as associated with the teaching of their selected topics indicate that both teachers were cognisant of their students' thinking and this is attributed to their knowledge about the students (Magnusson, 1999), which may better inform their choices of teaching strategies to modify their students' thinking.

Assessment knowledge

Knowledge about assessment was also examined through the interviews and classroom observations. Jay, Joy and Jimmy focused on assessing calculations while Gift mentioned that she was going to assess knowledge. Referring to the LGCSE Physical Science syllabus (NCDC, 2019: 5), from the three objectives of assessment the three teachers' focus on assessing calculations falls under objective B, which is "[h]andling information and problem solving". The objective includes questions involving calculations, which form part of the Physics assessment. Gift concentrated on assessing 'knowledge' in her the content that was taught. 'Knowledge' falls under objective A in the LGCSE Physical Science syllabus (NCDC, 2019). This objective involves recall and the giving explanations for the questions asked. When justifying her choice of assessment methods Gift said,

"[she is] going to employ oral questioning [and that] the main reason behind that is if everyone would have an exercise, it's going to be a long process to finish the marking. ... I could mark but *ke se ke le kante ho class* (when I am outside the class).

This shows that Gift was acquainted with other possibilities for assessment and that she could use them, but she was limited by time constraints. As much as the teachers' selection and assessment of the dimensions of scientific literacy were aligned with the Physics syllabus, objective C which is 'Experimental skills and investigations' was not mentioned in the interviews nor seen being assessed in the classroom. This might be attributed to the teachers' limited PCK as Magnusson *et al.* (1999) mention that teachers with developed PCK align the dimensions of Science learning towards the goals of the curriculum when they assess students' scientific literacy. The teachers had intended to engage different aspects of the students' understanding, as they described in their pre-observation interviews, but they used limited methods of assessment in their actual classroom teaching. Jay, Jimmy and Joy selected written short answers to assess their students while Gift had intended to use oral questions while she also engaged asked for a few calculations in the classroom. Joy had intended to use a variety of assessment methods during his teaching, even though in his actual teaching he engaged in oral questions and written work. It is expected that teachers with developed PCK would

engage a variety of assessment methods in their teaching (Magnusson *et al.*, (1999). The small number of observed lessons might have contributed to the limited number of assessment methods communicated and observed in this study. The other reason might be that the teachers had limited assessment knowledge; maybe lacking in their training, as this concurs with the observation made by Mabejane *et al.* (2017) that student teachers at fourth year level of their teaching practice exhibited a lack of assessment knowledge, citing that they feel they did not get enough assessment training during their teacher training.

Although the PCK test scores for the teachers selected as cases differ as follows: Jay - 4.00 (developed), Gift - 3.00 (intermediate), Jimmy - 2.50 (limited) and Joy - 1.50 (undeveloped), the knowledge of assessment in practice did not differ much amongst the teachers. These teachers portrayed partially developed skills for assessment because their intentions and actual practice showed that they assessed their students aligning themselves with the LGCSE syllabus assessment objectives, although they left out objective C of the assessment objectives. The assessment knowledge exhibited by the four teachers could not differentiate them as teachers, even with high PCK test scores and low PCK test scores. They all exhibited limited knowledge of assessment in their actual teaching.

4.5 CONCLUSION

This study found the ranking order of the development of PCK components in descending order as follows: pedagogical component, curricular knowledge, assessment knowledge, knowledge of students and content knowledge. These are the components that physics teachers draw on when executing their classroom practices. The order of the PCK components was different from that measured with the PCK test. The teachers selected as case studies exhibited a more developed content knowledge in their classroom practices except in the case where Jimmy was challenged by content. Although assessment knowledge emerged using the PCK test as moderately well developed, it was portrayed as being less developed in classroom practice, where the teachers didn't use assessment objective C to assess practical knowledge. The reported findings show

that self-reported PCK from the PCK test has different results to practical PCK employed in a classroom context.

CHAPTER 5: DISCUSSION OF RESULTS AND CONCLUSION

5.1 INTRODUCTION

The aim of this study was to investigate the PCK components that Physics teachers draw on to construct their classroom practices and to find out how classroom practices are structured with respect to the PCK components that Physics teachers possess. The study involved a mixed method approach with both quantitative and qualitative data collection methods to explore the PCK of qualified Physics teachers in Lesotho.

In this chapter a discussion of the results is presented. The chapter begins with an overview of the study, followed by a discussion of the results. Conclusions are drawn and the implications are looked at. The chapter also covers recommendations for practice, policy and further research. The chapter concludes by outlining final thoughts emanating from this study.

5.2 STUDY OVERVIEW

Teachers use their knowledge base, referred to in this study as PCK components, to teach in a variety of ways, drawing on their understanding of teaching (Gess-Newsome, 2015; Shulman 1987). The purpose of this study was to identify the PCK components used by Physics teachers to develop their classroom practices and to investigate how classroom practices are built in relation to the PCK components that teachers possess. The study employed PCK as a conceptual framework, which was appropriate for directing the choice of PCK test items used and for interpreting the classroom, practices of the

Physics teachers selected for the study. When it comes to comprehending and articulating both canonical and practical knowledge for teaching, PCK proved to be a valuable tool.

In this study, PCK in classroom practices is described using a modified Consensus Model of Gess-Newsome (2015), which is used in combination with the model of Magnusson *et al.* (1999). The Consensus Model was chosen because, in comparison to other models, it encompasses more knowledge bases that are transformed into PCK and enables the researcher to consider both PCK on-action and PCK in-action, respectively. The two, PCK on-action and PCK in-action, are useful in separating what the teacher knows about teaching Physics from how the teacher decides to teach Physics in the classroom. The model of Magnusson *et al.* was incorporated to make explicit what is manifested as PCK in classroom practice. Pedagogical knowledge (PK), content knowledge (CK), assessment knowledge (AK), knowledge of learners (KS), and curricular knowledge (CuK) are the PCK components examined in this study. To discover the PCK components that Lesotho Physics teachers use to teach Physics in a classroom setting, the study used an explanatory sequential mixed method design.

This study also looked at how instructional strategies are developed in relation to the PCK elements that Physics teachers use. As evidenced by the literature reviewed in chapter 2, researchers have, either quantitatively or qualitatively, looked at the PCK elements that Physics teachers use to build their instructional strategies. The use of mixed methodologies and several data collection techniques was because of the implicit and distinctive nature of PCK, which necessitates various approaches for exploring the construct (Park *et al.*, 2018; Maryati *et al.*, 2019).

The final two years of the secondary level, Grades 11 and 12, were used in this study to examine the PCK of Physics teachers. Qualified Physics teachers were given a paper-and-pencil PCK test to complete. The PCK test looked at the Physics teachers' domain-specific PCK. The four teachers selected as case studies, two of whom had high scores on the PCK test and two of whom received low scores, were interviewed and classroom observations were conducted to investigate the manifestation of practical PCK in a classroom setting. This study's sequential explanatory mixed methods methodology

provided insights into the PCK components held by Physics teachers and allowed for an explanation of how the teachers who demonstrated low or high PCK scores on a pen-and-pencil PCK test articulated their PCK in the classroom. This made it possible to compare test-takers who scored well on PCK with those who scored low marks.

The Extended Rasch Model was used to analyse quantitative data from the PCK test to determine the difficulty of the items that made up the PCK components and to categorize participants according to their PCK skill levels. Each teacher, the overall level of PCK across all participants, and the order of difficulty of the PCK components also utilized descriptive data from the SPSS to highlight the PCK mean scores. Qualitative data came from videotaped classroom observations, audio-recorded stimulated recall post-observation interviews and audio-recorded pre-observation interviews. The narratives of the four teachers, two who had high PCK test scores and two who had low PCK test scores, were used to analyse the qualitative data. Both the PCK that was expressed during the interviews and the PCK that was seen during classroom instruction were documented in the CoRes for the case teachers. The comparison between the teachers is also shown in the results, even though PCK is thought to be largely idiosyncratic (Park, Suh, & Seo, 2018).

The study was guided by the following research questions:

1. What components of PCK do Physics teachers use to teach Physics?

To better understand the PCK elements that direct Physics teachers' work, this question was asked. 87 qualified Physics teachers replied to the paper-and-pencil PCK test that was given to them. To fit the LGCSE Physical Science syllabus, the items were taken and modified from Kirschner *et al.* (2016), Ergönerenç *et al.* (2014) and Ergönerenç *et al.* (2018). By rephrasing the PCK test items with the help of 12 qualified Physics teachers in a pilot study, the PCK test's validity was established. To confirm the material, the pilot test was given to 12 Physics teachers with varying years of experience and qualifications as well as to a Physics teacher trainer. Furthermore, the Extended Rasch Model was used to validate the PCK test tool.

2. How are the components of PCK manifested in Physics teachers' classroom practice?

This question attempted to investigate how the Physics teachers demonstrated components of PCK in their respective classroom contexts. This was achieved by having the teachers participate in audio-recorded pre-observation interviews, video-recorded classroom observations and audio-recorded stimulated recall post-observation interviews. Pre-observation interview questions were prompts from the CoRe that were adapted from Loughran *et al.* (2004) and sought the teacher's PCK regarding the material they would be teaching in class. For the aim of refining the questions, the interview questions were piloted with two qualified Physics teachers who made up a sub-sample of the pilot study of twelve qualified teachers.

3. How can the role of Physics teachers' PCK in classroom practices be understood and explained?

To answer this research question, both quantitative and qualitative data were combined to see if there were any noticeable variations between the classroom practices of case teachers with high and low PCK test scores. These were investigated by contrasting a depiction of PCK components in a classroom setting with the PCK scores per teacher for each component. The study's main findings are presented in the section below.

5.3 KEY FINDINGS OF THE STUDY

The key findings of this study are based on the three sub-research questions discussed above (**section 5.2**) and also the themes stemming from the sub-research questions. The following section discusses the findings of the study.

5.3.1 PCK components possessed by Physics teachers

The PCK components discussed in this study are the knowledge bases in the Consensus Model (Gess-Newsome, 2015). These knowledge bases are utilized in the development of teachers' instructional strategies. Using the Extended Rasch Model and SPSS, the PCK test was analysed.

The Extended Rasch Model revealed that the Physics teachers' PCK was rather low since the person measures ranked in the interval $-1.37logit < PCK < +0.95logit$. This is an indication that there were no teachers in the high ability measures. The item measures were found to be in the interval $-0.968logits < difficulty < 0.584logits$. This also reveals that there were neither too easy nor too difficult items in the PCK test, thus an indication that all the test items were within the average range. The items from this average region should have been able to discriminate between teachers who are more and less competent. Evidently, this means that there were no teachers with a high level of PCK.

The outcomes of the descriptive statistics from SPSS complemented the Extended Rasch Model's findings. According to the Likert scale employed in this study, the PCK levels were: 1 for undeveloped, 2 for limited, 3 for intermediate and 4 for developed. The Extended Rasch Model was unable to classify PCK components into the various stages of development. The means of the PCK components were calculated using SPSS. According to the descriptive results, PK, CuK, and AK are at an intermediate level while KS and CK are at a limited level. The findings show that there were no PCK components at a developed level.

As observed in the foregoing paragraphs in this section, the PCK described in this study is that of qualified Physics teachers who have received training in their teacher preparation programs to develop content knowledge and other PCK components. Although research encourages teachers to have developed PCK to teach effectively, the startling results indicating their low PCK forecast a threat to their classroom practices.

This is because the components KS and CK indicated minimal amounts of development. Suffice to say, teaching is viewed as a complicated process that requires the formation of many PCK components for integration (Shulman, 1987), as well as a high PCK level. In as much as it has been argued that teachers with poor PCK exhibit low expertise in the teaching process (Qhobela & Moru, 2014; Barendsen & Henze, 2017), the low levels of CK and KS suggest that these components may not be adequately integrated in the teaching process, which may damage classroom practice. Therefore, the manifestations of classroom practice, which were revealed by the interviews and observations of the teachers with high and low PCK test scores, are discussed in the section that follows.

5.3.2 Manifestation of PCK in classroom practices

The manifestations of PCK reported in this study are based on how the teachers with high PCK test scores and low PCK test scores constructed and enacted their classroom practices using the PCK components they possess. Firstly, this study has found a generally low PCK in Physics teachers measured quantitatively, the classroom practices revealed a mismatch of the portrayed PCK and the self-reported PCK either from the PCK test or the pre-observation interviews. The most apparent differences were noted in the components of pedagogical knowledge, content knowledge and assessment knowledge. Secondly, the study found no difference between the classroom practices of teachers with high PCK test scores and teachers with low PCK test scores.

Mismatch between self-reported PCK and PCK practiced in classroom

Pedagogical knowledge

Pedagogical knowledge was more developed than other components having the mean of 2.91 according to the results of the PCK test (**table 4.6**). This implies that from the PCK test, the teachers had a broad knowledge of instructional strategies to use in the teaching of Physics. **Table 4.16** also reveals that the case teachers had high mean scores of PK ranging from 3.5 to 4.00, which are all at a developed level. The teachers used a range of instructional techniques in real classroom situations to meet the needs of the learners, including demonstrations, provision of pertinent examples, lively explanations and

discussions (Gess-Newsome, 2015). Magnusson *et al.* (1999) stated that experiments are vital when teaching science, but it was anticipated that teachers who had a strong PK component would incorporate experiments into their lessons. However, this was not the case (**section 4.4.2**). George (2017) observed that the laboratories in Lesotho's high schools are seldom ever used. The teachers' use of successful classroom teaching techniques like experiments seemed to be constrained by the setting of the situation. The contextual challenges reported by this study include lack of resources in schools (Qhobela & Moru, 2014; George, 2017), overcrowded classrooms and time constraints (Mabejane *et al.*, 2017). This demonstrates how challenging it is to demonstrate teaching expertise in a developing country. It would be assumed that these teachers were unaware of the significance of experiments in the teaching of Physics if they failed to list experiments as one of the activities they would carry out in class. This demonstrates that the knowledge shared during pre-observation interviews differs from the knowledge shared during classroom instruction. Melo-Niño *et al.* (2016) presented a conclusion that was similar in that they discovered that the PCK announced had a greater impact on planning than on-action.

Assessment knowledge

The component of assessment knowledge was reported as intermediate from the PCK test results with a mean score of 2.57 (**table 4.7**). According to Magnusson *et al.* (1999), a teacher with established PCK integrates the dimensions of Science learning to assess with the curriculum's goals and objectives to measure learners' scientific literacy. In determining their learners' understanding, the four teachers evaluated some of the assessment objectives. Their objectives were as follows: objective A - knowledge; objective B - information handling and problem solving (NCDC, 2019). Therefore, taking out objective C demonstrates that these four teachers' assessment knowledge had some shortcomings. Objective C is intended to measure learners' comprehension of experimental skills and investigations, and cutting out questions that would establish learners' grasp of this type when test questions are included may have a negative impact on learners' performance.

The teachers' employment of various assessment methods also indicates established PCK in assessment knowledge (Magnusson *et al.*, 1999). In this light, calculations were graded by three of the teachers as written classwork, assignments and oral questions (**section 4.4.2**). Because of time constraints and the congested classes, Gift used oral questions and calculations solved on the board as a form of assessment. Although the other three teachers used different assessment methods, they did not use a wide range of assessment methods, suggesting some lack of assessment competence. Despite this, Jimmy on the other hand added that he was limited in his instruction by focusing on what his learners needed to know for the examination. Jimmy maintained that his omission of experiments in his instruction was appropriate for the type of examination his learners were going to write because it was an alternative to a practical that does not necessarily require a learner to be familiar with the laboratory setting. The other indicator of weak knowledge of assessment was that teachers were unable to follow up on learners' incorrect answers. This suggests that some learners were left behind because they did not understand ideas, while teachers moved on to learners who did understand. According to Gess-Newsome (2015), assessment knowledge is the teachers' ability to design assessments and use the findings of these assessments to alter instruction so as to help learners understand. In the case of these four teachers, the assessments they prepared were not used to change their teaching to improve learners' comprehension. This demonstrates a lack of assessment knowledge. Weak knowledge about assessment was not a surprise in this study since Mabejane *et al.* (2017) reported the same finding in pre-service Physics and Biology teachers in their final year of study at one university in Lesotho. Weak assessment knowledge exhibited in classroom practices might result from the training that the teachers had received.

Content Knowledge

The intriguing outcome of this study was the case where teachers enacted a higher PCK competence than was suggested by their results in the PCK test. Content knowledge was reported to be the least developed component of PCK with a mean score of 2.00, indicating a limited level. Davidowitz and Potgieter (2016) and Rollnick (2017) agree on the significance of CK in the development of classroom practices and claim that teachers

with high levels of CK are more likely to engage in richer representations and demonstrate a greater awareness of learners' prior knowledge. Given that the CK of the four teachers chosen as case studies ranged from undeveloped to limited, as depicted in **Table 4.16**; the implication was that there would be a problem when transforming CK. It is possible to anticipate that these teachers would demonstrate less understanding of the ideas they were teaching.

The foregoing being the case, however, these teachers demonstrated that they knew the material they were teaching and used a variety of rich representations for instruction and also appropriate examples; except Jimmy. The four teachers Jay, Gift, Jimmy and Joy demonstrated knowledge of the key concepts in the subject they were teaching, as well as the connected ideas that were crucial for learning (refer to **Table 4.14** and **Table 4.15**). Despite the four teachers' demonstrations that they were familiar with the material they were about to teach, Jimmy occasionally demonstrated less content knowledge in his actual practice. This was demonstrated by the examples he used to develop the concept of the 'principle of moments' (NCDC, 2019: 23). He deliberately chose examples that did not meet the necessary criteria for equilibrium in the principle of moments. As part of the representations used to make the subject teachable, suitable examples are needed to help clarify the concept (Magnusson *et al.*, 1999). Jimmy's decision to use inadequate examples to illustrate the principle of moments and to teach learners about equilibrium might be seen as an example of how his low CK development affected his decision-making. This was a clear portrayal of compromised classroom practice when CK is low (Rollnick, 2017; Davidowitz & Potgieter, 2016).

In other findings there was a mismatch between manifested PCK and the PCK of the teachers measured through a paper-and-pencil test. This was not startling since the PCK measured through the paper-and-pencil test was canonical PCK. This excludes the context of practice according to the Consensus Model of PCK, while the manifested PCK is measured in the context in which the teacher teaches (Gess-Newsome, 2015). This study has shown that the actions of the teachers in classroom practices are more influenced by their teaching context than the knowledge of teaching they possess. For

instance, the case teachers' PK was found to be more developed than all other components of PCK emerging from the PCK test and in the interviews. These teachers were able to mention more effective teaching strategies that they were going to employ to teach their lessons. However, the manifested teaching strategies excluded some of the strategies that they had communicated as being effective for teaching. Nonetheless, it was discovered that fewer strategies were used for contextual reasons, such as time constraints, lack of resources and overcrowded classrooms.

There is no difference between classroom practices of teachers with high PCK test scores and teachers with low PCK test scores.

The sequential explanatory design of this study was meant to differentiate classroom practices between teachers with high PCK test scores and those who had low PCK test scores. The expectation being that the teachers with high PCK test scores would portray more developed PCK in classroom practices than those with low PCK test scores. In this study, the teachers with high PCK test scores were Jay and Gift while Joy and Jimmy had low PCK test scores. The expectation would be that Jay and Gift would use the PCK components in integration to construct classroom practices that show more expertise than others. However, this was not the case since there were similarities in the level of PCK manifested in classrooms illustrated by Joy. To illustrate this four examples of the manifested PCK are used.

Firstly, Joy used appropriate examples and Jay and Gift used a variety of representations such as verbal explanations, numerical and visual methods as well. Shulman (1986) considers it an indication of developed PCK when a teacher is able to use a variety of representations to transform content to be comprehensible to learners. Secondly, Joy used similar teaching strategies to the strategies engaged by Jay and Gift such as discussions, demonstrations and question and answer to transform content. Thirdly, Joy was also able to demonstrate the same level of curriculum knowledge as the other case teachers. Curriculum knowledge refers to the teacher's understanding of the curriculum's goals and objectives, as defined by Gess-Newsome (2015) and Magnusson *et al.* (1999).

Lastly, the four teachers demonstrated that their curricular knowledge was linked with the goals and objectives of the curriculum they were implementing. Teachers' intentions to teach concepts, for building learners abilities that can apply in their daily lives, are examples of such knowledge. This is aim number three in the LGCSE Physical Science syllabus (NCDC, 2019). Other indicators of curriculum knowledge included the appropriate selection of the topic's main concepts and the ability to sequence sub-topics within the topic to develop learners' understanding (Coetzee *et al.*, 2020) and also to progress from simple to complex concepts (Smith & Banilower, 2015). Unlike the other components of PCK, which classified Joy together with the other teachers with high PCK test scores, the component of curriculum knowledge did not separate teachers with high PCK test scores from teachers with low PCK test scores, as they all exhibited the same expertise in this area.

The reported findings were quite difficult to compare with the findings reported by other studies since the methodology used in this study differed from the methodologies engaged by other researchers. However, studies that measured components of PCK and examined their interaction with PCK were used to compare the findings of this study since the PCK test was composed of different components of PCK. In this study the lowest PCK level emerging from the PCK test was recorded in content knowledge, but the manifested PCK in classroom practices revealed a higher level of content knowledge versus the paper-and-pencil measured content knowledge. The case teachers showed a more developed PCK in practice. This contradicts the findings reported by (Davidowitz & Potgieter, 2016; Oztay & Boz, 2022) who found that teachers with low levels of content knowledge were likely to have low levels of PCK. Although in some components such as the component of assessment knowledge where all the case teachers portrayed less developed PCK, the case teachers illustrated a more developed PCK, except Jimmy whose PCK was recorded as being weak in more PCK components such as CK and PK. While this study engaged mixed methods, Davidowitz and Potgieter (2016) used a quantitative method to measure PCK and Oztay and Boz (2022) used a qualitative approach to investigation. The differences in the findings may be brought about by the different research approaches. These findings may also mean that a paper-and-pencil PCK test is not sufficient to

measure the PCK that is compared to PCK in-action for the reason that the PCK test has a limited number of items per PCK component measured and this might limit the knowledge of practice being explored. Secondly the PCK test explores the general knowledge of teaching excluding the context in which the teacher teaches. The findings also reveal that the PCK components are independent of each other, meaning when one PCK component is less developed, it does not necessarily mean that the teacher cannot show a better level of development in other PCK components.

5.3.3 Explanation of the role of Physics teachers' PCK in classroom practices

The literature shows limited research in relating the quantitatively measured PCK to classroom practices. Barendsen and Henze (2017) contend that there have been inconsistent results reported by the studies that related PCK to classroom instruction. The PCK test scores could not differentiate the PCK manifested in classroom practices among the case teachers. The fact that Joy with low PCK test scores portrayed PCK at the same level as Jay and Gift with high PCK test scores indicates that PCK measured through a paper-and-pencil test cannot define the type of PCK necessary for effective teaching. On the other hand, Jimmy illustrated less developed PCK in the components of CK, PK and AK, which is in line with his low PCK test score, but having been able to show a similar level of development in other PCK components supports that idea that PCK measured through a test does not play a significant role in the construction of classroom practice. This finding is supported by the findings of Mazibe *et al.* (2020) who found that enacted PCK and self-reported PCK displayed different levels where in other cases the enacted PCK was higher, in others lower or at the same level as the self-reported PCK.

The findings of this study illustrate a weak overall PCK of the Physics teachers measured through a paper-and-a-pencil PCK test, even though different levels were portrayed in different PCK components' manifestation. The difficulty in relating the role of PCK in classroom practices is explained by Barendsen and Henze (2017) who contend that the relationship complication is brought about by the involvement of both the knowledge on-action and the knowledge in-action. Magnusson *et al.* (1999) assert that for the teacher to teach effectively, the knowledge of components of PCK, which are TPKB, should be

well developed in all topics that are taught in the discipline. As much as there were areas of developed PCK manifested in the case teachers' classroom practices, there were also areas of underdeveloped PCK illustrated by their actions. This implies that the overall effective teaching was weakened when some components were underdeveloped, since these PCK components work in unison and complement each other to produce effective teaching in classrooms.

This study reports inconclusive findings on the role of PCK in Physics' classroom practices measured quantitatively. This is not a surprise since studies measuring PCK through a paper-and-pencil test also reported inconsistent results. For instance, Kulgermeyer *et al.* (2020) measured the professional knowledge of pre-service teachers before their teaching experience and found that pre-service teachers with higher scores of personal PCK enacted PCK better than those with lower scores of personal PCK. This large-scale study relating PCK and classroom instructional practices included the ProwiN project which measured PCK through a pen-and-pencil test and instructional quality by measuring the cognitive activation of learners in the classroom and found no relationship between the teachers PCK and cognitive activation (Cauet *et al.*, 2015). Similar findings were reported in the ProwiN II project where Liepertz and Borwski (2019) did not find a relationship between PCK and content knowledge in classroom practices, and also their interconnectedness. On the other hand, the QuIP project (Ergönenç *et al.*, 2014) found a negative relationship between PCK and learners' outcomes where Finnish teachers with low PCK had learners with gains greater than the German and Swiss learners. The findings of this study indicate that there is a difference between what the teachers know with respect to what they teach and what the teachers do with what they know when faced with a classroom context. All case teachers had a low score of content knowledge, but in their classroom they illustrated a better understanding of the content knowledge they were teaching, except in the case where Jimmy had misconceptions about the content he was teaching. This means that the component of content knowledge becomes more available in the mind of the teacher when in use than when examined through a paper-and-pencil test. This study also showed that Joy whose PCK test score was low had better PCK manifested in classroom practices than the teachers with high PCK test scores. This

means that the PCK measured through a paper-and-pencil test does not always translate into practice.

The case teachers in this study had AK mean score levels ranging from limited to developed. However, their manifested knowledge of assessment was at the same level. They commonly asked low order oral questions, assessed calculations and did not follow up with their students when they gave incorrect answers. The case teachers identified more methods of assessment in their interviews. The knowledge they have about assessment was influenced by different factors. For example, Gift mentioned that she engages methods which did not require her to mark because of the overcrowded class and indeed she asked oral questions or asked questions which were solved by working on the chalkboard. Jimmy on the other hand pointed out the type of examination written by his students, mentioning that they write an alternative to a practical examination; therefore there is no need to be assessed in the laboratory. His confidence that his learners would pass examinations indicated that he was not willing to change his approach to assessment. This indicates that the teachers' manifested PCK is more impacted by the circumstances surrounding their teaching than the actual knowledge they have about teaching.

While some studies argue the importance of content knowledge in shaping the teachers' PCK (Rollnick, 2017; Oztay & Boz, 2022), others do not single out one component, but consider PCK to be more developed where all the components are developed and are integrated to produce PCK effective for classroom practice (Magnusson *et al.*, 1999). This study agrees with Magnusson *et al.* that all the PCK components should be developed for effective teaching since it has been found that where any PCK component is not developed there is limited expertise engaged in classroom teaching.

5.4 CONTRIBUTION TO NEW KNOWLEDGE

The literature reveals the complexity of relating the PCK possessed by a teacher outside a classroom context with the PCK used by the teacher in the classroom (Barensen & Henze, 2017). The complications are brought about by the difficulty in measuring the PCK

in the mind of the teacher and the PCK that is used in the construction of classroom practices. The hurdles in measuring and depicting PCK result from the nature of the construct contended by researchers that PCK is tacit (Park, Suh & Seo, 2018; Rollnick, 2017; Maryati *et al.*, 2019) and that PCK is idiosyncratic (Park & Chen, 2012). This study adds to the literature that examines PCK by engaging a paper-and pencil PCK test that measured the general PCK for teaching physics. The paper-and-pencil test examines the episteme of teaching Physics as a discipline of Science to find out how much teachers know about the five components of PCK. This study also acknowledges the idiosyncrasy of PCK and involves multiple data collection methods to study four case teachers in their different contexts of teaching Physics to identify how these teachers manifest their knowledge of their disciplinary pedagogies with respect to their different PCK levels.

This study has used the modified Consensus Model of Gess-Newsome (2015) where the Model of Magnusson *et al.* (1999) has been incorporated to give explanations of PCK that can be manifested in classroom practice. The modified version contributes to new knowledge in that it allows a researcher to focus only on the canonical PCK and enacted PCK excluding the filters and amplifiers. It also excludes learners, whose contribution of classroom practice was out of the scope of this study.

The literature reviewed in this study showed contradictory results on studies relating PCK to classroom practice. While some studies reported a positive relationship of PCK with classroom practices (Kulgermeyer *et al.*, 2020), other studies found a negative relationship (Ergönenç *et al.*, 2014). The inconsistent results are brought about by the different methodologies that were engaged. Some studies engaged purely quantitative methods (Ergönenç *et al.*, 2014; Cauet *et al.*, 2015; Liepertz & Borowski, 2019) while others engaged purely qualitative methods to measure teachers' PCK and classroom practices (Mazibe *et al.*, 2020; Oztay & Boz, 2022) to conclude that the differences in PCK on-action and enacted PCK result from undeveloped PCK. This study extended the work of these studies by involving a sequential explanatory mixed method approach that measures PCK on-action quantitatively and examines PCK in-action qualitatively. The PCK that was measured quantitatively in this study is domain-specific PCK, which is the

general PCK for teaching physics, while other studies have focused on topic specific PCK (Pitjeng-Mosabala, 2018; Davidowitz & Potgieter, 2016). The purpose of this study was to measure the general PCK of qualified Physics teachers so as to compare the construction of the classroom practices of teachers with high PCK test scores and those with low PCK scores.

The literature reviewed in this study shows the scarcity of studies comparing in-service qualified Physics teachers' domain PCK and the PCK enacted in classrooms. The literature also shows that studies comparing self-reported PCK and PCK in-action are increasing in the different science disciplines, but there is still a paucity of these studies in Physics. Kulgermeyer *et al.* (2020) conducted a cross-lagged study to investigate the relationship of pre-service teachers' professional knowledge before and after teaching experience. They found that pre-service teachers with high scores of professional knowledge explained Physics better in the classroom. This study is contributing knowledge with the following additions to the literature: firstly, this study has shown that the actions of the teachers in classroom practices are more influenced by their teaching context than the knowledge of teaching they possess. Secondly, the paper-and-pencil PCK test is not sufficient to measure the PCK that can be related to PCK in-action since it is limited to the PCK in the mind of the teacher excluding the context. It also has a limited number of items that may not exhaustively explore the PCK of the teacher.

While some studies investigating the relationship of PCK and classroom practice engaged a few PCK components to examine the PCK on-action and PCK in-action this study extends their work by measuring the PCK involving the five PCK components that form teachers' professional knowledge base. Sæleset and Friedrichsen (2022) argue that PCK of a high value is exemplified by the amalgamation of PCK components in classroom practices. Therefore, this study has shown different levels of development in different PCK components and how teachers manifested their teaching expertise per PCK component, so as to better understand PCK. The study adds the independence of these PCK components, even though they are said to work in unison (Sæleset & Friedrichsen, 2022) in the process of teaching. This means that the underdevelopment of one component does not imply the underdevelopment of another.

This study involved different methods of data collection such as the PCK test; interviews and video recorded observations and stimulated video recall post observation interviews. As researchers argue that PCK is tacit (Park, Suh & Seo, 2018; Rollnick, 2017; Maryati *et al.*, 2019), this study found it necessary to involve another method of data collection which would engage teachers on are flection of their practice to get more insight about how they reason for the actions they take in the process of teaching. Through the use of this method, teachers were conscientised about their weak PCK in some episodes of their teaching and they suggested more effective strategies they could employ in their future teaching so as to improve their practice. This study found that the stimulated recall interviews did not only help to elicit the teachers' reasoning about their actions but also develops the teachers' enacted PCK to a higher level. Another novelty is that the stimulated recall interview also contributed to unlimited discussions on reflection of practice, making PCK less tacit.

Studies that investigated PCK are quite limited in Lesotho, especially in the discipline of Physics. Examples of studies that related PCK and classroom practices measured the perceptions of Physics teachers and compared them with their translation into reported practice (Qhobela & Moru, 2014; Marake, Jita & Tsakeni, 2022). As much as perceptions are valuable in terms of informing the teachers' practice, these aforementioned studies were vague in reporting about teachers' domain-specific PCK. With less known about Physics teachers' domain-specific PCK due to scarcity of research in that line, especially in the context of Lesotho, this study fitted in well in contributing to the literature about Physics domain-specific PCK in Lesotho. It does this by giving insights about the level of PCK possessed by Physics teachers and how this translates into actual practice in the classroom context. The findings of this study further give insights about the PCK components which were found to be weak and these findings suffice to be regarded as novel knowledge because they may be used to inform areas to be targeted by professional development for both novice and experienced teachers.

The study also introduced a different approach of analysis from using only descriptive statistics to also engaging an Extended Rasch Model. The Extended Rasch Model is rarely used in the analysis of quantitative data, but in this case it proved to be useful in analysing data that had to separate teachers' abilities in PCK. Using an Extended Rasch Model in studies such as this one adds to its popularity for being used in research and also contributes to literature tilted towards the Extended Rasch Model. Measuring PCK this way also contributes to the availability of a validated, reliable and unidimensional instrument, which may be used in larger studies in the same discipline or be modified for use in other disciplines of science.

5.5 CONCLUSION

This study used a sequential mixed method approach to quantitatively measure the PCK of Physics teachers and explored how the measured components were used in the construction of classroom practices of teachers with both high PCK test scores and low PCK test scores. The study involved a PCK survey of 87 Physics teachers across the ten districts of Lesotho and a multiple case study of 4 teachers, being a sub-sample of the 87 teachers; 2 with a high PCK test score and 2 with a low PCK test score. The findings of this study show that the PCK of Physics teachers is rather low, with the component of content knowledge being the least developed. A mismatch was found between levels of PCK measured quantitatively and the manifested PCK in classroom practices. Although this finding is confirmed by other studies, this study has examined both the canonical PCK and the PCK in the actual classroom context. This study has shown that the actions of the teachers in classroom practices are more influenced by their teaching context than the PCK measured by a paper-and-pencil test. The study also concludes that the results of a paper-and-pencil PCK test are not sufficient to compare with the PCK enacted in classrooms since it is limited to the knowledge of the teacher about the teaching of Physics excluding context and it also has a limited number of PCK items which may not thoroughly explore the PCK of the teacher.

This study used PCK as a conceptual framework to investigate the components of PCK that are regarded as the building blocks of teachers' classroom practices (Gess-

Newsome, 2015). In this study the Consensus Model of Gess-Newsome (2015) was used to guide the components of PCK examined by the PCK test and the Model of Magnusson *et al.* (1999) was used as a complementary framework to help clarify what each PCK component entails. The PCK components investigated in this study were AK, PK, CK, KS and CuK. These two models were used to construct the PCK test and also as tools for analysis. The use of these two models has helped to capture and articulate both the PCK on-action and the PCK in areal classroom situation.

In this study, multiple data collection methods were used to capture and illustrate the PCK in the construction of classroom practices. The different data collection methods were engaged with to elucidate PCK that could be written in the form of test responses, PCK that could be communicated in interviews and PCK that the teachers could not communicate but could be observed in-action through video recorded classroom observations. Among all these data collection methods, this study found the stimulated video recall post-observations to give more insights about the PCK in-action. The teachers' reflection on their practice led to deeper discussions of their practice, confronting their actions, questioning themselves, identifying areas of their weak PCK and suggesting ways of improving their practice if they were to teach the lessons again. This study contends that this data collection method does not only contribute to rich data on classroom practice, but also contributes to reducing the difficulty of capturing tacit PCK and making it explicit.

5.6 LIMITATIONS

The PCK test was designed to assess general knowledge for teaching Physics, which Kirschner *et al.* (2016) refer to as domain-specific. Four teachers were interviewed and observed teaching the effects of force where their PCK was articulated on a specific topic rather than on the general teaching of Physics for which the PCK test was designed. This could have resulted in discrepancies between the PCK levels reported from the PCK test results and the articulated PCK in the classroom context.

For reliability, I and another Physics teacher trainer graded the PCK test replies. Because we are both Physics teacher trainers, our expertise in teaching Physics and our conclusions in interpreting the meaning of the responses may have been subjective. To address this, a rubric for scoring the test was created and the rubric was discussed between the two raters to generate a shared understanding, but this does not eliminate subjectivity and bias.

Because of time constraints and varying responsibilities of the teachers selected for the case study, the post-observation interviews were not always conducted at the same times, with gaps between the classroom observation and the post-observation interview. In other cases, the post-observation interview was conducted immediately following the observation during which I examined episodes of interest with the case teacher and offered clarifying questions. In certain cases the post-observation interview was conducted when the teacher had the time. Although seeing the video together assisted with stimulated recall (Oztay & Boz, 2022), in some cases the teachers forgot the context of instruction and the reasons for their actions.

Some studies consider PCK to be topic specific (Pitjeng-Mosabala & Rollnick, 2018; Barendsen & Henze, 2017). This means the PCK a teacher has in one topic may differ from the PCK that the same teacher can have in a different topic. This study observed four teachers, three teaching ‘turning effects of force’ while one teacher taught ‘effects of force on shape’. In as much as the components of PCK were studied across the four teachers, the results might have changed if the four teachers were teaching the same topic. A physics teacher is expected to have developed the domain-PCK in physics. This means that even though the topics differ, it could not mean that the other teacher did not have PCK at all in the topic she was teaching. The similar interview questions that were asked to the four teachers and the same PCK components that were studied across them gave each an equal chance to manifest their PCK around the topic they were teaching.

Because PCK is considered as a tacit construct (Park, Suh, & Seo, 2018; Maryati *et al.*, 2019), it must be observed during classroom practice over a long period to collect data

that can clearly define teachers' PCK. I had planned to visit schools for a lengthy amount of time to observe classroom procedures, but this study was done during the COVID-19 era when school visits were limited to a small number of people and extensive classroom observations were not permitted. Due to the reduced number of school visits the data acquired in this study might contain some gaps. One of the possible gaps could be limited PCK articulated in limited classroom observations. To bridge the gaps, the study followed up every lesson observed and watched the episode of classroom practice video records with the teachers, allowing the teachers to comment on their practice in a relaxed environment to discuss reasons for their actions.

5.7 RECOMMENDATIONS

Little is known about studies that measure the PCK of Physics teachers and portray their classroom practices that have been conducted in Lesotho before this study. It is the case that this study pioneers the investigation of qualified Physics teachers' PCK using a paper-and-pencil PCK test to investigate the components of PCK that Physics teachers draw onto teach Physics and to investigate the manifestations of these PCK components in the classroom context. The findings of the PCK test, which included 87 competent Physics teachers, may not be generalizable, but they may provide an indication of the country's canonical PCK for teaching Physics. The use of several case studies provided insight into what occurs in Physics classrooms when Physics teachers perform their PCK by drawing on PCK components as their knowledge base to teach Physics. Although the findings of the case studies cannot be generalized, they can be utilized to provide suggestions for various stakeholders in education in Lesotho and also other nations with similar circumstances. The recommendations in this section are based on the study's findings. Recommendations are provided that may help policymakers, practitioners and future researchers.

5.7.1 Recommendations for Policy

The PCK test demonstrated that there are no outstanding PCK components at the developed level among Physics teachers. The low PCK test scores, with content knowledge ranking lowest, suggest that Physics teacher should be involved in regular refresher workshops designed to engage teachers in reflection on what they know about the topics they teach, focusing on different PCK components. The CoRe was utilized in this study to collect the teachers' PCK. The CoRe is a beneficial tool, which this study recommends for use during lesson planning to assist teachers in preparing for a specific topic that they intend to teach and to engage them in meaningful reflection of the knowledge that they have about the topics they are teaching. The CoRe may assist teachers in becoming aware of the main concepts, the topic's relationship to other topics previously taught, learners' difficulties and the challenges when teaching the topic, the most appropriate teaching approaches and the reasons for not using certain approaches.

Poor assessment knowledge scores and the lack of involvement in various assessment procedures suggest that the teachers' assessment expertise is lacking. If any of the assessment objectives are missed in classroom activities, learners' performance may suffer as a result of this lack of assessment knowledge. As a result, the study suggests that teacher-training institutions include assessment as a course in their curriculum and that Physics teachers should be engaged in professional development workshops that enhance assessment knowledge.

Overcrowded classrooms, according to this study, are one factor that inhibits the utilization of a variety of instructional styles. Gift stated that engaging some teaching techniques would take a long time in an overcrowded classroom, therefore she resorted to using teacher-centered methods such as lecturing to try to establish concepts more quickly. There could be schools with packed classrooms like Gift's. In such large schools, building more classrooms and hiring more teachers might help to allow teachers to engage in more learner-centered teaching practices with a manageable number of learners.

5.7.2 Recommendations for practice

This study has found that Physics teachers are conversant with effective strategies to teach Physics from their self-reported PCK, but they are hindered to use these effective strategies by contextual factors such as overcrowded classrooms, time constraints and lack of resources. Shulman (1986) contends that the use of various representations helps to better transform the content. In situations similar in context to the contexts in which these teachers work, this study recommends the inclusion of technology in the teaching of Physics. The use of simulations to illustrate experiments may help learners to access the information they miss in experiments and to watch these experiments in their own time where time constraints are a challenge.

5.7.3 Recommendations for future research

The findings of the PCK test were presented in this study that examined the PCK components using a paper-and-pencil test that tested a general understanding for teaching Physics. The teachers selected for the case study were interviewed and observations in their classrooms while they taught a certain topic were made. Although this study has provided insights into the components of PCK that Physics teachers use to teach Physics and has reported on what happens in the classroom when the PCK components are used, it does have limitations. The following recommendations for future research are made in light of the limitations indicated in this study and my observations in this investigation.

To begin with, a larger study with a similar design to this one may be undertaken, but with a topic-specific PCK test and a greater number of items per PCK component, as Pitjeng-Mosabala and Rollnick (2018) state that PCK is topic specific. Comparing domain-specific PCK to topic-specific PCK was complicated. Developing a topic-specific PCK test will facilitate less complicated data analysis and enable easier comparisons between the canonical topic-specific PCK and the enacted topic specific PCK as manifested in classrooms.

Secondly, the PCK of Physics teachers was reported in this study and the study also highlighted poor PCK in several components such as assessment knowledge articulated in classroom practice. Documenting the PCK of Physics teachers does not indicate how this PCK may affect learners' performance in Physics; therefore, additional research that records the PCK of Physics teachers and a test that explores learners' performance may be conducted to provide insights into the relationship between PCK and learners' performance.

Thirdly, a follow-up study to this one may be conducted that will involve classroom observations and immediate stimulated recall post-observation-interviews to better shed light on manifestations of PCK in classroom practice. This is because this study did not exhaust classroom practice due to limited classroom visitations owing to COVID-19 regulations in schools. Furthermore, this study focused on individuals with the highest and lowest PCK test scores whose schools appeared to face the same difficulty of a lack of resources, meaning that the results reported by this study are of schools facing the same challenge. It would be interesting to investigate the PCK of Physics teachers at resource-rich schools to see if the same results are reached.

The study focused on qualified teachers and discovered that some components of PCK are underdeveloped. This calls for further investigation into what the teacher training curriculum contains, whether the curriculum completely develops the components of PCK or not and whether the pedagogies used by teacher educators to train teachers have any influence on the lack of PCK demonstrated by practicing teachers.

5.8 MY FINAL THOUGHTS AND EXPERIENCES AS A RESEARCHER

The purpose of this study was to examine the PCK components used by Physics teachers to build their classroom practices and to investigate how classroom practices are constructed in relation to the PCK components that teachers possess. This study has taught me that theory is quite different from practice and therefore it is through engagement in research that the assumptions that are generated from the theories can

be verified through understanding the practice. To understand the teachers' professional knowledge that is defined quite differently by different scholars, but envisioned important for the teaching of Physics, is not straightforward. The use of PCK as a construct has helped me access the knowledge of teaching possessed by the teachers and how this knowledge is enacted in a classroom situation.

While research shows that PCK grows with experience (Cochran *et al.*, 1993) this study has taught me that experience is not always the best teacher in that the teacher with many years of teaching may have a weak PCK in the same discipline that has been taught for many years. This has opened my eyes to the fact that professional development should not always be focused on novice teachers but also on experienced teachers. As a teacher trainer, I have appreciated how video recorded classroom observations and video stimulated recall sessions contribute to a reflection on the practice of the teacher. This may be applied in teacher education to raise awareness of the weak PCK areas where the pre-service teachers may reflect on their practice without being observed by the teacher educator. The episodes of self-correction were quite interesting listening to the teacher questioning their practice and suggesting what they could have done to teach the concept better.

As a researcher, this study has triggered my curiosity to try other methods to investigate PCK with modified instruments to better access professional knowledge. This study has taught me that engaging in a mixed method research is quite expensive, time consuming and needs a lot of patience. This implies that these factors will have to be considered when pursuing studies in this area.

REFERENCES

- Aykutlu, I., Bezen, S. & Bayrak, C. 2015. Teacher opinions about the conceptual challenges experienced in teaching Physics curriculum topics. *Procedia, Social and Behavioural Sciences*, 174, 390-405.
- Ball, D.L., Thames, M.H. & Phelps, G. 2008. Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, 59, 389-407.
- Barendsen, E. & Henze, I. 2017. Relating teacher PCK and teacher practice using classroom observation. *Research in Science Education*, 1-35.
<https://doi.org/10.1007/s11165-017-9637-z>
- Baxter, P. & Jack, S. 2008. Qualitative case study methodology: study design and implementation for novice researchers. *The Qualitative Report*, 13(4), 544-559.
- Boone, W.J. & Noltemeyer, A. 2017. Rasch analysis: A prime for school psychology. Researchers and practitioners. *Cognet Educaion*, 4(1), 1416898.
- Bureau of Statistics, 2015. 2014 *Education Statistics Report. Statistical Report No. 15: 2015*, Maseru: Bureau of Statistics.
- Bureau of Statistics, 2018. 2016 *Education Statistics Report. Statistical Report No. 28: 2018*, Maseru: Bureau of Statistics.
- Carlson, J., Stokes, L., Helms, J., Gess-Newsome, J. & Gardner, A. 2015. The PCK summit: a process and structure for challenging current ideas, provoking future work and considering new directions. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.). *Re-examining Pedagogical Content knowledge in Science education*. London: Routledge Press: 24-37.
- Cauet, E., Liepertz, S., Borowski, A. & Fischer, H.E. 2015. Does it matter what we measure? Domain-specific professional knowledge of Physics teachers. *Schweizerische Zeitschrift für Bildungswissenschaften*, 37(3), 462-479.

- Chabongora, B.N. & Jita, L.C. 2013. Opportunities to learn (OTL) grade-10 algebra in three South African catholic secondary schools. *Journal of Educational Studies*, 12(1), 172-188.
- Chapoo, S., Thatong, K. & Halim, L. 2014. Understanding Biology teachers' pedagogical content knowledge for teaching "the nature of an organism". *Procedia-Social and Behavioral Sciences*, 116, 464-471.
- Cochran, K. F., Deruiter, J. A., & King, R. A. 1993. Pedagogical content knowing: an integrative model for teacher preparation. *Journal of Teacher Education*, 44(1), 263-272.
- Coetzee, C., Rollnick, M. & Gaigher, E., 2020. Teaching electromagnetism for the first time: A case study of pre-service science teachers' enacted pedagogical content knowledge. *Research in Science Education*, 1-22.
- Cohen, L., Manion, L., & Morrison, K. 2007. *Research methods in education*. London: Routledge.
- Cohen, L., Manion, L., & Morrison, K. 2018. *Research methods in education*. London: Routledge.
- Council on Higher Education, (2012). Report on the state of higher education in Lesotho 2010/11-2011/12. Council on Higher Education, Maseru.
- Creswell, J. W. 2015. *Educational research: planning, conducting, and evaluating quantitative and qualitative research*. New Jersey: Pearson Education Inc.
- Creswell, J.W. & Creswell, J.D. 2018. *Research Design: Qualitative, Quantitative, and mixed Methods approaches*. Los Angeles. SAGE Publications.
- Creswell. J.W. & Hirose, M. 2019. Mixed methods and survey research in family medicine and community health. *Family Medicine and Community Health*, 7(2). <https://doi:10.1136/fmch-2018-000086>

- Davidowitz, B. & Potgieter, M. 2016. Use of the Rasch measurement model to explore the relationship between content knowledge and topic specific pedagogical content knowledge for organic Chemistry. *International Journal of Science Education*, 38(9), 1483-1503.
- de Ruiter, C. & Smid, W. 2007. Rasch comprehensive system data for a sample of 108 normative subjects from the Netherlands. *Journal of Personality Assessment*, 89(S1), S113-S118.
- ECoL. 2019a. 2018 LGSCE Examiners' Report: Physical Science paper II (181/02). Maseru: ECoL
- ECoL. 2019b. 2018 LGSCE Examiners' Report: Physical Science paper III (181/03). Maseru: ECoL
- ECoL. 2019c. 2018 LGSCE Examiners' Report: Physical Science paper IV (181/04). Maseru: ECoL
- Ekiz-Kiran, B., Boz, Y. & Oztay, E.S. 2021. Development of pre-service teachers' pedagogical content knowledge through a PCK-based school experience course. *Chemistry Education Research and Practice*, 22(2), 415-430.
- Ergönenç, J., Neumann, K. & Fischer, H.E. 2014. The impact of pedagogical content knowledge on cognitive activation and student learning. In H.E. Fischer, P. Labudde, K. Neumann, and J. Viiri (Eds). *Quality of instruction in Physics*: Munster: Waxmann: 145-160.
- Ergönenç, J., Neumann, K. & Fischer, H.E., 2018. Test instrument for Physics teachers' pedagogical content knowledge. Downloaded from; <https://www.researchgate.net/publication/323557316>. ISBN 978-3-9812480-7-4
- Erickson, F. 2012. Qualitative research methods for science education. In *Second Handbook of Science Education*. Springer, Dordrecht, 1451-1469.

- Escobar-Pérez, J. & Cuervo-Martínez, A., 2008. Content validity and experts' judgment: an approach to its usage. *Avances en Medición*, 6, 27-36.
- Fielzer, M.Y. 2010. Doing mixed methods research pragmatically: implications for discovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research*, 4(1), 6-16.
- Gamer, M., Lemon, J., Fellows, I. & Singh, P. 2019. irr: Various coefficients off interrater reliability and agreement.
- George, M. J., Kolobe, M. & Moru, E.K. 2018. Exploring the Mathematics and Science subject matter content in primary school level in Lesotho teachers. *International Journal of Science and Technology Education Research*, 9(2), 9-17.
- George, M.J. 2017. Assessing the level of laboratory resources for teaching and learning of Chemistry at advanced level in Lesotho secondary schools. *South African Journal of Chemistry*, 70, 154-162.
- Gess-Newsome, J. 1999. Pedagogical Content knowledge: an introduction and orientation. In: Gess-Newsome, J.; Lederman, N.G. (Eds.) *Examining pedagogical content knowledge*. Dordrecht, Netherlands: Kluwer Academic Publishers, 3-17.
- Gess-Newsome, J. 2015. A model of teacher professional knowledge and skill including PCK: results of the thinking from the PCK summit. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.). *Re-examining pedagogical content knowledge in Science education*. London: Routledge Press, 28-42.
- Gess-Newsome, J., Taylor, J.A., Carlson, J., Gardner, A.L., Wilson, C.D. & Stuhlsatz, M.A., 2019. Teacher pedagogical content knowledge, practice, student achievement. *International Journal of Science Education*, 41(7), 944-963.
- Grossman, P.L. 1990. *The making of a teacher. Teacher knowledge and teacher education*. New York: Teachers College Press.

- Großschedl, J., Welter, V. & Harms, U. 2019. A new instrument for measuring pre-service Biology teachers' pedagogical content knowledge: The PCK-IBI. *Journal of Research in Science Teaching*, 56(4), 402-39.
- Hallgren, K.A., 2012. Computing inter-rater reliability for observational data: an overview and tutorial. *Tutorials in Quantitative Methods for Psychology*, 8(1), 23.
- Hanson, W.E., Creswell, J.W., Plano Clark, K.L., Petska, K.S. & Creswell, J.D. 2005. Mixed methods research design in counselling psychology. *Journal of Counselling Psychology*, 52(2), 224-235.
- Ivankova, N.V., Creswell, J.W. & stick, S.L. 2006. Using mixed methods sequential explanatory design: from theory to practice. *Field Methods*, 18(1), 3-20.
- Jacob, F., John, S. & Gwany, D.M., 2020. Teachers' pedagogical content knowledge and students' academic achievement: A theoretical overview. *Journal of Global Research in education and Social Science*, 14(2): 14 – 44.
- Jüttner, M., Boone, W., Park, S & Neuhaus, B.J. 2013. Development and use of an instrument to measure Biology teachers' content knowledge (CK) and pedagogical content knowledge (PCK). *Educational Assessment, Evaluation and Accountability*, 25(1), 45-67.
- Keller, M.M., Neumann, K. & Fischer, H.E. 2017. The Impact of physics teachers' pedagogical content knowledge and motivation on students' achievement and interest. *Journal of Research in Science Teaching*, 54(5), 586-614.
- Kirschner, S., Borowski, A., Fischer, H.E., Gess-Newsome, J. & von Aufschnaiter, C. 2016. Developing and evaluating a paper-and-pencil test to assess components of Physics teachers' pedagogical content knowledge. *International Journal of Science Education*, 38(8), 1343-1372.
- Kivunja, C. & Kuyini, A.B. 2017. Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, 6(5), 26-41.

- Kothari, C.R. 2004. *Research methodology: Methods and techniques*. New Age International.
- Kulgermeyer, C., Borowski, A., Buschhüter, D., Enkrott, P., Kempin, M., Reinhold, P., Riese, J., Schecker, H., Schröder, J. & Vogelsang, C. 2020. Professional knowledge affects action - related skills: The development of preservice physics teachers' explaining skills during a field experience. *Journal of Research in Science Teaching*, 57(10), 1554-1582.
- Lekhetho. M. 2021. Exploring factors influencing the performance of high achieving secondary schools in Lesotho. *Issues in Educational Research*, 31(3), 871-890.
- Liepertz, S. & Borowski, A. 2019. Testing the consensus model: relationships among Physics teachers' professional knowledge, interconnectedness of content structure and student achievement. *International Journal of Science Education*, 41(7), 890-910.
- Lodico, M.S, Spaulding, D.D. & Voegtle, K. 2006. *Methods in educational research: from theory to practice*. San Fransisco CA: Jossey-Bass.
- Loughran, J., Mulhall, P. & Berry, A. 2004. In search of pedagogical content knowledge in Science: developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, 41(4), 370-391.
- Mabejane, M.R., Nyabanyaba, T., Koliopoulos, D. & Ravanis, K., 2017. The probable causes for the espoused inadequacies in science student teachers' practice teaching in schools at the National University of Lesotho. *Journal of Subject Didactics*, 2(1), 1-19.
- Mackenzie, N. & Knipe, S. 2006. Research dilemmas: paradigms, methods and methodology. *Issues in Educational research*, 16(2), 193-205.
- Magnusson, S., Krajcik, J. & Borko, H. 1999. Nature, sources and development of pedagogical content knowledge for Science teaching. In J. Gess-Newsome & N.G.

- Lederman (Eds.). *Examining pedagogical content knowledge: the construct and its implications for Science education*. Dordrecht: Kluwer Academic Publishers, 95-132.
- Majid, M.A.A., Othman, M., Mohamad, S. F., Lim, S.A.H & Yosuf, A. 2017. Piloting for interviews in qualitative research: Operationalization and lessons learnt. *International journal of Academic Research in Business and Social Sciences*, 74(4), 1073-1080.
- Makhechane, M. & Qhobela, M. 2019. Understanding how chemistry teachers transform stoichiometry concepts at secondary level in Lesotho. *South African Journal of Chemistry*, 72, 59-66.
- Malmqvist, J., Hellberg, K., Mo"lla's, G., Rose, R. & Shevlin, M. 2019. Conducting the pilot study: A neglected part of the research process? Methodological findings supporting the importance of piloting in qualitative research studies. *International journal of Qualitative Methods*, 18, 1-11. DOI: 10.1177/1609406919878341
- Malva, L. & Leijen, "A. Arcidiacono, F. 2021. Identifying teachers' general pedagogical knowledge: A video stimulated recall study. *Educational Studies*: 1-26.
- Marake, M., Jita, L.C. & Tsakeni, M., 2022. Science teachers'perceptions of their knowledge base for teaching force concepts. *Journal of Baltic Science Education*, 21(4), 651-662. <https://doi.org/10.33225/jbse/22.21.651>
- Maryati, M., Pasotyo, Z.K., Wilujeng, I. & Sumintono, B. 2019. Measuring teachers' pedagogical content knowledge using many facet Rasch model. *Jurnal Cakrawala Pendidikan*, 38(3), 452-464.
- Mavhunga, E. & Rollnick, M. 2013. Improving PCK of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science and Technology Education*, 17(1-2), 113-125.
- Mavhunga, E., Ibrahim, B., Qhobela, M. & Rollnick, M. 2016. Student teachers' competence to transfer strategies for developing PCK for electric circuits to another

- Physical Science topic. *African Journal of Research in Mathematics, Science and Technology Education*, 20(3), 299-313.
- Mazibe, E.N., Coetzee, C. & Gaigher, E. 2020. A comparison between reported and enacted pedagogical content knowledge (PCK) about graphs of motion. *Research in Science Education*, 50, 941-964.
- McCrudden, M.T. & McTogue, E.M. 2019. Implementing integration in an explanatory sequential mixed methods study of belief bias about climate change with high school students. *Journal of Mixed methods Research*, 13 (3), 381-400.
- McHugh, M. L., 2012. The interrater reliability: the Kappa statistics. *Biochemia Medica*, 22(3), 276-282.
- Melo, L., Cañada, F., González-Gómez, D. & Jeong, J.S. 2020. Exploring pedagogical content knowledge (PCK) of physics teachers in a Colombian secondary school. *Education Sciences*, 10(12), 362.
- Melo-Niño, L.V., Cañada, F., Martínez, G. & Mellado, V. 2016. The importance of PCK in the education of secondary school Physics teachers: a case study on teaching electric fields. In E. Harvey (Ed). *Secondary education perspectives, global issues and challenges*. New York: Nova Science Publishers, 133-159.
- Mim, S.A., Rahman, S.M. & Jahanara, Q.A., 2017, December. Secondary science teachers' pedagogical content knowledge from content representation (CoRe) on genetics. In *Asia-Pacific Forum on Science Learning & Teaching*, 18(2), 20.
- MoET, 2009. *Curriculum and Assessment Policy: Education for individual and social development*. Maseru: MoET.
- MoET, 2016. *Education Sector Plan 2016-2026*. Maseru: MoET.
- NCDC, 2019. Physical science syllabus. *Lesotho General Certificate of Secondary Education*. Maseru: National Curriculum Development Centre and Examination Council of Lesotho.

- Nguyen, N. T., McFadden, A., Tangen, D. & Beutel, D. 2013. Video-stimulated recall interviews in qualitative research. *Australian Association for research in Education*.
- Nilsson, P. & Karlsson, G. 2019. Capturing student teachers' pedagogical content knowledge (PCK) using CoRes and digital technology. *International Journal of Science Education*, 41(4), 419-447.
- Nilsson, P. & Vikström, A. 2015. Making PCK explicit—capturing science teachers' pedagogical content knowledge (PCK) in the science classroom. *International Journal of Science Education*, 37(17), 2836-2857.
- Ogunniyi, M.B. & Rollnick, M. 2015. Pre-service science teacher education in Africa: Prospects and challenges. *Journal of Science teacher Education*, 26(1), 65-79.
- Opie, C. 2019. Research approaches. *Getting Started in Your educational Research: Design, Data Production and Analysis*. Thousand Oaks, California: SAGE publications, 137-159.
- Oztay, E.S. & Boz, Y. 2022. Interaction between pre-service chemistry teachers' pedagogical content knowledge and content knowledge in electrochemistry. *Journal of Pedagogical Research*, 6(1), 245-269.
- Park, S., & Chen, Y-C. 2012. Mapping out the integration of the components of pedagogical content knowledge (PCK) for teaching photosynthesis and heredity. *Journal of Research in Science Teaching*, 49(7), 922–941.
- Park, S., & Oliver, J. S. 2008. Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, 38(3), 261–284.
- Park, S., Suh, J. & Seo, K. 2018. Development and validation of measurement of secondary Science teachers' PCK for teaching photosynthesis. *Research in Science education*, 48(3), 549-573.

- Pimentel, J.L. & Pimentel, J.L. 2019. Some biases in Likert scaling usage and its correction. *International Journal of Science: Basic and Applied Research (IJSBAR)*, 45(1): 183-191.
- Pitjeng-Mosabala, P. & Rollnick, M. 2018. Exploring the development of novice unqualified graduate teachers' topic-specific PCK in teaching the particulate nature of matter in South Africa's classrooms. *International Journal of Science Education*, 40(7), 742-770.
- Planinic, M., Boone, W.J., Susac, A. & Ivanjek, L., 2019. Rasch analysis in physics education research: Why measurement matters. *Physical Review Physics Education Research*, 15(2), 020111.
- Qhobela, M & Moru, E.K. 2014. Understanding challenges Physics teachers come across as they implement students-centered approaches in Lesotho. *African Journal of research in Mathematics, Science and Technology Education* 18(1), 63-74.
- Qhobela, M. 2008. Construction of meaning by second language students in access Physics classes in Lesotho. Unpublished doctoral dissertation. University of Witwatersrand, Johannesburg.
- Qhobela, M. & Moru, E.K. 2009. The Lesotho high school Physics teachers' support needs. Proceedings of the 17th annual conference of the Southern African Association for Research in Mathematics, Science and technology education. Grahamstown: Rhodes University, 503-509.
- Riese, J. & Reinhold, P. 2010. Measuring Physics student teachers' pedagogical content knowledge as an indicator of their professional action competence. In M.F. Taşar & G. Çakmakçı (Eds.). *Contemporary Science Education Research: Teaching*. Ankara, Turkey: Pegem Akademi, 21-28.
- Rollnick, M. 2017. Learning about semi-conductors for teaching-the role played by content knowledge in pedagogical content knowledge (PCK) development. *Research in Science Education*, 47(4), 833-868.

- Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N. & Ndlovu, T. 2008. The place of subject matter knowledge in pedagogical content knowledge: a case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education*, 30(10), 1365-1387.
- Sæleset, J. & Friedrichsen, P. 2022. A Case Study of Specialized Science Courses in Teacher Education and Their Impact on Classroom Teaching. *Journal of Science Teacher Education*, 33(6), 641-663. DOI: 10.1080/1046560X.2021.1971859
- Shulman, L.S. 1986. Those who understand: knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.
- Shulman, L.S. 1987. Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-23.
- Smith, A.B., Rush, R., Fallowfield, L.J., Velokova, G. & Sharpe, M. 2008. Rasch fit statistics and sample considerations for polytomous data. *MBCMedical Research Methodology*, 8(1), 1-11.
- Smith, P.S. & Banilower, E.R. 2015. Assessing PCK: a new application of the uncertainty principle. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.). *Re-examining pedagogical content knowledge in Science education*. London: Routledge Press, 98-113.
- Statistical Bulletin, 2019. Lesotho general certificate of secondary education results. Ministry of Education and Training. Maseru.
- Sürücü, L. & Maslakçı, A. 2020. Validity and reliability in quantitative research, *BMIJ*, 8(3), 2694-2726, doi: <http://dx.doi.org/10.15295/bmij.v8i3.1540>
- Susac, A., Planinic, M., Klemencic, D. & Sipus, Z.M. 2018. Using Rasch model to analyse and test the understanding of vectors. *Physical Review Physics Education Research*, 14(2). 023101-1 – 023101-6.

- Teddlie, C. & Tashakkori, A. 2009. *Foundation of Mixed methods Research*. Thousand oaks: Sage.
- Teddlie, C. and Yu, F. 2007. Mixed methods sampling: a typology with examples. *Journal of Mixed Methods Research*, 1(1), 77-100.
- ten Hove, D., Jorgensen, T.D. & van de Ark, L.A., 2017, July. On the usefulness of interrater reliability coefficients. The Annual Meeting of Psychometric Society, 67-75. Springer, Cham.
- Terrell, S.R. 2012. Mixed methods research methodologies. *The Qualitative Report*, 17(1), 254-280.
- Veal, W.R. & MaKinster, J.G. 1999. Pedagogical content knowledge taxonomies. *The Electronic Journal for Research in Science & Mathematics Education*, 3(4).
- Wahyuni, D. 2012. The research design maze: understanding paradigms, cases, methods and methodologies. *Journal of Applied Management Accounting Research*, 10(1), 69-80.
- William, N. 2010. *Research Methods: The Basics*. London: Routledge Press.
- Wilson, S.M., Shulman, L.S., & Richert. A.E. 1987. '150 different ways' of knowing: representations of knowledge in teaching. In Calderhead, J. (Ed.), *Exploring teachers' thinking*. London: Cassell educational, 104-124.

APPENDIX A: PCK TEST INSTRUMENT

PCK TEST INSTRUMENT FOR PHYSICS TEACHERS
PLEASE ANSWER ALL THE QUESTIONS
The information you will provide is for research purposes only. Your responses will be kept confidential.

BACKGROUND INFORMATION				
Name and Surname (use pseudonyms)				
Sex (tick)	Female		Male	
Name of the present school where you are teaching				
District				
Please fill in details about all post school qualifications. (Since you left secondary school.)				
Qualification e.g (Dip. Sec. Ed or BScEd or any)	Major subjects			
1.				
2.				
3.				
4.				
Please provide the following information about your teaching experience, from your first year of teaching.				

School	Subjects taught	Classes taught	Number of years
1.			
2.			
3.			
4.			

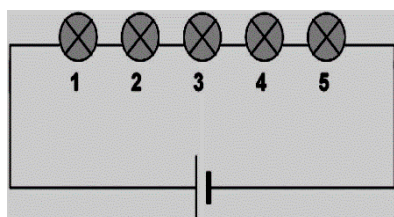
Question 1

Imagine you are teaching speed-time graph in a lab and students report their results graphically in a diagram using smoothing functions. Write at least **three points** of the general criteria you would use to score students presentation of their results.

Criteria for scoring students presentation of graphical results

Question 2

You have discussed the topic, '**Electric current in series and parallel circuits**'. The concept of current is already familiar to your students. You will use the following circuit to assess students' understanding of current in both **series and parallel circuits**:

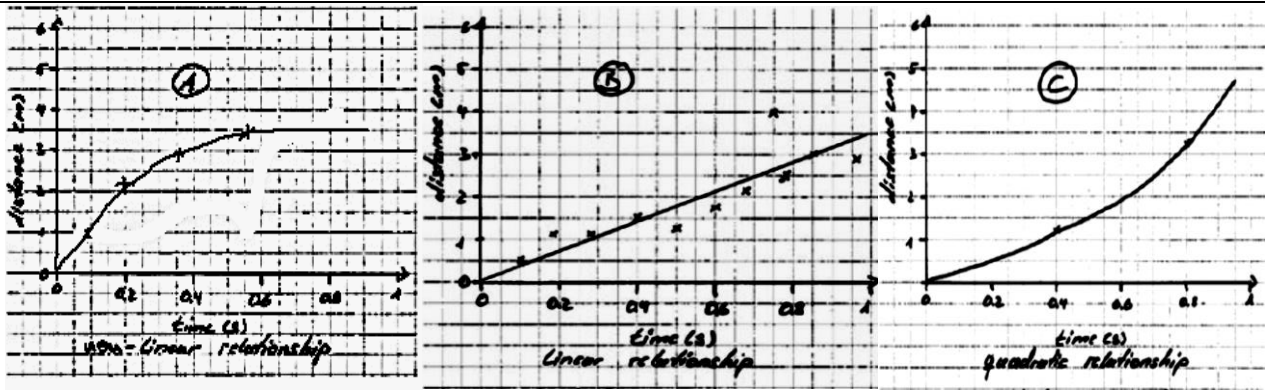


The five light bulbs connected in this circuit are identical. **What can you say about the brightness of the five lamps?**

- a) **One student's answer to the task above is that the brightness decreases from lamp 1 to lamp 5.**

What reason would the student give for this answer? Please explain giving at least two points, the thought processes behind this response.
Reason given by student:
Explanation of the student's thought process:
b) Write down three questions you would use to assess students' understanding of current in series or parallel circuits. One question per assessment objective: A:Knowledge with understanding B:Handling information and problem solving C:Experimental skills and investigations
Assessment objective
A:Knowledge with understanding Question:
B:Handling information and problem solving Question:
C:Experimental skills and investigations Question:
Question 3
Why do you use experiments in Physics lessons? Please give at least three reasons.
Reasons for using experiments in Physics lessons:

Question 4	
You would like to introduce a law of Physics by conducting a student experiment. After all student groups completed the experiment, there are 20 minutes left before the end of the lesson. The results are so poor that they do not clearly support the law. During the experiment, you had the impression that the students had been working carefully, and you were unable to find any errors. Considering that your goals are to maximize learning opportunities, which of the following tactics would you use to proceed with this lesson? Select your choices and write them in the space provided. A. If you have pre-prepared values available, you tell your students that you do not know what they did wrong. You then use the prepared values to tabulate the experiment results. B. You tell your students that you cannot work with the results and use modified values. C. If the students recognize that their results are poor, you try to find the source of the errors together and apply any recommended changes in a follow-up experiment. D. You be honest and tell your students that the experiment did not work as expected, and then you conduct a different experiment. E. You postpone the tabulation/analysis of results to the next lesson so that you can think further about it, and decide to start another experiment. F. You have the students formulate their own Physics law using their current results, and in the next lesson you let them conduct an experiment that proves their formulation wrong. After this, you and your students reflect on all that you have done.	
Write your choice(s) as alphabet(s)	Choice(s)
Question 5	
Force, Energy and Power are different, although related concepts	
a) Show the relationship between force and energy, force and power, power and energy. Use 100N and 100J, 100N and 100W and lastly 100W and 100J to provide examples which show these relationships.	
Force and energy	
Relationship	Example: 100 N and 100 J
Force and power	

Relationship	Example: 100 N and 100 W
Power and energy	
Relationship	Example: 100 W and 100 J
b) What makes it difficult for students to understand the concepts force, energy and power? Explain giving at least three points.	
Explanations:	
Question 6	
Imagine that you are planning to teach a lesson whose purpose is for students to experimentally determine the relationship between distance and time for an object in free fall. The groups of students present their data in the form of distance-time diagrams and derive the relationship with smoothing functions. Select a group whose distance-time diagram best defines the relationship between distance and time in free fall. Explain with one reason per group why the two groups which you have not chosen are incorrect.	
	
Correct group: _____	

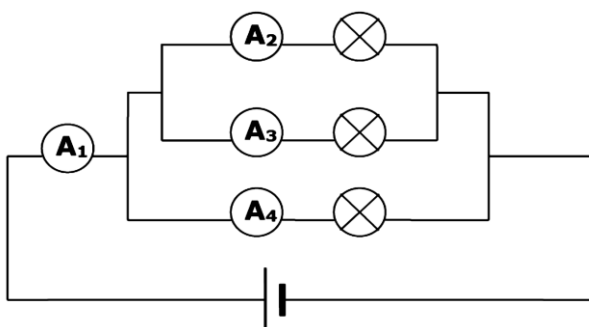
Group _____	Incorrect because
Group _____	Incorrect because

Question 7

You have covered the topic of 'Current in Series and Parallel Circuits' with your students in the previous lesson.

You set the following task to examine the content in more depth.

Ammeter A1 in the circuit below shows a current of 1.2 A.



a) What do the other meters read?*(all lamps are identical)*

Meter	Reading
A ₂	
A ₃	
A ₄	

b) One student gives the following answer:

A₂ reads 1.2A.

A₃ reads 1.2A.

A₄ reads 1.2A.

What reason would the student give for this answer?

Please explain, giving at least **two points** why the student would give these responses.

Student reason:

Explanation:

Question 8
Literature on students learning says that it is important for the learning process to consider students' preconceptions while planning lessons. Please give at least three reasons to explain why.
Reasons:
Question 9
Students may have misconceptions having to do with the Physics concepts of speed and velocity . Write down one misconception about velocity related to the following:
(a) Direction (b) Force (c) Calculations of speed and velocity
(a) Misconception about direction in speed and velocity
(b) Misconception about speed and velocity related to force
(c) Misconception about speed and velocity related to calculations
Question 10
What are the benefits of emphasizing units in Physics lessons? Please explain, giving at least three points.
Explanations:

Question 11
When you enter one Physics classroom, you see the sketch below from the previous lesson on the board.
What might the sub-topic of the previous lesson have been and what content was covered in the lesson?
Sub-topic:
Content covered in the lesson:
Question 12
In which grade level would you teach the content in question 11? List at least two concepts you would need to have covered before you could teach this concept.
Level: _____
Prior concepts:

THANK YOU VERY MUCH FOR YOUR PARTICIPATION, YOUR CONTRIBUTION IS HIGHLY APPRECIATED.

APPENDIX B: PCK TEST RUBRIC

RUBRIC FOR SCORING PHYSICS TEACHERS' PCK TEST

Question 1			
Expectations: general criteria to score students' presentation of their results graphically in a diagram using smoothing functions. • Graphs should have a title • Variables must be correctly labelled on the axes. • Appropriate units of variables must be shown • Appropriate scale must be used • The best fit line must be drawn • The graph should take most of the x and y scales • Or any other points, important in marking smoothing functions			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No relevant point from the expectations or no response at all	One relevant point mentioned	Two relevant points mentioned.	Three relevant points mentioned.
Question 2			
• Expectations: Reasons • Large quantity of current is consumed by bulb 1 as it is the first bulb and consumption decreases along the bulbs. • Bulb1 receives more voltage that decreases along the bulbs. • Resistance of bulb 1 is lower than the resistance of all other bulbs. • Bulb 1 is near the current source than other bulbs. student's thought process: • Current is consumed by bulbs • Bulb 1 receives more voltage which is used up and the remaining voltage goes to the other bulbs. • The first bulb has lower resistance because there is more energy to push electrons to flow through • The positive terminal is the source of current, bulb 1 is near the current source • The amount of charge entering the light bulb is less than the charge exiting the light bulb, so the next bulbs get less charge.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No relevant point from the	Correct reason given, no thought processes give.	Correct reason, one correct thought	Correct reason, two correct thought processes

expectations or no response at all	Or no reason given, one correct though process.	process or incorrect reason, two correct thought processes	
a) Expectations according to LGCSE syllabus A: Knowledge with understanding Question often beginning with one of the following words: define, state, describe, explain or outline, testing the knowledge of one of: scientific phenomena, facts, laws, definitions, concepts and theories, scientific vocabulary, terminology and conventions, scientific instruments and apparatus, including techniques of operation and aspects of safety, scientific quantities and their determination, scientific and technological applications with their social, economic or environmental implications, related to current in parallel and series connection. B: Handling information and problem solving Questions testing these objectives will often begin with one of the following words: discuss, predict, suggest, calculate, or determine. Questions testing these skills may be based on information that is unfamiliar to candidates, requiring them to apply the principles and concepts from the syllabus to a new situation, in a logical, reasoned or deductive way. C: Experimental skills and investigations A question assessing the knowledge to plan simple investigations and use techniques, apparatus and materials, to make and record observations, measurements and estimates to interpret and evaluate experimental observations and data to plan investigations and/or evaluate methods and suggest possible improvements.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
All questions do not assess the stated objectives.	One question correctly testing one objective.	Two questions correctly testing two objectives.	Three questions correctly testing the three objectives.
Question 3			
• Experimentation develops causal and functional thinking and creativity • Experimenting develops the ability to work in a team • Experiments are motivating, increase variety and arouse interest • Experiments make it easy to experience learning • Students are actively engaged • Experiments support the learning of scientific research methods • Experiments are an established method of gaining knowledge in Physics (generating hypotheses and working with them) • Experiments make physical facts visually concrete • Experiments make physical facts/relationships plausible / explain them • Experiments support concept formation • Experiments may lead to cognitive conflict • Students practice handling of data and data analysis • Students practice handling of deviances/establish a relationship to them • Haptic/psychomotoric aspects are developed • Retention of concepts Examples of incorrect answers: • Experiments are required by the curriculum • To practice			

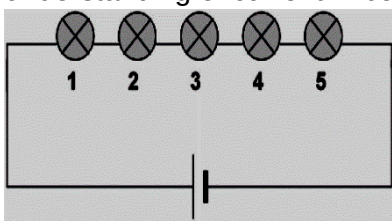
To use diverse methods			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
Wrong answer or no response	One point from expectations.	Two points from expectations.	Three points from the expectations.
Question 4			
Expectations: Choices C to F can maximize learning.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No choice or choices A and B	One of C, D, E or F	Two of C, D, E and F	Three of C,D, E and F or all 4 correct
Question 5			
a) Expectations:			
Force and energy			
Relationship Energy (J) = force (N) × distance (m)	Example How much energy would it take to lift a stone weighing 100N over a distance of 1m? Any example that would relate 100J and 100N 100J= 100N×1m Energy transfer of 100 J results when a force of 100 N is applied over a distance of 1m. Or any examples showing the relationship.		
Force and power			
Relationship Related by the amount of work done by a force. Power = rate at which work is done by a force applied over a distance.	Example $100W = \frac{100N \times 1m}{1s}$ How much power would it take to lift a stone weighing 100N over a distance of 1m in 1 second? A force of 100N applied over a distance of 1m on an object for a period of 1 second produces 100W Or any example the can relate 100W to 100N.		
Power and energy			
Relationship Power = energy transferred per unit time When the rate of energy transfer is 100J/s, the power is 100W.	Example $100W = \frac{100J}{1s}$ When Pule climbs up the hill, the energy transferred is 100J every second. Calculate Pule's power. Or any example relation 100W to 100J.		
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No answer or answers showing no relationships	One example and corresponding relationship correct	Two examples and corresponding relationships correct	Three examples and corresponding relationships correct.
b) Expectations: The language problem, students use the words force, energy and power interchangeably.			

- The limited Mathematics concepts required to use equations involve in problems engaging force, energy and power. - Failure to use units for force, energy and power correctly - The misconceptions around the concepts: examples of such misconceptions given: Energy is used up Objects at rest do not have energy An object stops moving because energy is used up An object with more energy has high power etc.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No response or irrelevant responses given.	One relevant response given	Two relevant responses given	Three relevant responses given
Question 6			
Expectations: - Group: C Group A, Incorrect because - The graph shows that speed decreases as the object falls, which contradicts what actually happens, owtte. Group B, Incorrect because - The graph shows the object moving with a constant speed, while in free fall the object accelerates, owtte.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No answer or A or B	Answer as C, both reasons are incorrect.	Answer as C One reason is correct.	Answer as C Two reasons are correct.
Question 7			
a) Expectations: $A_2 = 0.4A$ $A_3 = 0.4A$ $A_4 = 0.4A$			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
All responses incorrect	One response correct	Two responses correct	Three responses correct
b)			
Expectations: Reason: - The bulbs are identical and therefore have the same amount of current flowing. owtte Explanation - Current is the same at all points of the circuit irrespective of the connection. - The bulbs are identical therefore consume the same amount of current. - Identical bulbs have the same amount of charge flowing. - Identical bulbs draw the same amount of energy from the battery, therefore have the same current flowing.			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed

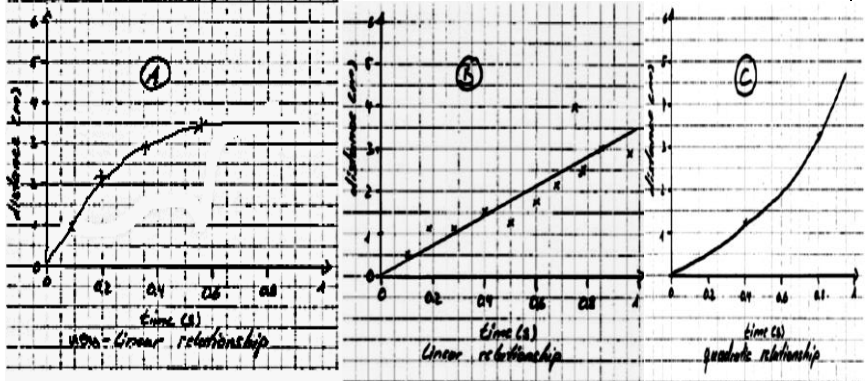
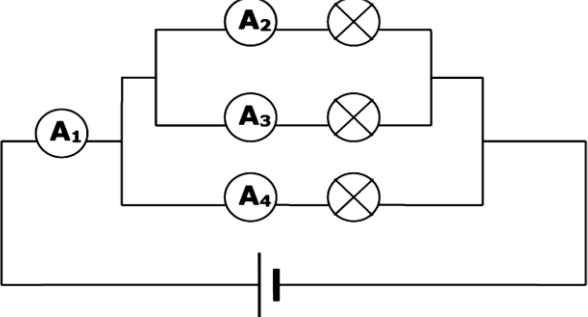
No responses or all responses incorrect	Reason correct and explanations incorrect or reason incorrect and one explanation correct	Reason and one explanation correct or reason incorrect and two explanations correct	Reason correct and two explanations correct
Question 8			
- To select the best teaching strategies that can help address the misconceptions - To build on existing acceptable concepts - To select the best examples, analogies and representations informed by the misconceptions around the concepts - To logically sequence conceptual change strategies in the classroom etc			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No answer or answers not related to lesson planning	One correct reason	Two correct reasons	Three correct reasons
Question 9			
Misconceptions related to the direction - Velocity and speed are the same - Velocity has no direction - Two bodies have the same direction of motion when they have the same goal Misconceptions related to force - A body in motion can cause something / has force; it has more force when it moves faster - Without force there is no motion - A uniform movement requires a force - Bodies become slower by themselves - High speed is the result of a large force (neglecting the time aspect) Misconceptions related to the relationship between distance and time $v = s/t$ always can be used for calculation - The formula is $v = s \cdot t$ - Average speed and mean speed are the same			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
Incorrect responses or no responses given	One misconception correct	Two misconceptions from two categories correct	Three misconceptions from three categories correct.
Question 10			
Expectations: Units help students to: - express measurements of physical quantities - describe observations quantitatively - compare the amount of the same physical quantity - establish a common understanding of the quantity of a physical quantities irrespective of the location - differentiate between physical quantities which are used to describe nature quantitatively. - establish mathematical relationships between physical quantities.			

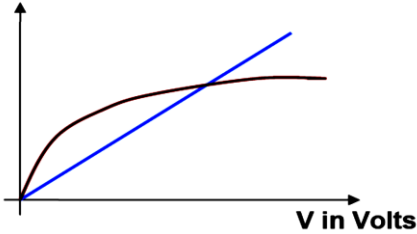
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No responses or incorrect responses given	One correct explanation given	Two correct explanations given	Three correct explanations given
Question 11			
Sub-topic: Resistance			
Content covered in the lesson - The relationship of current and voltage in ohmic and non-ohmic materials or - Resistance of ohmic and non-ohmic materials - V/I characteristic graphs for ohmic and non-ohmic materials			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No sub-topic given No content given Or Incorrect sub-topic and incorrect content	Sub-topic given and no content No sub-topic or incorrect sub-topic and one concept given in content	Correct sub-topic and one correct concept Or Incorrect sub-topic and two correct concepts given for content.	Correct sub-topic And two or more correct concepts given as content.
Question 12			
Expectations			
Level: Grade 11 or 12 or 9 and 10 because of the new syllabus			
Prior concepts			
- Current - Emf, p.d or voltage - Resistance - Electric circuits - Measurement of current and voltage			
1 points: Undeveloped	2 points: Limited	3 point: Intermediate	4 points: Developed
No grade, no prior concepts or Wrong grade and wrong prior concepts	Correct grade and wrong prior concepts Or Wrong grade and one correct prior concept	Correct grade and one correct prior concept Or Wrong grade and two correct prior concepts	Correct grade and two or more correct prior concepts

APPENDIX C: DESCRIPTION OF THE PCK TEST ITEMS

Question		PCK Component	Adapted from
1	Imagine you are teaching speed-time graph in a lab and students report their results graphically in a diagram using smoothing functions. Write at least three points of the general criteria you would use to score students presentation of their results.	Assessment knowledge: Knowledge of dimensions of science learning that are important to assess	Kirschner <i>et al.</i> (2016) Adapted
2	You have discussed the topic, 'Electric current in series and parallel circuits'. The concept of current is already familiar to your students. You will use the following circuit to assess students' understanding of current in both series and parallel circuits:  The five light bulbs connected in this circuit are identical. What can you say about the brightness of the five lamps?		
a)	One student's answer to the task above is that the brightness decreases from lamp 1 to lamp 5. What reason would the student give for this answer? Please explain giving at least two points the thought processes behind this response.	Knowledge of students: Knowledge of misconceptions and students' difficulty	Ergönenç, Neumann and Fischer (2018) Adapted
b)	Write down three questions you would use to assess students' understanding of current in series or parallel circuits. One question per assessment objective: A: Knowledge with understanding B: Handling information and problem solving C: Experimental skills and investigations	Assessment knowledge: Knowledge of dimensions of science learning that are important to assess	Kirschner <i>et al.</i> (2016) Adapted
3	Why do you use experiments in physics lessons? Please give at least three reasons.	Pedagogical Knowledge: Knowledge of instructional	Kirschner <i>et al.</i> (2016) Adopted

		strategies and their advantages	
4	You would like to introduce a law of physics by conducting a student experiment. After all student groups completed the experiment, there are 20 minutes left before the end of the lesson. The results are so poor that they do not clearly support the law. During the experiment, you had the impression that the students had been working carefully, and you were unable to find any errors. Considering that your goals are to maximize learning opportunities, which of the following tactics would you use to proceed with this lesson? Select your choices and write them in the space provided. G. If you have pre-prepared values available, you tell your students that you do not know what they did wrong. You then use the prepared values to tabulate the experiment results. H. You tell your students that you cannot work with the results and use modified values. I. If the students recognize that their results are poor, you try to find the source of the errors together and apply any recommended changes in a follow-up experiment. J. You be honest and tell your students that the experiment did not work as expected, and then you conduct a different experiment. K. You postpone the tabulation/analysis of results to the next lesson so that you can think further about it, and decide to start another experiment. You have the students formulate their own physics law using their current results, and in the next lesson you let them conduct an experiment that proves their formulation wrong. After this, you and your students reflect on all that you have done.	Pedagogical Knowledge: Knowledge of instructional strategies	Kirschner <i>et al.</i> (2016) Adopted
5	Force, Energy and Power are different, although related concepts		
a)	Show the relationship between force and energy, force and power, power and energy. Use 100N and 100J, 100N and 100W and lastly 100J and 100W to provide examples which show these relationships.	Content Knowledge: Knowledge of subject matter	Kirschner <i>et al.</i> (2016) Adapted
b)	What makes it difficult for students to understand the concepts force, energy and power? Explain giving at least three points.	Knowledge of students: Knowledge of students' difficulties	Newly added
6	Imagine that you are planning to teach a lesson whose purpose is for students to experimentally determine the relationship between distance and time for an object in free fall. The groups of students present their data in the form of distance-time diagrams and derive the knowledge with which functions. Select a group whose distance-time diagram best defines the relationship between distance and time in free fall. Explain with one reason per group why the two groups which you have not chosen are incorrect.	Content Knowledge: Knowledge of subject matter	Kirschner <i>et al.</i> (2016) Adapted

			
7	You have covered the topic of 'Current in Series and Parallel Circuits' with your students in the previous lesson. You set the following task to examine the content in more depth. Ammeter A1 in the circuit below shows a current of 1.2 A. 		
a)	What do the other meters read?(all lamps are identical)	Content knowledge: Knowledge of subject matter	Ergöner, Neuman and Fischer (2018) Adopted
b)	One student gives the following answer: A2 reads 1.2A. A3 reads 1.2A. A4 reads 1.2A. What reason would the student give for this answer? Please explain, giving at least two points why the student would give these responses.	Knowledge of students: Knowledge of misconceptions	Ergöner, Neuman and Fischer (2018) Adopted
8	Literature on students learning says that it is important for the learning process to consider students' preconceptions while planning lessons. Please give at least three reasons to explain why.	Knowledge of students: Knowledge of misconceptions	Kirschner <i>et al.</i> (2016) Adopted
9	Students may have misconceptions having to do with the physics concepts of speed and velocity. Write down one misconception about velocity related to the following: (d) Direction (e) Force (f) Calculations of speed and velocity	Knowledge of students: Knowledge of misconceptions	Kirschner <i>et al.</i> (2016) Adopted

10	What are the benefits of emphasizing units in physics lessons? Please explain, giving at least three points.	Knowledge of students: Knowledge of students' understanding of science	Kirschner <i>et al.</i> (2016) Adopted
11	When you enter one physics classroom, you see the sketch below from the previous lesson on the board.  What might the sub-topic of the previous lesson have been and what content was covered in the lesson?	Curricular Knowledge: Knowledge of topics taught at a particular level.	Ergönerç, Neumann and Fischer (2018) Adopted
12	In which grade level would you teach the content in question 11? List at least two concepts you would need to have covered before you could teach this concept.	Curricular knowledge: Knowledge of prior concepts.	Ergönerç, Neumann and Fischer (2014) Adapted

APPENDIX D: INTERVIEW SCHEDULE

INTERVIEW SCHEDULE

Questions

1. Which topic or sub-topic are you going to teach today?
2. What are the main concepts you are going to teach in this topic?
3. Why do you think it is important for students to know these concepts?
4. What else do you know about these concepts that you do not intend students to know yet?
5. What are the difficulties connected with teaching these concepts?
6. What knowledge can you share about students' thinking that influences your teaching of these concepts?
7. Are there any other factors that would influence your teaching of these concepts?
8. What teaching procedures would you employ?
9. Why would you use these procedures?
10. What aspects of Science learning are you going to assess in this topic?
11. What methods would you use to assess students' understanding of this topic?

APPENDIX E: ETHICS CLEARANCE APPROVAL (Letter 1)

GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)

16-Oct-2019

Dear Mrs Hlaela, Nthoesele N

Application Approved

Research Project Title:

**EXAMINING THE COMPONENTS OF PEDAGOGICAL CONTENT KNOWLEDGE AND THE
CONSTRUCTION OF PHYSICS TEACHERS' CLASSROOM PRACTICES**

Ethical Clearance number:

UFS-IISD2019/1243

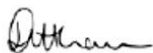
We are pleased to inform you that your application for ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. Furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Yours sincerely

Prof Derek Litthauer

Chairperson: General/Human Research Ethics Committee

Digitally signed
by Derek
Litthauer
Date: 2019.10.16
12:05:01 +02'00'



205 Nelson Mandela
Drive
Park West
Bloemfontein 9301
South Africa

P.O. Box 339
Bloemfontein 9300
Tel: 051 401 9398 /
7619 / 3682
RIMS@UFS.ac.za
www.ufs.ac.za





GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)

20-Aug-2020

Dear Mrs Nthoesele Hlaela

Continuation/Report Approved

Research Project Title:

EXAMINING THE COMPONENTS OF PEDAGOGICAL CONTENT KNOWLEDGE AND THE CONSTRUCTION OF PHYSICS TEACHERS' CLASSROOM PRACTICES

Ethical Clearance number:

UFS-HSD2019/1243/1908

We are pleased to inform you that the application to extend your ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. Furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Yours sincerely

Dr Adri Du Plessis

Chairperson: General/Human Research Ethics Committee

205 Nelson Mandela
Drive
Park West
Bloemfontein 9301
South Africa

P.O. Box 339
Bloemfontein 9300
Tel: +27 (0)51 401
9337
duplessisA@ufs.ac.za
www.ufs.ac.za



APPENDIX G: MINISTRY OF EDUCATION PERMISSION LETTER



THE KINGDOM OF LESOTHO
MINISTRY OF EDUCATION AND TRAINING

The Ethics Committee
Department of Education
UFS

23rd August 2019

Dear Sir/Madam,

**RESEARCH TOPIC: EXAMINING THE COMPONENTS OF PEDAGOGICAL
CONTENT KNOWLEDGE AND THE CONSTRUCTION OF PHYSICS TEACHERS'
CLASSROOM PRACTICES.**

I 'Mabakubung Seutloali, the CEO-Secondary Schools in Lesotho give permission to Nthoesele Hlaelā of the University of the Free State to conduct the research on the above-mentioned topic at schools in this country. I understand that the study will involve writing the PCK test, audio-recorded interviews and video-recorded classroom observations. I also understand that no harm will result from the teachers' participation in this study, and that the study is being conducted for purposes of improving the teaching of physics in schools. This permission is on condition that the material will be used for research purposes only.

This consent does not oblige the teacher to participate and I understand that teachers may withdraw from the study at anytime.

I understand that the real names of the schools will not be used in the study. I also understand that the names of participating teacher and those of the people they will refer to in the interview will be kept confidential. I also understand that the results for the PCK test will be used for research purposes only and will be kept confidential.

I understand that the results of the study will be presented in the research report, may be presented at a conference and/or published in an academic journal, but the name of the school and that of the teacher will remain unknown.

I have received a signed copy of the informed consent agreement.

B. M. SEUTLOALI (MRS)
CEO – SECONDARY

Principal's Informed Consent Form for Conducting Research in Physics Classrooms

Research Topic: Examining the components of pedagogical content knowledge and the construction of physics teachers' classroom practices.

I _____, the principal of _____ give permission to Nthoesele Hlaela of the University of the Free State to conduct the research on the above mentioned topic. I understand that the study will involve writing the PCK test, audio-recorded interviews and video-recorded classroom observations. I also understand that no harm will result from the teachers' participation in this study, and that the study is being conducted for purposes of improving the teaching of physics in schools. This permission is on condition that the material will be used for research purposes only.

This consent does not oblige the teacher to participate and I understand that teachers may withdraw from the study at any time.

I understand that the real name of the school will not be used in the study. I also understand that the names of the participating teachers and those of the people they will refer to in the interview will be kept confidential. I also understand that the results for the PCK test will be used for research purposes only and will be kept confidential.

I understand that the results of the study will be presented in the research report, may be presented at a conference and/or published in an academic journal, but the name of the school and that of the teacher will remain unknown.

I have received a signed copy of the informed consent agreement.

Full Name of Principal: _____

Signature of Principal: _____ Date: _____

Full Name of Researcher: Nthoesele Hlaela

Signature of Researcher:  Date: _____



TEACHER'S CONSENT TO PARTICIPATE IN THIS STUDY

I, _____ (participant name), confirm that Nthoesele Hlaela, of the University of the Free State, asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read and understood the study as explained in the information sheet. I have had sufficient opportunity to ask questions and am prepared to participate in the study. I understand that my participation is voluntary and that I am free to withdraw at any time. I am aware that the findings of this study will be anonymously processed into a research report, journal publications and/or conference proceedings.

I agree to write the PCK test, the audio-recording of the semi-structured interview and video-recording of classroom observations.

I have received a signed copy of the informed consent agreement.

Full Name of Participant: _____

Signature of Participant: _____ Date: _____

Full Name(s) of Researcher(s): Nthoesele Hlaela

Signature of Researcher:  Date: _____

13 Union Street

Villiersdorp

6848

22 June 2023

Professor L.C. Jita
School of Education Studies
University of the Free State
Bloemfontein

**EXAMINING THE COMPONENTS OF PEDAGOGICAL CONTENT KNOWLEDGE
AND THE CONSTRUCTION OF PHYSICS TEACHERS' CLASSROOM PRACTICES**

NTHOESELE HLAELA

This is to confirm that I have edited the language of Nthoesele's doctoral thesis to the best of my ability.

Yours sincerely

A handwritten signature in black ink, appearing to read 'D. Gripper', with a horizontal line drawn underneath it.

Derek Gripper

derekgripper@gmail.com

APPENDIX K: TURNITIN REPORT



this study sought to measure the PCK components that Physics teachers in Lesotho possess and to investigate how these PCK components are manifested in classroom practice. It is important to find out what Lesotho teachers know about teaching Physics and how their professional knowledge shapes their teaching by looking at what these teachers do in their classroom with the pedagogical content knowledge that they have.

Barendsen and Henze (2017) assert that there have been inconsistent findings in large-scale studies to relate PCK and classroom instructional practices, thus the call for more studies that explore the relation of PCK and classroom practices so as to understand the role of PCK in teachers' classroom actions. While we are becoming better informed about the relationship of PCK and classroom practices, we know much less about how this relationship varies across subjects and country contexts. For instance, not much has been done in Lesotho to measure Physics teachers' PCK and/or to portray what teachers with more or less developed PCK do in class when teaching Physics. This study sought to close the gap and contribute insights by measuring Physics teachers' PCK and illustrating how Physics teachers use their PCK in a senior secondary level classroom context of a developing country. To understand better the relationship between PCK and

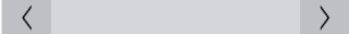
7



Match Overview



9%



1	hdl.handle.net Internet Source	1% >
2	scholar.ufs.ac.za Internet Source	1% >
3	www.tandfonline.com Internet Source	<1% >
4	www.researchgate.net Internet Source	<1% >
5	repository.lib.ncsu.edu Internet Source	<1% >
6	ueaeprints.uea.ac.uk Internet Source	<1% >
7	lsg.ucy.ac.cy Internet Source	<1% >