THE DEVELOPMENT AND VALIDATION OF A THEORETICAL CONSTRUCT DESCRIBING CONTENT KNOWLEDGE FOR TEACHING SCIENCE: A CASE STUDY WITH ORGANIC CHEMISTRY

BONGANI PRINCE NDLOVU

SUPERVISOR

PROFESSOR E MAVHUNGA

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DECLARATION

I declare that this thesis is my unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

(Signature of candidate)

DEDICATION

This piece of work is dedicated to the three most important persons in my life.

(i) To my mother, Thokozile Cathrine Thwala, thank you so much for the love and support you have given me over the years.

(ii) To my beautiful daughter Luyanda, daddy loves you kindly. I believe that great things are awaiting you in the future.

(iii) To my grandson, Siyanda “Prince-Junior”. May the gracious Lord protect and guide you through your life my boy.

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I want to thank and acknowledge the people who helped me realize this project till its end.

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ABSTRACT

The distinction between academic disciplines and school subjects has not found enough attention in teacher education research. Thus, a question about the nature of content knowledge suitable for pre-service teacher education and as a base for PCK development in science was raised. The purpose of this study was to conceptualize and validate a theoretical construct that describes a version of content knowledge appropriate for training secondary school science teachers. This construct was termed Teacher-related Science Content Knowledge (TerSCK).

The study followed the traditional two-step process of developing a theoretical construct. The first phase entailed the conceptualization of the envisaged theoretical construct through a systematic literature review. This was followed by the second phase which empirically proved the validity of the conceptualization as a theoretical construct TerSCK. The validation of the conceptualization was located in the methodology class of the 3rd year pre-service science teachers (PSTs), who majored in physical sciences. As such, the study employed a mixed-method research design with a whole class sample of 35 PSTs. The PSTs were exposed to a TerSCK-based intervention to explore various shifts in the quality of their content knowledge for teaching Organic Chemistry.

The findings from the systematic review presented TerSCK as a unique construct located between the academic discipline content and the school science content knowledge. The construct is described through three dimensions that describe the relationship between academic discipline and school subjects. These relational dimensions are the "*logical, epistemological and social dimensions*". Translating the relational dimensions into the curriculum through Schwab's three faces yielded five curriculum elements of TerSCK. These are (i) Fundamentals of the discipline on the topic, (ii) Interconnections between the concepts that make up the fundamental concepts, (iii) Tensions emerging from the process of filtering the discipline fundamentals into the school curriculum scope, (iv) Scientific and other modes of inquiry from other disciplines, and (v) Cultivating social agency.

Findings emerging from the empirical study presented the TerSCK construct as valid based on the acceptable calculated fit statistics values at 0.5 to 1.5 and -2.0 to +2.0 for MNSQ and ZSTD, respectively. The empirical findings further indicated that participant PSTs experienced a significant improvement in the quality of TerSCK after the intervention. Implications for initial teacher education have been drawn and the recommendations include large-scale research on the nature of TerSCK in organic chemistry and other chemistry curriculum topics.

Keywords:

Academic Discipline; School Subject, Organic Chemistry, Pedagogical Content Knowledge; Teacher-related Science Content Knowledge (TerSCK).

PUBLICATIONS/CONFERENCE OUTPUTS

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LIST OF ACRONYMS

CCK	:	Common Content Knowledge
CE	:	Creative Exercise
CK	:	Content Knowledge
HCK	:	Horizon Content Knowledge
ITE	:	Initial Teacher Education
MFfT	:	Mathematical Knowledge for Teaching
MRTEQ	:	Minimum Requirements for Teacher Education and Qualification
NC	:	National Curriculum Statement
NSC	:	National Senior Certificate
PCK	:	Pedagogical Content Knowledge
PRISMA-P	:	Preferred Reporting Items for Systematic Review and Meta-Analysis for Protocol
PSTs	:	Pre-service Teachers
SCK	:	Specialized Content Knowledge
SLR	:	Systematic Literature Review
SRCK	:	School-Related Content Knowledge
TerSCK	:	Teacher-related Science Content Knowledge
TSPCK	:	Topic-specific Pedagogical Content Knowledge
TSPK	:	Topic-specific Professional Knowledge
TSKT	:	Topic-specific Knowledge for Teaching

CHAPTER 1 INTRODUCTION TO THE STUDY

The current chapter gives an outline of the whole research study. It begins by justifying the rationale behind this study. This is well supported by an articulation of the comprehensive purpose of the research. The focal research question and corresponding critical questions which guided this inquiry are mentioned concerning the objectives. Furthermore, the current chapter shares some insights about the researcher and positionality and closes by providing an outline of the chronological order of the chapters that make up this whole research dissertation.

1.1 Introduction

It is commonly accepted that all professions at some point in their advancements have worked towards achieving agreements about key elements of a professional education curriculum, the building blocks of training for all entrants into the occupation (Daza et al., 2021). In teacher education, this assertion levies a need to articulate clearly defined standards of what exactly should teachers recognize about the subject matter they are going to teach (Sims & Fletcher-Wood, 2021). This includes how much of both substantive and syntactic structures of their respective disciplinary content should they acquire during PST education programmes. Such articulated standards are further important in informing the statutory policies that govern and inform teacher accreditation programmes.

What science teachers should teach is thought to be centred on the central concepts that are essential to the substantive and grammatical structures of the subject matter knowledge of science, according to the literature on science education (Mavhunga et al., 2016). About how much teachers should comprehend the content knowledge they should teach, there are various discussions and hypotheses; for more information, read Goodwin et al. (2014). They have prevented a clear and widespread awareness of the qualifications that newly qualified science instructors ought to possess.

Over the last three decades, the efforts of Lee Shulman have shaped the idea of professionalizing and standardizing teaching as a valid profession. Thus, the notion of Pedagogical Content Knowledge (PCK) has been at the centre of considerable research and reformations in the teacher training agenda. In its own right, it separates teachers from any other profession (Shulman, 2015). However, teachers do not teach PCK to their students instead, they use it to reformulate disciplinary content in ways that are suitable for pedagogical practice and reasoning. So, teachers teach the subject matter content of the discipline they are specializing in. The most pertinent question linked to this expectation is how much of the substantive and syntactic aspects of the subject matter content should they know and acquire during their initial teacher education.

1.2 Research problem

A study by Käpylä et al. (2009) found that content knowledge experts were better adept to handle content structure and students' conceptual problems whilst they were less adept at producing topic-specific teaching methods than the content knowledge novices. As a result, there is a need to explicitly develop PCK and subject content knowledge as separate knowledge domains as argued by Lederman and Gess-Newsome (1992). Whilst maintaining this understanding, literature has shown that academic disciplines are fundamentally and conceptually different from their related school subjects (Hordern et al., 2021; Van der Aalsvoort & Kroon, 2015). As a result of their noticeable distinction, the nature of the content knowledge they teach embody is different in theory type, source analogue and representation, as argued by Deng (2012). Along with this argument, international studies on PCK have shown that content knowledge is a precursor to developing decent PCK (Kind & Chan, 2019; Şen et al., 2022). Similarly, in South Africa, the same postulation has been endorsed by the works of Coetzee et al. (2022) and Pitjeng-Mosabala and Rollnick (2018).

Amid these postulations, there is a recurrent inattention given to the similarities and differences in content knowledge embodied by academic disciplines and their related school subjects (Mavhunga & Ndlovu, 2023). Consequently, in science education, this has raised the question about the kind of content knowledge referred to and apposite as a base for PCK development. Is it the academic discipline or school subject content knowledge? Or, there is another version distinct from both? The lack of clarity about the content knowledge for teaching puts teacher education at risk of lacking ways to continuously sharpen the aptness and relevancy of disciplinary content with contemporary social issues such as climate change, sustainable development and digitization.

In a country like South Africa, the policy framework on the Minimum Requirement for Teacher Education Qualification (MRTEQ) mentions the knowledge of content in the subject matter specialization as one of the teacher competencies that must be developed during PST education training (DHET, 2011; Rusznyak & Bertram, 2021). However, despite this policy position, there is no clear policy articulation of the nature of profession-specific subject matter content that is suitable for pre-service teacher (PST) education, particularly in science teacher education.

Commonly, two models are employed in PST education. These are the concurrent and the consecutive approach (Gracia et al., 2021; Zuzovsky & Donitsa-Schmidt, 2017). The consecutive approach focuses on high-end academic disciplinary knowledge and the concurrent approach does not. Recently, it has been discovered that PSTs who were trained in high-end academic disciplinary content knowledge from the science faculties could not create their teacher identity in the content modules used in the mainstream science disciplines (Khoza, 2022). Meanwhile, anecdotal conversations with the academics from institutions employing the concurrent model reveal that they generally take up to the second year of the academic disciplinary content. Others indicated that they consider only the first year and align it with the national school curriculum content. As a result of these variations, there are discrepancies in the scope of content knowledge needed for teaching purposes. Hence, there is a rationale to rethink the version of content knowledge related to training secondary school teachers.

Commonly, it is accepted that teachers start with their comprehension of content, albeit the source, and they are expected to transform this content for their pedagogical practice (Mavhunga & Rollnick, 2013; Shulman, 1987). Hence there is a need to clarify the theoretical nature and scope of content knowledge suitable for pedagogical practice and that should also underpin PST initial development education programmes.

1.3 Purpose of the research

The overall purpose of this research study is to conceptualize and validate a theoretical construct that describes the version of content knowledge that is suitable to teach secondary school science and the base for PCK development. This version of content knowledge in science is argued in this study to be distinct from the academic discipline content and school science content.

1.4 Objectives of the research

The study was underpinned by three measurable objectives.

(i) To conceptualize a theoretical construct that would distinctly define the content knowledge suitable for science teacher development.

(ii) To develop the tools to measure the quality of the newly conceptualized construct

(iii) To develop the means to validate the newly conceptualised theoretical construct.

1.5 Research questions

Flowing from the purpose highlighted above, the main research question guiding this study asked:

> How could content knowledge suitable for developing science secondary school pre-service teachers be conceptualized and validated as a distinct theoretical construct from the academic science discipline and school subjects' content?

A set of three critical research questions were used to unpack the main research question above:

(i) How could a theoretical construct for defining and developing the content knowledge of secondary school science pre-service teachers be conceptualized?

(ii) How could the newly conceptualized theoretical construct be validated?

(iii) What valid instrument could be used to measure the quality of the newly conceptualised theoretical construct in pre-service teachers?

1.6 Significance of the study

This study builds on the arguments highlighted above, specifically in science education to conceptualize a theoretical construct that describes a distinct content knowledge for teaching secondary school science. This discussion has the potential to open up new research in the untouched areas of professional teacher knowledge beyond the boundaries of this study. In advancing science education research, the study also raises the need to develop suitable tools that are designed to measure this version of the content. In addition, it is an important theoretical contribution that lays out a fertile ground to explore empirical research that investigates the nature of the kind of content that is argued as a precursor in the development of good-quality PCK. Furthermore, this study has the potential to influence changes and reformations in the policy for the development of the Minimum Requirement for Teacher Education Qualification in South Africa. It raises the need to be explicit concerning the nature, scope and depth of disciplinary content knowledge (CK) geared for science teacher education programmes.

1.8 Researcher and positionality

When I completed my first undergraduate B. Ed degree I worked as a secondary school teacher for three years, I was teaching both Mathematics and Physical Sciences. Later in that career trajectory, I was promoted to a departmental head in Mathematics Sciences and Technology. Before joining Academia, I also worked as a Senior Education Specialist (Physical Sciences) in the Department of Basic Education. This senior role exposed me to work with secondary school teachers in curriculum and planning at a district level. As I result I was largely involved in the proficient development of in-service teachers. My earlier work as a scholar was focused on PCK and later topic-specific pedagogical content knowledge (TSPCK) for my Master's Degree. It is in this field and space that I have developed an interest in studying teacher professional knowledge, particularly in PST education.

As a researcher, I associate myself with a pragmatism worldview. Pragmatism draws its existence from the fortress of positivism and interpretivism (Teddlie & Tashakkori, 2012; Wahyuni, 2012). Pragmatism as a philosophy is concerned with “what works” in solving a particular research problem in a particular context (Morgan, 2014). Instead of questioning ontology and epistemology, pragmatists establish their research framework by starting with the research question. (Creswell & Clark, 2017; Wahyuni, 2012). For this research paradigm, the focus is on the results of the research and the several kinds of data collected to inform the problem being studied

As such, pragmatism is strongly associated with the use of a mixed-method research approach (Creswell, 2014; Johnson & Onwuegbuzie, 2004; Teddlie & Tashakkori, 2012). On an epistemological level, the study issue will determine whether observable phenomena or subjective meanings are considered to be valid knowledge. To assist in making sense of the facts and interpretations, pragmatics focuses on realistically applicable research that incorporates several perspectives (Wahyuni, 2012).

Regarding axiology, Wahyuni (2012) argues that the researcher is value-bond and they tend to lie in the continuum between the etic and emic approaches. In this study, while interpreting the findings, values play a significant role. Both objective and subjective points of view are used. This potentially can lead to biased and unbiased perspectives in data analysis (Creswell & Clark, 2017).

In conclusion, the next section outlines briefly the contents of the sequential chapters that comprise this research dissertation.

1.9 The structure of the thesis

Nine chapters make up this dissertation. Below is a brief outline of these chapters. Chapter 2 is the summary of the literature review underpinning this study. It is made up of six sub-sections. These are the (i) teacher's professional knowledge, particularly PCK, (ii) the impact of disciplinary CK on PCK, (iii) approaches for developing CK for teaching, (iv) methods and rationale for developing valid instruments, (v) issues in teaching and learning organic chemistry and (vi) the theoretical framework of the study informed by the substantive and syntactic structures of the knowledge.

Chapter 3 is the outline of the research design used to carry out this inquiry. The research design speaks to two distinct stages of this study. The first stage has a qualitative research design. This design speaks to the research processes used to build a conceptual argument for the construct through a qualitative meta-synthesis of the findings from a systematic literature review. The second stage has a mixed–method design as it speaks to the empirical processes leading to the statistical validation of the newly conceptualised version of CK, as a theoretical construct.

Chapter 4 uses Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-P) to technically account for how the systematic literature review was conducted and reported.

Chapter 5 presents a full conceptual argument describing the version of content suitable for teaching secondary school science. This chapter further positions the theoretical construct conceptualized in this study alongside a specific theory of content leading to powerful knowledge. This chapter provided answers to the first research sub-question.

Chapter 6 draws from Chapter 5 to describe the kind of intervention exemplifying the introduction of the validated construct as content knowledge for a typical Chemistry PST program, using a case of organic chemistry. This Chapter culminates with a piece of curriculum content and performance objectives that informs the process of developing the instrument and the subsequent intervention in organic chemistry

Chapter 7 is a detailed report on the development of a valid and reliable instrument that is designed to measure the quality of the newly conceptualized content knowledge for science teachers. This instrument development process was important to answer the third research sub-question in this study.

Chapter 8 presents the empirical study for generating data for the validation of the newly conceptualized content knowledge for science teachers as a theoretical construct. The study includes an explicit intervention with PSTs using a case of organic chemistry. This chapter was important to explore ways of validating the theoretical construct conceptualized in this study, thereby responding to the second research sub-question.

Chapter 9 pulls it all together presenting collated evidence responding to the main research question in this study. The Chapter further highlights the theoretical and research methodological contributions made in this study to advance the field. Limitations for consideration when interpreting the findings are also listed. The Chapter closes by drawing implications for science teacher education, as well as recommendations for further research in the field of science education.

The next chapter presents the literature review of this study.

CHAPTER 2 LITERATURE REVIEW

This current chapter provides an overview of the literature that has shaped the current debates on teacher content knowledge in science education research. It begins with a focus on teachers' professional knowledge, distinguishing content knowledge from the domination of its teachability through PCK explorations leading to the refined consensus model (RCM). It further reflects on tools designed to measure and capture teachers' content knowledge. In addition, it reflects on the various models used in initial teacher development programmes to teach content knowledge thereby illustrating the ambiguity in conceptualization. As organic chemistry has been used as a case in point, the chapter also reflects on the teaching and learning of the topic. The chapter closes by foregrounding this study on Schwab's notion of content knowledge structures as the theoretical framework grounding the study.

2.1 Introduction

In this thesis, it is argued that academic discipline content is not suitable as a precursor for PCK development. Likewise, secondary school content knowledge alone cannot be sufficient as a source for teacher identity and PCK development. This study hypothesized that there is a different version of content knowledge that is geared toward PST education and should be considered as a base for PCK development. Taking this into consideration, the first part of this review commences by deliberating on issues around professional teacher knowledge debates as well as how the focus has largely been on PCK compared to other teacher professional domains.

2.2 Teacher professional knowledge

In the last three decades, research on teacher education has loosened its grip on behavioural studies towards a strong focus on professional teacher development. Much of the debates in this research area resounded around the content knowledge to be taught and its teachability for learner understanding. These are two of the seven knowledge categories of teachers acknowledged by Shulman (1987). PCK has been widely associated mainly with the teachability of disciplinary content knowledge and extensively researched in the science education literature. In the next paragraph, the notion of PCK is discussed and its genesis as a germane knowledge for teachers is accounted for.

2.2.1 Pedagogical content knowledge

Since its inception, PCK has pervaded the science teacher education literature as a theoretical construct and lens for studying teachers' professional knowledge (Chan & Hume, 2019; Herrmann-Abell et al., 2013; Kind, 2009). In South Africa, this has been the case, for example, in the work by Mavhunga and Rollnick (2013); Pitjeng-Mosabala and Rollnick (2018) with PSTs and Rollnick et al. (2008) with practising teachers. PCK has also found a place in policy directives such as the revised framework for MRTEQ, Act 67 of 2008 as one of the competencies that must be developed during PST training. Because of its dominion in teacher education research, it has formed a large body of literature both internationally and within the country over the past three decades.

PCK was among the knowledge domains that Shulman (1987), also known as the knowledge foundation for teaching, introduced. They included familiarity with the subject matter, understanding of general pedagogy, familiarity with the curriculum, familiarity with pedagogical content, familiarity with learners, familiarity with educational environments, and familiarity with the goals, objectives, and values of education. According to him, the conception of PCK was made possible by the intersection of subject matter content and appropriate pedagogies that pointed to the distinct teacher's fields of knowledge and their unique form of specialized knowledge. From Shulman's early designs, there have been several PCK-building conceptions over the years (Gess-Newsome, 2015). Because of this, the PCK community needed to get together at a summit to discuss these ideas and develop a single model of PCK. In the next section, the birth of the model of teacher professional knowledge and skills in which PCK is situated is discussed.

2.2.2 Model for teacher professional knowledge and skills

In 2012, the first PCK high-level meeting generated a more explicit body of collective wisdom and critical review of PCK that has the probability to increase rigour and its value in science education. In addition, this summit identified and developed coherent definitions, measures and frameworks for PCK employability in the teacher education research agenda (Gess-Newsome, 2015).

Because of these agreements in the first summit, PCK is now defined as the understanding of the justification for and actualization of teaching specific topics in a specific manner with specific kinds of learners for a specific cause. (Carlson et al., 2015). Furthermore, the definition stems from accepting the complexity of PCK by nature and being multi-dimensional as first argued by Veal and MaKinster (1999) through their introduction of the taxonomies of PCK. The implication of this definition postulates that PCK is not just a static knowledge of content and pedagogy. Instead, it is specialised topic-specific knowledge that is context-bound (Knievel et al., 2015). Considering that PCK is topic-specific, key questions that arise are: is there a pathway followed in transferring planned PCK to enacted PCK in science topics? Is there a pathway that is followed in which PCK is transferred from one topic to another? Is PCK at a topic level sufficient enough to competently prepare learners for high-stakes examinations? These are some of the questions that are pertinent in science teacher education both locally and beyond.

The first PCK summit developed a model of Teacher Professional Knowledge and Skills (TPK&S), shown in Figure 2.1 in which PCK was included (Gess-Newsome, 2015).

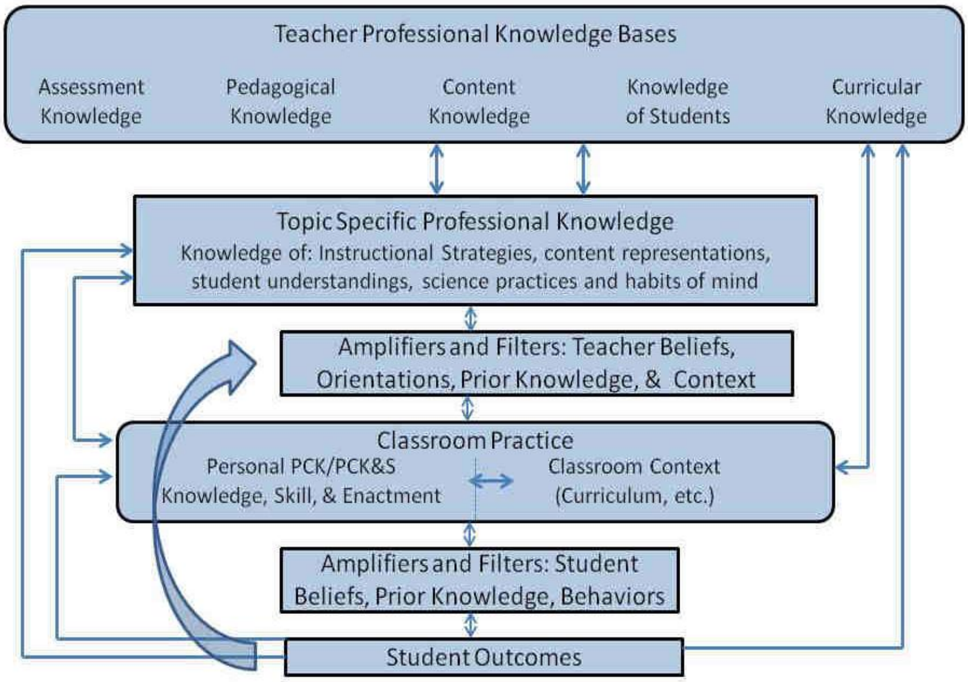


Figure 2.1: Model for Teacher Professional Knowledge and Skills (Gess-Newsome, 2015)

At the top of this TPK&S model, Teacher Professional Knowledge Bases (TPKB) which are outcomes of research and best practices are uncovered (Gess-Newsome, 2015), these knowledge bases are best described at a disciplinary level and are less topic-specific. The knowledge of assessment, pedagogy, students and curriculum are among these knowledge bases. For example, knowledge of assessment in science is “generally” the same across a wide range of science topics. Pedagogical knowledge is also specific to a discipline, for example, in science teaching it is important to be aware of the learner's prior knowledge and be able to use appropriate representation to align those ideas to scientific ideas through conceptual teaching (Waldrip et al., 2010).

While TPKBs are generic, their influence lies in their application when teaching a topic (Gess-Newsome, 2015), this application occurs through Topic Specific Professional Knowledge (TSPK). These are knowledge of teaching strategies, regarded as Conceptual Teaching Strategies in the topic-specific PCK literature (Mavhunga & Rollnick, 2013). Secondly, it involves knowledge of representations, known as just knowledge of Representation in the TSPCK model (Mavhunga & Rollnick, 2013). Other aspects of knowledge shown in the TSPK includes knowledge of student understanding which possibly deals with what makes a particular idea difficult to understand and lastly the habits of the sciences practices and the habits of the mind which are less cognitive. There is a paucity of research that has empirically shown how these TSPK elements relate to each other. Most of the research has been reported on topic-specific PCK components interaction. For example, studies by Aydin and Boz (2013), Rollnick and Mavhunga (2014) with practising teachers and Aydin et al. (2015), Ndlovu and Malcolm (2022) with training teachers.

The notion of TSPK espoused in this initial consensus model reduces the supremacy of generalised PCK (Kind, 2015) and situates PCK as personal knowledge for a particular topic taught to a specific group of learners. Thus, the model shows personal PCK that is observable during the act of teaching. On the other hand, TSPK is theorized as canonical (Gess-Newsome, 2015), that is PCK is shaped through research and the collective wisdom of experts.

The classifications above necessitated the differences between PCK and TSPK to be made explicit, which was another milestone during the first PCK summit. Since the birth of the TPK&S model, there were challenges as reported by Carlson and Daehler (2019) due to trifling details about PCK in the first PCK consensus model. Further to that, Carlson and Daehler (2019) argued that the model was an illustration of TPK&S positioning PCK and its influence on classroom practice and student achievements. Particularly, PCK is positioned in classroom practice in relation to other expert knowledge sources. This model coherently adds teaching skills to the PCK concept to indicate that PCK is self-motivated rather than static knowledge and it distinguishes the personal PCK from canonical TSPK. However, Carlson and Daehler (2019) have argued that situating PCK along these knowledge aspects and skills did not unpack the variables, levels and intricacies of PCK. Thus, a need for an RCM was inevitable.

2.3.2 The Refined Consensus Model (RCM)

The next PCK high-level meeting in 2016 was held in which an RCM was developed. See Figure 2.2:

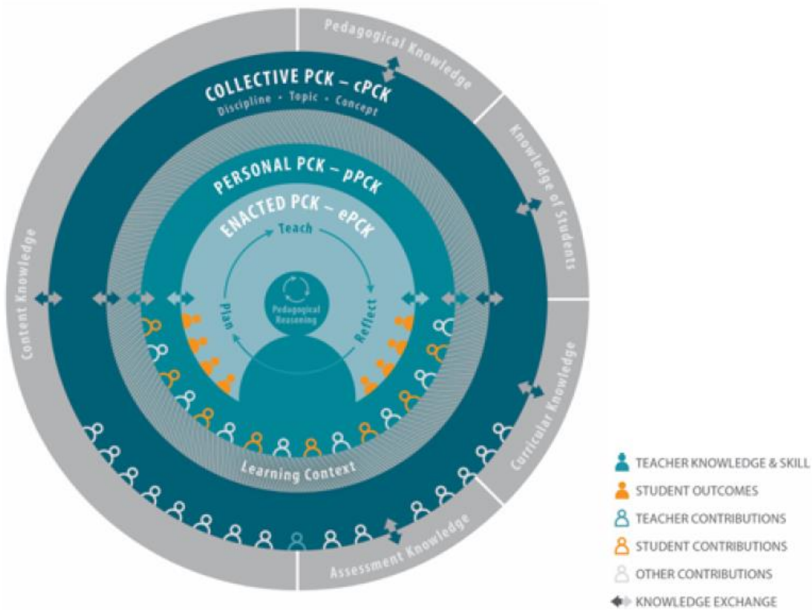


Figure 2.2: Refined Consensus Model of PCK (Carlson & Daehler, 2019)

The RCM of PCK visibly introduces diverse kinds of PCK, which are: personal PCK, enacted PCK and collective PCK. These PCKs are interrelated to one another such that they inform and are informed by each other (Carlson & Daehler, 2019). In the model the notion of enacted PCK is observed when teachers are engaged in the act of teaching, at that phase, three pedagogical stages are involved, as follows: *planning*, *teaching* and *reflecting*. These processes are dynamic and unique to individual teachers as testified by Carlson and Daehler (2019). They further reflect the context within which they occur (Akyuz, 2023).

According to a finding by Kim (2020), personal PCK is linked to enacted PCK and it provides a resource for skills and knowledge that teachers can draw upon throughout their instructional practice. This implies that a teacher draws immensely from their personal experiences to plan, execute and reflect on the specific acts of teaching. Personal PCK differs from one teacher to another, it is context-specific, and it is regarded as the knowledge that teachers put into practice. In the recent literature, there is less that is empirically known from this assertion except for the inferences of the RCM.

Smith and Banilower (2015) argued that if scientific knowledge is normative, then PCK at the disciplinary level is normative, hence canonical. This is also seen in the work of

Cooper et al. (2015) who used the CoRe (Content Representation) to portray teachers' PCK for a particular topic. These CoRes and their associated Pap-eRs require a set of Big Ideas to be identified and conventionally agreed upon at a topic level, and this action is canonical rather than personal (Smith et al., 2018). Second, it's crucial to recognize that the normative aspect of PCK can be comprehended at both the discipline- and/or topic levels. So, in order to avoid needless doubt, it is crucial to understand how canonical PCK affects personal PCK.

The RCM positions collective PCK above personal PCK, though the nature of the relationship between the two is interchangeable. Collective PCK has an impact on enacted PCK and personal PCK. Mavhunga and van der Merwe (2020) published a simplified version of RCM that indicated the relationship between the two PCK and how the translations occur embedded in various filters and enablers. They articulated their version with the process of content transformation along with topic-specific components such as learner prior knowledge, curricular saliency, difficult concepts to teach, representation, and conceptual teaching strategies to shape the way they plan and enact their lessons.

From the arguments by Mavhunga and van der Merwe (2020), it is clear that PCK is associated largely with content knowledge transformation. The outer concentric circles of the RCM show that the knowledge base that impacts the process of pedagogical reasoning more than the others is the content knowledge base. It takes about fifty per cent contribution more than the others combined, see Figure 2.2 of the RCM. This view is in sync with the earlier postulations of (Gess-Newsome et al., 2019). Therefore, the next section will reflect on empirical studies that have looked into the role of content knowledge in PCK across various disciplines in teacher education research.

2.3 Impact of content knowledge on PCK development

Generally, the claim of content knowledge (CK) on PCK touches back to the initial ideas of Shulman (1986) who connected CK to the content of the subject matter, hence conversely it is mentioned as subject matter knowledge in this study. Shulman defined CK as full comprehension of the content being taught in a manner that ensures that students learn the material, examples, explanations, and descriptions. This knowledge refers “*to the amount and organisation of knowledge per se in the mind of the teacher*” (Shulman, 1987, p. 9). Across disciplines, it is well-founded that CK provides ground for authority and supports the idea of teaching as a profession. For instance, by reviewing the actual mathematics instruction and identifying mathematical content knowledge for teaching, Ball et al. (2008) explored the sort of profession-specific content knowledge in mathematics. Whereas Neumann et al. (2019), in examining the amalgam, looked at how secondary science instructors, both inexperienced and experienced, improve their topic-specific knowledge, pedagogical knowledge, and PCK and how this affects students' learning. On the other hand, Khani and Hajizadeh (2016) in Linguistics investigated the construct definition of an English Language teacher's content knowledge and how it affects the PCK. Nearly all of these studies highlight the importance of CK as a prerequisite for healthy PCK development. This is related to the study's primary goal, which is to create and validate content knowledge appropriate for PCK development in science education.

Kind (2014) looked into the effectiveness of instructors' CK and its effect on teaching. Despite having "excellent" Bachelor of Science degrees, she found that non-chemists CK is inadequate for teaching secondary school concepts in chemistry. The results of Rollnick et al. (2017), who investigated the performance of chemical specialists in relation to teachers on CK and PCK in organic chemistry, were in contrast to those of Kind (2014). They observed a difference in performance in the PCK where the chemistry experts performed better and demonstrated competency in curricular saliency. They were better at expressing the usage of a range of structural representations for instruction. These elements make for good PCK.

Similarly, in other disciplines such as mathematics education, there are disagreements about the relationship between CK and PCK. Firstly, other scholars even question the notion that the two are distinct constructs or if CK is just covered by PCK as part of it (Rozenszajn & Yarden, 2014). Teachers’ PCK has been theoretically and empirically distinguishable from CK. Baumert et al. (2010) used multilevel structural equation models to reveal a substantial positive influence of content knowledge on PCK and subsequently on students' performance.

Empirical evidence has shown that high CK in teaching school mathematics does not imply high-quality teaching (Oppermann et al., 2016). This is in contrast with Baumert et al. (2010) findings that indicated a strong correlation between PCK and CK in teaching secondary school mathematics.

Similar trends have also been testified in physics education research by Schiering et al. (2023) and in biology education literature by Rozenszajn and Yarden (2015). Despite the variation in literature across the disciplines, at this juncture, we cannot dispute the extensively reported relationship of PCK and CK dating from the initial ideas of Shulman (1986). One of the challenges noted in pre-service teacher education is the view that pre-service teachers do not have well stable subject matter (Lederman et al., 1994). These authors further note that, if these structures exist they are often the result of college course work and they are fragmented and disjoined with little coherence (Lederman et al., 1994). Thus, a question in this thesis is raised if this dearth of coherence is due to the lack of specificity to the kind of content knowledge appropriate for teacher development and thus their base for pedagogical reasoning.

2.4 Debates signalling the need for distinct content knowledge for teachers

Predominantly, academic disciplines typically have their specialized bodies of knowledge, well-tested ideas and concepts, unique terminology, and distinct research procedures (Junghans & Olsson, 2014). The content of school topics, however, is derived from a variety of sources and is created from the standpoint of societal efficiency (Deng, 2012). In general, they want to keep and increase social output. Under the framework of the school curriculum, school subjects closely align with the demands of occupation, profession, and vocation and involve the choice and reorganization of content, the expansion of skills, and the corresponding translation of that content knowledge (Geddis & Wood, 1997).

According to the comparisons mentioned above, it is hypothesized in this study that there are differences between the subject matter content knowledge reflected by academic disciplines and school subjects. This is a product of the various political, social, and philosophical motivations that both academic disciplines and the subjects that they are tied to in the classroom serve. This separation between academic disciplines and subject matter has not received enough attention in research, especially in science education on a national and worldwide level, according to the PCK literature.

Deng (2007) raised concerns about the difference flanked by academic disciplines and school subject content and asked: "*Why are academic disciplines being used as a basis for theorizing about teachers' specialized subject-matter knowledge? Why is the notion of school subjects largely hidden, if not invisible, in research discourse on teachers' specialized subject-matter knowledge?"* (p. 507). It appears reasonable enough to expect PSTs in science to rely on the content knowledge they have been exposed to for the longest in their training as they acquire knowledge about teaching their subjects.

In this thesis, the researcher agrees with Deng's view that academic discipline content knowledge is not entirely appropriate for PCK development. However, this study also adds to the argument that the school subject content is also lacking as the main source of PCK development. Hence, there is a need for a conceptual argument and empirical evidence that redefines the content knowledge suitable for teacher training and PCK development as a specialized form, distinct from the academic discipline and the corresponding school subject curriculum content.

There has been empirical research along the aforementioned postulation published internationally. For instance, Dreher et al. (2018) in Germany investigated the concept of school-related content knowledge (SRCK), which defines profession-specific material for teaching mathematics about interactions between academic and school mathematics. Hermanns (2021) operationalized the same concept about how preservice chemistry teachers felt about the importance of assignments in organic chemistry. Before this, Ball et al. (2008) in the US created the Mathematical Knowledge for Teaching (MKFT) framework, a practice-based theory of subject knowledge relating to teaching. This framework which hypothesized a special content knowledge for teaching has been widely used in mathematics internationally and nationally, for example, by Bansilal et al. (2014); Hill et al. (2008); Speer et al. (2015).

Deng (2001) in Hong Kong emphasized the distinction in science education by examining how and why important notions in secondary school physics instruction conflict with fundamental concepts in the field of physics. His theoretical foundations included Harré's epistemology of science and Dewey's logical-psychological structures (1986). Deng demonstrated how and why the fundamental principles used to teach high school students about colour theory, light speed, and light interference differ from those used to teach fundamental principles at the disciplinary level. Notwithstanding these findings, Deng did not recommend a particular type of content that would be appropriate for aspiring teachers. In South Africa, existing studies in science education have proposed a possible construct for teaching science CK to PSTs. For example, a study by Toerien (2017) in chemical bonding and Malcolm (2018) in stoichiometry proposed a construct called Topic Specific Knowledge for Teaching (TSKT). Regardless of this literature and theoretical contributions in redefining content knowledge for teaching science, there is still a lack of clear understanding about the version of science CK suitable for teaching pre-service science teachers. This lack of understanding is disseminated by the vacuum between academic discipline CK and school subject CK. As a result of this gap, institutions of higher education and training design their teacher training programs differently. Some adopt a disciplinary approach with less focus on PCK whereas others follow a watered-down approach to CK with a strong focus on PCK. In light of the aforementioned literature, the following part will examine the models that are typically used to create PSTs in South Africa and abroad.

2.5 Models for the development of professional teacher knowledge

The structure, curriculum and content of teachers' education programmes do vary from country to country (Yusuf, 2022). Both internationally and in South Africa, there are generally two common models with minor variations that are followed in PST training. These are the consecutive and the concurrent models. The following paragraphs sequentially present the consecutive and concurrent pathways of initial teacher training.

2.5.1 The consecutive pathway

The consecutive model entails preservice teachers completing a disciplinary degree in mainstream academics such as a Bachelor of Science (B.Sc), or Bachelor of Art

(BA) that covers high-end disciplinary content. Consecutively, they advance to the school of education for practicum courses in teacher education or postgraduate certificate in education (PGCE) in which the professional knowledge related to teachers and teaching practice is undertaken (Darling-Hammond et al., 2002; Yusuf, 2022).

2.5.2 The concurrent pathway

On the contrary, in the concurrent model, PSTs complete a four or five-year degree specializing in both academic disciplinary content and teacher-professional courses that run concurrently (Yusuf, 2022; Zuzovsky & Donitsa-Schmidt, 2017). A study by Khoza (2022) on content modules as areas for emerging science teacher identity revealed that the concurrent model has several variations within itself, particularly with a focus on secondary teachers. In the first variation, he reported that PSTs enrol for their content courses with mainstream faculties and concurrently take their teacher professional courses with the schools of education. Generally, they would be taught by academics who are content specialists with high-end disciplinary CK and academics who are teacher educators with education specialization.

In the second variation, PSTs enrol for both academic disciplinary content courses and teacher-related professional courses within a school of education (Khoza, 2022). There are two further cases reported within this variation. The first case has the disciplinary content offered by academics with high-end disciplinary qualifications and without teaching qualifications whilst the teacher professional courses are offered by those with a formal teaching qualification. The second case has both the disciplinary content courses and the teacher professional courses offered by the same academics with a teaching qualification and less disciplinary qualification.

2.5.3 A comparison between the consecutive and concurrent pathways

In 13 countries, the concurrent teacher education system was used to train 61% of secondary school teachers and 71% of primary school teachers, according to the Organization for Economic Cooperation and Development's 2014 report (OECD, 2014). In contrast, the sequential approach was used to train 25% of secondary school teachers and 20% of elementary school teachers. This demonstrates the supremacy of the concurrent pathway over the consecutive pathway on a global scale.

In most European countries such as Ireland, Germany and Lithuania teachers are generally trained following consecutive and concurrent models. However, according to Sederevičiūtė-Pačiauskienė and Vainorytė (2015), PSTs who sequentially pursue pedagogical courses are less likely to participate in mobility programs, develop cultural aptitude, be ready to work in a multicultural environment, and have an increasingly complicated sense of European national identity. Instead, Sedereviit-Paiauskien and Vainoryt (2015) found that graduates of the concurrent model ensure the circumstances of the implementation of the modern learning paradigm when the role of the teacher and university teacher is changing and when learning is more than just the transfer of knowledge but also cooperation, reflection, and experience which is not obtained quickly. Such observations infer that the high-end disciplinary content construed in the concurrent model does not necessarily produce quality teachers. These are similar sentiments expressed by Kind (2014) that a chemistry degree alone is not enough.

In contrast, a study by Zuzovsky and Donitsa-Schmidt (2017) in Israel explored the effectiveness of each model's efficiency and equity measures of the PST education programmes. This was a longitudinal survey that followed two cohorts of graduates who finished an initial teaching qualification. The results indicated that the consecutive pathway was better in most of the PST measures examined. Similarly, the findings by Yusuf (2022) in South West Nigeria tally with those of Zuzovsky and Donitsa-Schmidt (2017) in Israel.

In the US, Darling-Hammond et al. (2002) looked at data from a 1998 survey of over 3000 beginning STEM education teachers in New York to find out how they felt about their readiness for teaching, what they believed and did, and how they planned to stay in the profession. They discovered that instructors who received their training in teacher education programs (concurrent model) were more equipped than those who entered the profession through alternative programs in most areas of teaching (consecutive and other variations not explicated in this work). This had a strong correlation with their feeling of identification as teachers, their sense of accountability for students' academic progress, and their decision to stay in the teaching profession.

In a country like South Africa, there has been a paucity of empirical studies exploring the efficacy of one model compared to the other. This is except the findings from the work of Khoza (2022) that teachers who were trained from the high-end disciplinary content modules did not create their teacher identities within those modules. This lack of clarity on the CK suitable for PSTs continues to cloud the research about which approach is more appropriate for the preparation of prospective teachers.

In science education, there is a lack of a valid construct that defines the version and nature of CK that is appropriate for science teacher education programmes. Anecdotal records with teacher educators in South Africa revealed that academics in the concurrent model just take up to the second-year level of the academic disciplinary content when designing content modules for PST education programmes. To some extent, other academics indicated that they just consider up to the first year of the academic discipline content curriculum in line with the school curriculum to design their content courses. This creates variations across teacher education programmes within the country, thus ushering the need to define succinctly the epistemological structure of content knowledge suitable for science teacher development, as is the purpose of the current study.

2.6 Instruments for measuring content knowledge for teaching

In this section, the focus is given to the notion of measuring and capturing professional knowledge for teaching. This section is two folds, firstly it reflects on existing instruments for measuring content knowledge for teaching and highlights the rationale for developing new instruments. Secondly, it reviews the literature on different designs for instrument development in social science research.

2.6.1 The rationale for developing new instruments to measure content knowledge for teaching

Over the last two decades, science education has explored a variety of ways in which teacher knowledge can be captured and measured, in particular, the content knowledge for teaching key science topics. For example, Jong et al. (2005) explored multi-method evaluation using structured and unstructured questionnaires, observations and concept mapping to explore PST PCK. Before that, Loughran et al. (2004) contributed immensely to PCK measurement by designing special instruments called CoRe (content representation). These were designed in line with PaP- eRs (professional and pedagogical experience repertoires) to capture the quality of planned PCK for teaching. On the other hand, the use of paper-and-pencil tests has been a promising approach for a standardized and quality indicator-oriented method to measure teachers' PCK in large-scale studies (Gardner & Gess-Newsome, 2011)

Recently, with the ascendancy of topic-specific PCK in science education research and training, CoRes have been adapted also to include and evaluate the knowledge of content-specific PCK at a topic level. For example, a study reported by Rollnick and Mavhunga (2014) in South Africa is one amongst others in which data was collected using an adapted version of the CoRe to explore content knowledge for teaching in electrochemistry with practising teachers.

The majority of the current subject knowledge assessment tools were created in collaboration with TSPCK tools using both in-service and pre-service instructors. For instance, Davidowitz and Vokwana (2014) evaluated CK and PCK with in-service teachers using the case of organic chemistry. Toerien (2017) developed a tool for assessing subject-specific knowledge for teaching chemical bonding by applying the same concept to the instance of chemical bonding. Moreover, Pitjeng-Mosabala and Rollnick (2018) examined the TSPCK of inexperienced science teachers using the topic of the particle nature of matter. Also, they created a tool to assess the topic's TSPCK and CK quality. In the recent past, Malcolm et al. (2019) created and validated a tool to assess the calibre of topic-specific PCK in stoichiometry using in-service teachers through a lesson study.

Practically, all these studies have evaluated and assessed the level of content knowledge for teaching these key chemistry topics whilst developing these tools. However, the existing instruments are either focused on assessing the academic discipline content and the extent to which it is transformed into a content version for teaching purposes. There is a paucity of instruments that measures a specialised version of content argued to be suitable for teacher education training and a base for PCK development. Hence, there is a need to develop and validate new instruments specifically intended to measure the content version which is geared for teacher education training.

The process of instrument development and validity estimates in psychological tests has long existed in social research. This dates back to the seminal works of Cronbach and Meehl (1955) on construct validity in psychological test construction to assertions about the role of definitions, roles of constructs in validations, the differences between interpretations and the use of test statistics by Kane (2012). Much of this work in social science education research has been guided by the taxonomy of instrument-designed methods described by Oosterveld (1996) and recently by Oosterveld et al. (2019). In the next paragraphs, these design methods for test construction are discussed briefly.

2.6.2 Methods to design measuring instruments

Within these various research approaches, Oosterveld et al. (2019) have described six questionnaire design methods. They use four stages of concept analysis, item production, scale construction and evaluation in test construction to describe these design methods.

In a nutshell, the concept analysis is a step of definition that describes the idea that guides the design of the test. The theoretical construct from the concept analysis serves as the foundation for the pool of questions created during item production. While assessing the nature of the objects at this level, expert opinions play a crucial role. At the scale construction step, items are selected for the scales based on a process of selection that strengthens the psychometric component that is the method's core. Finally, the central and additional pertinent psychometric elements of the questionnaire are examined (Oosterveld & Vorst, 1996). The taxonomy of questionnaire design is found in these phases. Each of these designs is briefly explained in the paragraphs that follow.

The first design method, the rational method is mainly qualitative, and intuitive and relies profoundly on aspects of face validity (Oosterveld et al., 2019). An example of a questionnaire designed using the rational method was noted in the work of Francis and Chorpita (2010) who developed a parent-report questionnaire aimed to assess parental beliefs about their child’s anxiety. The empirical underpinnings of this method are not of great concern. Predominantly, this is used when the theoretical construct is explored superficially (Oosterveld et al., 2019).

The second method is prototypical which is also largely qualitative, and intuitive but relies heavily on process validity (Oosterveld et al., 2019). An example of the questionnaire construction based on this method is reported by Morselli and Passini (2015) in a correlational study on the Social Generativity Scale. This method is recommended for the specification of implicit ideas about the theory and the difficult operationalisation of concepts that makes up the theory (Oosterveld et al., 2019).

The third method is the internal method which is inductive and relies on factor analysis. According to Oosterveld et al. (2019), this method is often used to improve existing instruments. For example, Costa Jr and McCrae (2008) revised the NEO personality inventory to improve the item selection, scale development, approaches to validation, and applications of the instrument. Since this design uses statistical relationships between the items, it cannot be predicted in advance if the resulting measurements would perform well in other criteria such as face and predictive validity (Oosterveld et al., 2019).

The fourth method is the external method. Just like the internal, it is also inductive but uses the aspects of criterion validity as opposed to the internal method which uses aspects of homogeneity. The external method is guided by both the concurrent and predictive empirical relationship of the instrument and an external criterion. It is commonly used in the medical industry, for example on screening *vs* prevalence estimation done by Hand (1987).

The construct method, the fifth approach, is of particular importance in this study. In contrast to the first four, it is deductive and bases its methodology on construct validity (Kane, 2012). The construction and validation of a theoretical construct representing subject knowledge for teaching is the primary goal of this research study. This research study also links the construct method to this goal. This approach takes a coherent theory of the construct as its guide to develop the questionnaire-related hypothesis that is then experimentally tested. The creation of the TSPCK instruments in many chemistry disciplines is one example of a study that utilized this taxonomy. A case involving chemical equilibrium, organic chemistry and stoichiometry (Mavhunga & Rollnick, 2013; Davidowitz & Vokwana, 2014; Malcolm et al. 2019).

In the construct method, an operational definition of the construct is provided and related or confounding variables are overtly specified (Oosterveld, 1996). By related variables, we mean those that may be correlated to the construct under investigation but are conceptually different from each other (Oosterveld, 1996). For example, in TSPCK, the learner's prior knowledge is conceptually different from representations, however, it is important in how the teacher chooses a particular use of representation to confront that prior knowledge (Ndlovu & Malcolm, 2022). The construct method, as a deductive approach has been widely endorsed since it produces measurements with favourable psychometric properties over the family of the intuitive and inductive approaches (Mellenbergh, 2011)

The last taxonomy is the facet design method. Just like the construct design, it is deductive and follows the aspect of content validity. According to Oosterveld et al. (2019), both the facet and construct designs have been recommended in social science research as they largely produce scales with favourable psychometric results. The faceted design has been used in the work of Landsheer and Boeije (2008) about facet analysis as a qualitative method to improve questionnaire design.

In summary, the taxonomies described above provide a clear structure for organizing the host of methods for instrument or test construction. However, for Oosterveld et al. (2019), this does not mean that there could not be any combination of the design process elements. For example, “one could generate items with an act nomination procedure [which is prototypical], and focus on homogeneity [which is internal] in the scale construction phase” (Oosterveld et al., 2019, p. 2508).

Regardless of the assertion above, there is no empirical data or evidence that shows the integration of one taxonomy into another. One possible reason could be the fact that test constructors are usually not explicit about the design taxonomy they are adopting when constructing tests. In teacher education, the signature procedure that is generally followed is that of Rohaan et al. (2009). They illustrated how a multiple-choice test to measure teachers' PCK in primary technology education could be developed and validated but there was no clarity of the design taxonomy followed in their work. In this study this method is also followed, the details are provided in Chapter 7.

This study uses the case of organic chemistry to explore the development of content knowledge for teaching science. Hence in the next paragraphs, the focus will be given to organic chemistry as a curriculum subject within the National Curriculum Statement as well as other issues related to teaching and the topic.

2.7 Issues in teaching and learning organic chemistry

2.7.1 Organic chemistry as a curriculum topic

According to the American Chemistry Society (ACS), the topic of organic chemistry deals with the study of the structures and chemical and physical properties of carbon-containing compounds. These include organic compounds that contain carbon and hydrogen, and other elements such as oxygen, nitrogen, halogens atoms, etc.

In the National Curriculum Statement (NCS), organic chemistry is one of the topics in Physical Sciences that is taught under the Chemistry domain. It is introduced later at the exit grade in the last year of the secondary schooling system in South Africa under the knowledge area of Matter and Material. This topic contributes to about 35% of the final year chemistry examination (Department of Education, 2011) and it is divided into three major areas. These are the knowledge of organic molecules and nomenclature, knowledge of basic chemical properties of organic molecules and the knowledge of physical properties of organic compounds.

With the Revised NCS, this is done for up to 8 carbon molecules across all homologous series. There are major curriculum content similarities with other sub-Saharan countries such as Zimbabwe. Yet there are noticeable differences in the depth and scope of the curriculum. For example, in the Zimbabwean Curriculum Statement (ZCS), the curriculum includes up to 10 carbon molecules. In addition to hydrocarbons, halogen-containing, carbon-containing and hydroxyl-containing compounds, the ZCS include nitrogen-containing compounds, aromaticity and stereoisomerism. This is almost similar to other states' curricula such as the UK and the US. Comparatively speaking, the content of organic chemistry in the South African Curriculum Statement is relatively lower compared to most of the developing and developed countries. The following section briefly describes some of the issues that are linked to difficulties associated with teaching and learning organic chemistry as a curriculum topic.

2.7.2 Teaching and learning organic chemistry

In general, chemistry is one of the most difficult subjects among the science domains to comprehend because of its intangible and abstract nature (Sirhan, 2007) and the need to manoeuvre between different levels of representations (Davidowitz & Chittleborough, 2009; Johnstone, 1991).

Among the chemistry topics, organic chemistry has long been identified as the most difficult (Davidowitz & Rollnick, 2011; Green & Rollnick, 2006). There are also various issues contributing to these observations. For example, it was found by Green and Rollnick (2006) that some text resources use functional group chemistry as their organizing principle, while others use the knowledge of bonding. As a result of this organisational mismatch, organic chemistry differs fundamentally from all other chemistry subdisciplines. Furthermore, the conclusion by the authors suggested that as a subdiscipline of chemistry, organic chemistry possesses “a few, identifiable, fundamental concepts, principles, and conventions that underpin the entire discipline and permeate all [*chemistry*] sections” (Green & Rollnick, 2006, p. 1379).

In America, Duis (2011) explored “organic chemistry educators’ perspectives on fundamental concepts and misconceptions”. His findings pointed out that reaction mechanisms and the correlation between structural formulae and properties/reactivity of organic molecules are the most fundamental concepts in the topic. Even though this was identified as fundamental, there is a long-standing view by the ACS that what is fundamental in the topic is relative since scientific knowledge is flexible and develops over time (Lederman, 2013). In addition, Duis (2011) found that chemistry teachers view reaction mechanisms and acid-base chemistry as the most difficult ideas to teach.

A Ghanaian study by Hanson (2017) identified several of the naïve and disorganised ideas about organic chemistry concepts held by students regarding nomenclature, representations and the principles of chemical bonding. These included (i) poor knowledge about the tetravalent nature of carbon, (ii) the covalent nature of organic compounds, (iii) reactivity of substances and their derivatives with a common functional group, (iv) misconception about the polarity of organic compounds, (v) poor knowledge of electronegativity, electron affinity and (vi) general application of the IUPAC rules on certain organic structures.

The findings from the study by Hanson (2017) also confirm some of the observations made by earlier scholars. For example, Johnstone (2006) reported the knowledge of drawing and representation of organic compounds as a challenge to students, whilst Domin et al. (2008) reported the classification of organic compounds as being difficult. Furthermore, reaction mechanisms and reaction types were found to be difficult by Ferguson and Bodner (2008) whilst Taagepera and Noori (2000) identified isomerism as difficult when “mapping students' thinking patterns in learning organic by the use of knowledge space theory”.

In South Africa, similar observations are made from the Senior Certificate Examination reports. Poor learner performance is attributed to several common errors and misconceptions in the topic. These include the incorrect use of the rules of nomenclature, and misconceptions around the classification of organic compounds (Department of Basic Education, 2021). In addition to these observations, Bodner et al. (2017) added that there is a pervasive tendency of learners to fail to process the information given as symbols as well as their tendency to see organic structures as lines, letters, and numbers instead of looking at them as symbols. This observation indicates an inability to move from the symbolic representation to either macro or microscopic representation. This has been argued as the most important requisite in chemistry understanding (Davidowitz & Chittleborough, 2009).

Given the debates highlighted in the literature above, there is a need for a theoretical construct that describes content knowledge for teaching secondary school science. However, the description of this construct has to be guided by existing theoretical frameworks. In the next section, the theoretical framework of this study is outlined.

2.8. Theoretical framework

The views of Joseph Schwab regarding the substantive and syntactic structures of knowledge possessed in a certain field of knowledge serve as the theoretical foundation for this investigation. These knowledge structures are discussed in more detail below and established as the study's theoretical lens.

2.8.1 The substantive and syntactic structures of knowledge

Joseph Schwab was widely regarded as a spokesperson for the disciplines' structures reform movement in the US in the early 1960s because of his publications on the structure of knowledge in the disciplines. A reform movement made teaching the "structure of the discipline" in primary, secondary, and higher education settings a top priority (Deng, 2015). He described the discipline as being arranged according to the knowledge's substantive structure and syntactic structure. The concepts, tenets, and frameworks that direct discipline-specific research is included in the substantive structures. Although each discipline's forms of investigation, canon of evidence, and methods of proof are reflected in the grammatical structures (Deng, 2015).

According to Bullock (2009), the boundaries between the substantive and syntactic forms of knowledge are distinct in academic fields like physics or chemistry. The conceptual underpinnings of the field are its substantive structures, and its rational organizational principles are its syntactic structures. For example, chemistry, physical, quantum, analytical, spectroscopic, material, and organic chemistry are only a few examples of the substantial conceptual structures that are frequently used to categorize chemistry. The scientific method and peer-reviewed research are inherently based on the syntactic structures of chemistry, which are the "*methods of verification and justification of conclusions*" (Bullock, 2009).

When referring to content knowledge, Shulman described it as “the amount and organization of knowledge per se in the mind of the teacher” (Shulman, 1986, p. 9), including knowledge of the substantive and syntactic structures of the academic discipline. However, much of the research in teacher education about teachers’ content knowledge has largely focused on the substantive rather than the syntactic structures of knowledge as they largely provide a resource for pedagogical transformation (Deng, 2018). Therefore, there is a need for a clear line of research that considers the explicit inclusion of syntactic structure in the content knowledge for teaching.

A review by Rollnick (2017) shows that the term “content knowledge” has not been theoretically conceptualized the same. For example, she states that “*differing terms for content knowledge are used in the literature in both mathematics and science education*”. Shulman (1986) identified three main kinds of teacher knowledge. These are the subject matter content knowledge, pedagogical content knowledge and curricular knowledge. Later, the work of Shulman listed CK instead of “subject matter content knowledge” as one of the seven categories for a teacher’s knowledge.

In mathematics, Ball et al. (2008) interpreted CK as a subject matter knowledge and its organising structure. This incorporated Schwab’s notion and distinction between the syntactic knowledge structure and the substantive knowledge structures. Grossman et al. (1989) brought in additional two knowledge categories. These are the knowledge of content as well as beliefs about a discipline. Regarding Ball and colleagues' work, they found it difficult to separate the kind of mathematics used in teaching from mathematics content per se and advanced another kind of specialized CK called mathematical knowledge for teaching. For Rollnick (2017), this CK version is similar to topic-specific professional knowledge in science education in two ways, Firstly, content knowledge is interpreted as knowledge of the subject matter and its organising structure. Secondly, it takes into consideration Schwab’s distinction between syntactic and substantive knowledge structures

A study on subject matter expertise for PSTs was conducted and published by Cochran and Jones (1998). They proposed a conceptual framework for knowledge that encompasses beliefs about the subject matter as well as content knowledge, substantive knowledge, syntactic knowledge, and substantive knowledge. Also, in favour of this viewpoint were Kind and Kind (2011). Yet, in this study, the substantive structures and content knowledge are integrated and viewed as one, sharing the same perspective as Abell (2007). The current study suggests that considering the aforementioned, PSTs should acquire the subject matter in a fashion that reflects both the substantive and syntactic components of the knowledge in the disciplines.

The theoretical framework described herein has influenced the choice of the research design and the treatment of the various stages of the design

The next chapter presents the research design and methodology that guided this study.

CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

The research approach used to carry out this full investigation is described in the present chapter. The chapter introduces the overview structure of the research design as two distinct phases guided by the traditional process of developing a theoretical construct. It proceeds to describe the research design within each phase reflective of the purpose of the respective phases. Issues of rigour involved in each phase and ethical issues for consideration are also explained per phase. The chapter closes by pulling together the two phases into a summarized overview picture.

3.1 Introduction

The requirements for construct validity guided the research design of this study. This was consistent with the primary objective of this investigation, as was described in chapter 1. The theoretical construct was conceptualized and validated following a pragmatic philosophical perspective. The pragmatic paradigm for this investigation is detailed in the following section.

3.2 Research paradigm

The pragmatic paradigm informs the placement of this research inquiry. The foundation of pragmatism as a research paradigm is provided by the philosophical achievements of the movement throughout history. Pragmatism embraces a plurality of methods in conducting a research study (Kaushik & Walsh, 2019). The idea that researchers should employ the philosophical and/or methodological approach that is most effective for the specific research problem being investigated underpins pragmatism as a research paradigm (Tashakkori et al., 1998). As such, pragmatism is often associated with a mixed-methods approach (Creswell & Clark, 2017; Johnson & Onwuegbuzie, 2004). Instead of the research's procedures, the emphasis is on the study's outcomes and research questions.

Pragmatism does not conform to argumentative abstract concepts like truth and reality (Creswell & Clark, 2017). As an alternative, it admits that there may be one or several realities that are susceptible to empirical investigation (Kaushik & Walsh, 2019). Given that this study purports a theoretical construct that has not been investigated in any study, such a worldview is befitting for this inquiry.

The main epistemological support of a pragmatist is the notion that facts and knowledge are experience-bound. One's world perception is predisposed by social experiences (Kaushik & Walsh, 2019). Each individual's understanding is inimitable since it is shaped by their sole experiences. Yet, because it was developed from socially shared experiences, most of this knowledge is shared in society (Morgan, 2013; Morgan, 2014). The goal of pragmatic knowledge is to help people manage their lives and participate more effectively in the actual world. Pragmatism does not view knowledge as an absolute reality (Goldkuhl, 2012).

As indicated above, pragmatism and a mixed-method research approach are compatible. Thus, the next section summarises the research method adopted and its rationale in this study is outlined.

3.3 Research Method: Mixed Method Research

The overarching research design employed in this study is a mixed-method research (MMR) design. In the MMR, the research is driven largely by the nature of research questions which ultimately require both quantitative and qualitative data sets to answer them (Cresswell & Cresswell, 2018). MMR is "*formally defined as the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single research study*"(Johnson & Onwuegbuzie, 2004, p. 17). There is a need for researchers to justify their choice of the methodology used in a particular study (Cohen et al., 2007). So, in the next section, I give a rationale for adopting this methodology

To begin with, the MMR was chosen in this study based on the researcher's worldview and positionality highlighted above which is pragmatism. MMR uses pragmatic methods and systems of philosophy to collect or generate and analyse data (Cohen et al., 2007; Creswell, 2014; Johnson & Onwuegbuzie, 2004), a view strongly held by the researcher in this study. So, it was appropriate to consider the use of the MMR approach for this study. This perspective supports an epistemological assumption that “either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question” (Wahyuni, 2012, p. 17).

In addition to the researcher’s worldview, the general purpose of this research was to develop and validate a specific theoretical construct describing the version of content knowledge related to teaching. Kane (2012) argued that such a process requires both the conceptual argument as well as the corresponding statistical means to validate the existence of the conceptual argument. Based on this requirement for construct validity, the overall study adopted MMR which uses both qualitative and quantitative approaches and techniques (Tashakkori et al., 1998).

Furthermore, in science education, MMR has gained a substantial reputation because of its strength as an enquiry that continues to evolve and advance in utilizing the fortes of qualitative approaches and quantitative approaches independently in a similar study (Cresswell & Cresswell, 2018). The additional and important rationale for adopting MMR in this study was entrenched in the notion of exploring issues holistically and employing different research methods (Okeke & Van Wyk, 2015). In this study, such an approach was justified in unravelling the complexity of a fairly new theoretical construct that has not been substantially explored empirically in science education research studies.

By description, MMR is an intentional combination of both quantitative and qualitative research approaches in a single research study (Shannon-Baker, 2016). It allows for different methodologies to be employed or data sets to be collected and analysed, sequentially and, in convergence, to generate and support research claims.

According to Creswell (2014), the MMR has three basic designs, these are “*convergent*, *explanatory sequential* and *exploratory sequential design”*. Summarily, in the convergent design, the researcher collects quantitative data and qualitative data in a single-phased approach, analyses the data separately and compares the results to find out if they corroborate or contrast with each other. In the sequential designs, either qualitative or quantitative data is collected first to inform the next phase of the research. They are called exploratory and explanatory sequential designs respectively (Clark, 2019).

However, there are instances in which two basic designs can be combined into an advanced mixed-method approach (Creswell & Clark, 2017). Given the comprehensive purpose of this study, and in line with Kane's (2012) requirements for developing and validating a theoretical construct, an advanced MMR approach following the multiphase design was adopted. In the next section, this approach is explained in detail.

3.4 Approach within the Mixed Method Research: Multiphase Design

Commonly, the multi-phase design (MPD) combines both sequential and convergent strands during the study, the strands are employed as multiple projects within a larger programme of inquiry (Creswell & Clark, 2017). This study initially used the exploratory sequential design. The intent was to study a problem first by using qualitative data and its analysis. This was sequentially important to inform the second phase which was generally both qualitative and quantitative, as illustrated in Figure 3.1.

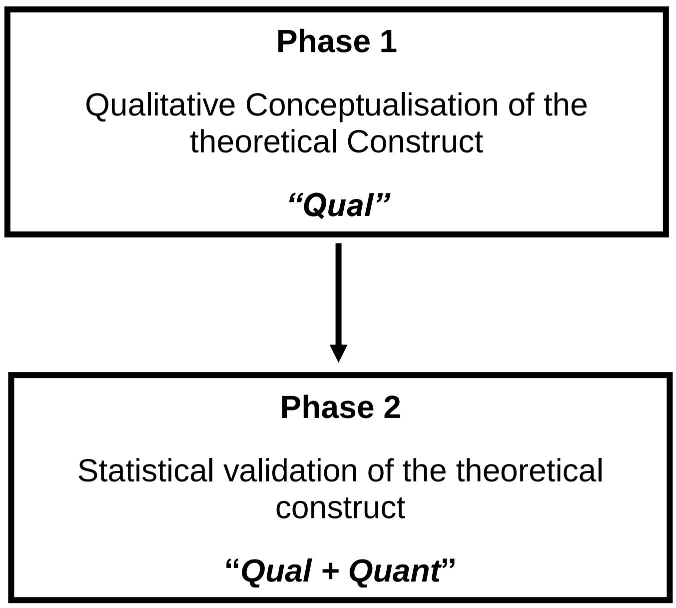


Figure 3.1: Overview of the research study phases design

The implementation of the above research design, particularly the need to validate the newly conceptualized construct demanded an intermediate step for the development and design of a purposefully designed instrument to measure the quality of the theoretical construct. This demand resulted in an amended project overview as presented in Figure 3.2 including the intermediate step between the phases.

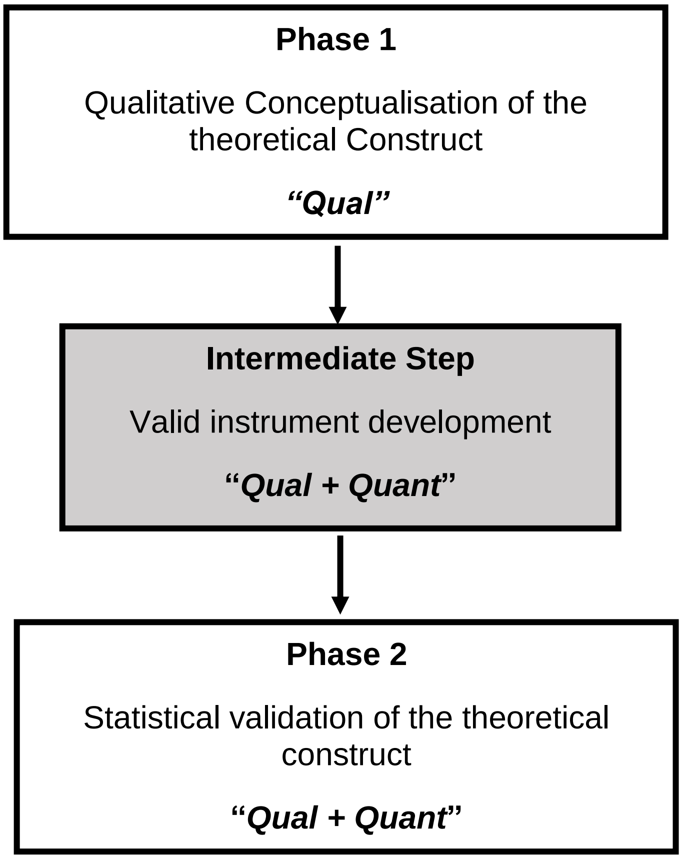


Figure 3.2: Amended overview of the research study phases design

As indicated in Figure 3.2, the amended research project design entailed three key phases with three different but suitable research cycles which were undertaken chronologically in this study. The first research cycle was related to the methods of conducting a systematic literature review. The intermediate step was related to the intuitive methods of construction of a measuring tool and the last cycle entailed the empirical methods of conducting the validation of the construct.

Clark (2019) emphasised the need to be explicit about the points of convergence, where the integration of quantitative and qualitative data happens. So, for this study, the first phase collected qualitative data for the conceptualization of the theoretical construct. At this point, there was no integration of data since the phase was purely a qualitative meta-synthesis. Within the intermediate and second phases, there were elements of convergence where the collected ordinal qualitative data were translated into scalar or ordinal quantitative data for analysis through quantitative methods.

As highlighted above, each of the respective internal cycles had its elements of sampling, data collection, analysis and corresponding findings. Included in these cycles are clear points of data convergences as pointed out by Clark (2019). These also included strategies for improving reliability and validity accordingly for each cycle. These are summarized herein below as more details on some of the specific steps have been provided in dedicated chapters.

RESEARCH DESIGN FOR PHASE 1

3.5 Conceptualization of a theoretical construct describing content knowledge for teaching science

Phase 1 of this study was geared towards developing a theoretical argument that conceptually defines a postulated construct that distinguishes the science content knowledge suitable for developing science teachers. The conceptualisation of this theoretical construct as the content knowledge for science teachers was done through a qualitative meta-synthesis (Sandelowski & Barroso, 2007; Sandelowski et al., 2007) that followed a systematic literature review of previous studies in the field. This phase aimed to respond to the first research question which asked:

> *How could a theoretical construct for developing the content knowledge of secondary school science teachers be conceptualized?*

3.5.1 Research strategy

As was previously said, a comprehensive systematic literature review (SLR) underpinned this phase. This type of review is distinct from the conventional literature review. This approach is described as an effort to locate, evaluate, and synthesize all empirical data that satisfies pre-established qualifying requirements to address a certain research issue. (Higgins et al., 2019; Piper, 2013).

Grant and Booth (2009) provided a descriptive analysis of the furthermost common types of reviews, with descriptive examples from health sciences domains. These insights have been taken and adapted to fit within social science education research in this study. A simple analytical framework —Search, Appraisal, Synthesis and Analysis (SALSA) (Mengist et al., 2020) was followed to conduct this qualitative meta-synthesis.

When undertaking the SLR, there are important steps that must be considered explicitly and transparently. For example, Siddaway et al. (2019) mentioned these steps as follows, (i) the identification of a specific research question, (ii) conducting a comprehensive search, (iii) selecting initial relevant studies, (iv) appraisal of the quality of initially selected studies, (v) synthesizing findings of selected studies using qualitative techniques, and (vi) presenting the synthesised findings across the studies to address the research question.

A comprehensive report on these key stages is offered in chapter 4 which details a technical account of how the SLR was conducted. As part of the requirements of reporting the SLR, Chapter 4 uses the Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols 2015 (PRISMA-P 2015). This PRISMA-P consists of a 17-item specification proposed to enable the preparation and reportage of a robust procedure for SLR (Moher et al., 2015). In this chapter, I will mention just briefly some of these items and how they informed selection criteria, ways of collecting data and preliminary analysis of the reviewed studies. A comprehensive report is given in chapter 4 as per the requirements of reporting on the processes of systematic reviews.

3.5.2 Conducting the systematic literature review

In line with the PRISMA requirements, Okoli and Schabram (2010) offered a practical guide that novice researchers can follow in conducting SLR. The guideline has eight discreet steps, each of which is essential for the SLR data collection leading to data extraction, analysis and meta-synthesis.

The statement of the purpose of the literature review is the first step. The reviewer must specify the objective and anticipated outcomes of the review. The goal of the review in this study was to conceptualize a notion that distinguished content knowledge for teaching from content knowledge for academic disciplines and school subjects. The intended outcome was a theoretical construct that characterizes this particular type of content knowledge.

The second step entails a protocol development outlining the inclusion and exclusion criterion. A PICOS model was used to develop the inclusion and exclusion criterion of relevant studies. Generally, PICOS stands for P – Population/Participants, I – intervention, C – comparison, O – outcomes and S – study design (Amir-Behghadami & Janati, 2020). This included all studies which were done in sciences, mathematics, and technology as participants. For intervention, the focus was given to studies that focused on developing and operationalising content knowledge for teaching, teacher content knowledge or specialised content knowledge for teaching. For study design, the focus was on qualitative and mixed-method studies.

The third stage involves running a comprehensive search of the literature. To collect data for this phase, the EBSCOhost search engine through the university library login was used: *https://ebscohost.com.innopac.wits.ac.za*. Through this search engine, four databases were searched. These are (i) Academic Search Ultimate, (ii) Education Research Complete, (iii) Education Resources Information Centre (ERIC) and (iv) Teacher Reference Centre. According to (Batten & Brackett, 2021), the exhaustive literature search is not completed by algorithmic methods, hence multiple engines can be used to obtain grey literature. So, for this purpose, other studies were manually added as they met the eligibility criterion pre-set by the review protocol. These were accessed through a Google Scholar search.

The initial search used search identities such as “Academic Discipline and School Subjects” and 6711 articles were retrieved. Filters were then added as follows; time frame from 01/01/1990 till 31/12/2019. An article must be from a peer-reviewed journal and 1251 records were generated. The search identities were further modified to include (i) Knowledge for Teaching, Mathematics and Science for “all text”, excluding Pedagogical Content Knowledge/PCK, Language Teaching, Social Sciences and Economics. This yielded about 31 articles from the algorithmic comprehensive search. See Appendix A for the search protocol. In addition to this, 9 articles were manually added as suggested by Batten and Brackett (2021).

Practical screening is the process's fourth step. This procedure, which is also known as screening for inclusion, calls for the reviewer to be clear about which research was taken into account for review and which ones were disregarded without further investigation (Okoli & Schabram, 2010). The reviewer must explain the additional exclusion criteria for rejected studies and justify how the final evaluation can still be thorough and adhere to the review protocol.

The reviewer must specify the criteria for determining whether articles are of insufficient quality to be included in the review synthesis in the fifth stage, which is also known as screening for exclusion. The reviewer must evaluate the quality of the papers screened in the fourth step. The quality of each included article must be evaluated based on the research techniques or designs used in the publications. To do this an adapted checklist from Erwin et al. (2011) was used, see Appendix B. The former and the latter steps were represented using a PRISMA-P diagram.

After all the studies that should be included in the review have been found, evaluated, and met the criteria, the sixth step is the extraction of data from the appraised publications. To inform the final stage of the review process, the reviewer or reviewers must methodically extract the pertinent information from each study and analyse it. Amongst the various way of data extraction available in the literature, this study used an excel sheet to extract and tabulate findings from each paper. This was important to compare and contrast findings across the studies.

The final phase entails merging the data obtained from the research using the proper techniques, whether quantitative, qualitative or a combination of both, i.e. mixed methods. This step is known as a synthesis of studies, though it is also sometimes referred to as meta-synthesis. I, therefore, describe the procedure that guided data analysis in the following section.

3.5.3 Data analysis

To analyse data, a qualitative meta-synthesis approach was used. By description, qualitative meta-synthesis is a planned and coherent method followed in analysing data across qualitative studies (Erwin et al., 2011; Sandelowski et al., 2007). It is a deliberate process that facilitates the selection, appraisal, summarizing, and combining of qualitative evidence to address the research question (Erwin et al., 2011). In analysing and synthesizing qualitative findings in this study, the researcher used the same approach employed by Sandelowski and Barroso (2007). The first thing the researcher did was scan the studies that were part of the meta-synthesis for common themes. Second, it made it possible to derive literary taxonomies or structures from the themes. Therefore, to best define the phenomena, the relevant studies that fell under a given theme were combined.

Resulting of this process, three literature taxonomies emerged in the analysis as major themes. These were: (i) the kinds of relationships between academic discipline and school subjects, (ii) dimensions that relate academic discipline to school subjects, and (iii) content knowledge for teaching secondary school subjects. The first theme was crucial in positioning this version of content between the academic discipline and school subject content. The second theme was important in providing a set of dimensions that related academic disciplines and school subject matter content. Lastly, the third theme explored some of this rationale in line with empirical studies in mathematics.

The results of the first phase were important in revealing the nature of the tools needed in the intermediate phase for use in the validation of the newly conceptualized construct. To increase the trustworthiness of the findings and claims made in phase one, the conceptualisation was continuously presented to a group of experts in the field for critique and constant feedback. In the next paragraph, the research cycle for tool development is outlined.

RESEARCH DESIGN FOR THE INTERMEDIATE STEP

3.6 Developing suitable instruments to measure content knowledge for teaching

In Chapter 2, it was highlighted that for this version of content knowledge, there are no suitable instruments designed to measure its quality. Hence, there was a need for an intermediate step about suitable developing tools to measure content knowledge for teaching secondary school science in the topic of focus. The findings emerging from this intermediate step responded to the sub-research question that asked:

> *What valid instrument could be used to measure the quality of the newly conceptualised theoretical construct in pre-service teachers?*

The next sections provide a summary of the research cycle followed in the development of the appropriate instrument. More details on the steps of this research cycle and its findings are given in Chapter 7.

3.6.1 Steps followed in the development of the new instrument

This study followed the seven discreet steps advocated by Rohaan et al. (2009) in their work about developing an instrument to measure PCK for primary teachers, These steps in their chronological order are (i) specification of the theoretical framework; (ii) construct analysis; (iii) specification of item characteristics; (iv) production of items; (v) judgement of items; (vi) construction of the instrument, and (vii) validation of the instrument.

These steps are usually situated in some instrument design methods, these were explained in detail in chapter 2. Oosterveld (1996) discussed some of these designs and later refined them as questionnaire design taxonomies for instrument development Oosterveld et al. (2019). For this study, the construct design method was adopted as this study aimed to develop and validate a theoretical construct called describing a distinct content knowledge for teaching science. This method belongs to the class of deductive approaches in test designs informed by construct validity (Cronbach & Meehl, 1955; Kane, 2012). The detailed process is outlined in chapter 7, with an overview procedure provided here.

(i) Specification of Theory and Construct Analysis

Firstly, the concept analysis phase in construct design was guided by the construct theory expressed in a network of concepts and the specification of the assumed relationships between the elements of the construct. In this case, this was done during the conceptualisation phase which preceded the process of instrument development. To ensure issues of trustworthiness, the emerging construct conceptualisation was continuously presented to the reference group for critical insights and feedback towards a shared understanding.

(ii) Specification of Item Characteristics

The items designed for the instrument development were open-ended questions for most of the elements of the construct. The items the knowledge of pure CK were close questions that required direct answers.

(iii) Item Production

The item production in the construct design method is grounded on the definition outlined in the concept analysis. To begin with, in this study, an instrument designed by Davidowitz and Vokwana (2014) was adapted to assess the knowledge of "pure" content in organic chemistry, see Appendix I for an adapted CK instrument. This catered for the logical aspects of the conceptualized construct in terms of content evaluation.

Based on the criteria established in the concept analysis, the researcher created an item pool for extra items related to the other logical, epistemological, and social aspects of the construct. The produced items were taken from a variety of resources, including the CK tool in Appendix I, a college manual on chemistry and old Physical Sciences exam papers for grade 12 are included.

(iv) Item Judgement

The item judgement utilises the review inputs by judges, e.g., experts, or potential respondents (Kline, 2015), and a preliminary pilot administration of the instrument (Oosterveld et al., 2019). For the instrument construction, two reference teams of experts were set up. The first team comprised two PhD students in chemistry education, a Professor and a Doctor of Science Education (4 experts). They were assigned the task of the first judgement of items and putting together the first draft of the instrument, see Appendix K for the first draft.

The second team comprised three Professors in teacher education, three Doctors of science and two PhD students all in the same field of teacher training (8 experts) was set up. The second larger group was tasked with the second and final judgement of items and the construction of the final version of the instrument. The second team was also expected to establish both the face validity and content validity of the items that make up the instrument.

(v) Construction of an Instrument

The designed instrument had closed questions and open-ended questions, in which the test items have options for the participants to select but also have the opportunity to provide a rationale for their choices, see Appendix K for a first draft and Appendix L for the final version of the instruments. The first version of the instrument was constructed with the inputs of the first team of experts who judged items for inclusion in the draft instrument.

3.6.2 Piloting and validating the instrument

A sample of fourth-year B. Ed students (N = 5) who had already completed and passed the methodology course and a related content course on the focus area of organic chemistry were used to pilot the final edition. The pilot sample included 3 postgraduate students who are certified and working teachers in addition to the fourth-year PSTs, making a total of 8 respondents. To create the final version of the instrument, they were required to respond to the questions and provide feedback on their clarity and/or ambiguity (see Appendix L for the final version).

3.6.3 Validation of the Newly Developed Instrument

The conceptualization of the theoretical construct pointed to the specific features which defined the nature of the construct. Hence, the instrument developed illuminated these features. The information gathered before the intervention played a significant role in the process of assessing the tool's validity. There are several validity issues for consideration reported in the literature as highlighted by Cohen et al. (2007). For this study, three were given attention, these were content validity, face validity and construct validity in test construction (Simms & Watson, 2007). The instrument's content validity assures that it fairly and thoroughly covers the area or things it claims to cover (Cohen et al., 2007).

Face validity guarantees that the test seems to measure what it was designed to measure (Mohajan, 2017). Contrarily, construct validity tests how well an instrument evaluates a certain construct as demonstrated by convergent, discriminant, divergent, etc. validity (Cohen et al., 2000). In other words, for construct validity, the instrument designed must provide a fair operationalization of the construct. To assess the validity of the construct, it was necessary to empirically test the instrument with a bigger sample. This process interleaved the intermediate step and phase 2 of the research study. Hence, the next sections describe research cycle number 3 about means to validate the conceptualized construct.

RESEARCH DESIGN FOR PHASE 2

3.7 Validation of the newly conceptualized theoretical construct

The second phase entailed statistical validation of the newly conceptualized theoretical construct per Kane's approach towards construct validity (Kane, 2012). The instrument development process was interleaved with stages that demanded qualitative data in the early stages of tool development and at some points, quantitative data was related to the validation of the instrument. This ultimately provided means for the validation of the theoretical construct. Accordingly, this had elements of exploratory sequential design as if followed the conceptual phase.

A set of pre-intervention data was gathered following the construction of the new instrument in the intermediate phase to assess the statistical validity of the test items and ultimately the construct validity. Overall, these procedures addressed the following second research question:

How could the newly conceptualized theoretical construct be validated?

The next sections outline the key process involved in phase 2 towards construct validity.

3.7.1 Research method

The second phase followed a case study research strategy. Predominantly, case study research is understood as an enquiry where the researcher develops an in-depth analysis of a case, often a program, event, activity or process (Cresswell & Cresswell, 2018). The case of organic chemistry was employed in this study to create a thorough comprehension of the construct being studied. When the lines between the phenomena and the context in which the phenomenon occurs are blurred, a phenomenon is typically researched in its real-life context in case-study research (Yin, 2018). In this study, the selected participants were bound together for an elongated period as they were enrolled on a course geared to develop knowledge for teaching science.

Case studies are described as an event surrounded by certain factors which must be kept constant during the investigation (Cohen et al., 2007). Thus, there is a need for a case study researcher to identify and describe these boundaries. These boundaries determine the appropriateness of the participants in the study, and to a larger extent, the type of data and literature that must be considered towards answering the research question. The population sample is to meet certain criteria which are explained under ‘participants’ below. It is more significant that the study concentrated on this sample, which was brought together by a particular criterion, and that it covered the entire term of the study, allowing it to establish the breadth and character of the teachers' expertise. To establish answers to the research questions posed in this stage of the study, it was necessary to follow a case study as a design. Also, the researcher in this study focused on the content knowledge needed to teach the subject in the secondary school curriculum by using the case of organic chemistry.

There are a few benefits associated with case study research methods. Firstly, it promotes the use of quantitative and/or qualitative methods in the in-depth exploration of an issue (Mcmillan & Schumacher, 2014) within a specific context. Given that this is a novel construct, not explored in any empirical research, using the case study method is justifiable to unravel the complexity of learning about this theoretical construct describing a distinct teacher knowledge domain. Secondly, Cohen et al. (2007) pointed out that case studies generally have a narrow focus and can combine subjective and objective data. In this study, this was appropriate as both qualitative and quantitative data were collected to explore the phenomenon within a pragmatic paradigm drawing on both subjectivity and objectivity positions.

On the contrary, Cohen et al. (2007); Cresswell and Cresswell (2018) pointed to three major weaknesses of conducting case study research. Firstly, the results may not be generalized since the phenomenon is studied within a particular context for a particular group of people. Secondly, case study research is not open to member cross-checking and as a result, this leads to selectivity, bias and personal prejudice. Lastly, they are predisposed to the problems of observer biases and weaknesses related to the credibility of findings generated by case studies. Therefore, to mitigate some of these concerns, the outcomes of this research study will not be generalized; however, they are interpreted and understood within the context. In addition, findings emerging from this phase were also presented continuously in the PCK reference group and other forums for member cross-checking and subjectivity checks when making claims.

3.7.2 The participants

This phase adopted a case study research method as indicated earlier. In line with this choice of method, non-probability sampling is often used (Opie, 2004; Taherdoost, 2016). Generally, case studies tend to focus on small samples to examine a real-life phenomenon (Cohen et al., 2007) and not to make statistical inferences about the wider population (Yin, 2018). Hence, a sample of participants does not need to be representative, or arbitrary, but chosen with a clear justification for the inclusion of a particular individual over others (Taherdoost, 2016).

As a result of these requirements, the second phase used a non-probability purposive sampling technique. Purposive sampling is also regarded as subjective sampling by Sharma (2017). According to Cohen et al. (2007), researchers in this sampling method include the participants in the sample based on possessing particular characteristics. By so doing, the researcher builds a sample that satisfactorily caters to the specific research needs.

In line with this, the researcher selected a sample of PSTs (N = 35). These were 3rd year B. Ed students registered in one of the South African universities. They were mainly comprised of 19 to 26-year-old males and females of African and Indian communities from the province of KwaZulu-Natal. These PSTs were selected based on their specialization in physical science education. They are training as prospective teachers who will teach chemistry in a secondary school within the South African context.

These PSTs have never had an elongated classroom exposure except for the first and second-year teaching practice that lasts for about 3 weeks annually. So, in total, they have been exposed to the classroom for about 6 weeks. The participants were chosen based on having enrolled on a Methodology 2 course and having covered some aspects of teaching and learning in physical sciences. Refer to Appendix C for the physical sciences methodology course they have undergone in which the intervention was embedded.

The next section briefly outlines the principles that guided the explicit intervention. For further details, chapter 6 outlines the content and the instructional approach of the intervention.

3.7.3 The guidelines of the intervention

The explicit intervention developed in this study was designed on the following grounds. Firstly, the intervention was located in the 3rd-year B. Ed methodology course for teaching physical sciences, see Appendix C for the course outline of the methodology course. This course was geared to prepare PSTs to teach physical science in the curriculum and assessment policy statement (CAPS). Secondly, the intervention was conducted with PSTs with the assumption that they have either been exposed to high-end academic disciplinary content knowledge and/or a version of secondary school content espoused in the national curriculum statement (NCS). The intervention was designed to run over four weeks, including administering the pre-and post-tests.

Thirdly, the primary goal of the explicit intervention was to create a case study of organic chemistry to build the topic understanding needed to teach secondary school science. Given the complexity of organic chemistry, the intervention only paid attention to two major concepts. They are isomerism and functional group chemistry. Last but not least, the intervention was built on the presumption that explicit exposure to the intervention would enhance their subject matter expertise for teaching organic chemistry and maybe serve as the foundation for the growth of their PCK/TSPCK after the intervention in the area. As previously said, chapter 6 provides more information about the intervention.

3.7.4 Data collection

The validity of the hypothesized construct was investigated at many stages throughout the second phase of data collecting. The collection of pre-intervention data was gathered using the instrument after it had been piloted and validated for content and face validity. This was predicated on an organic chemistry case using an understanding of functional chemistry and isomerism, as was previously mentioned. Written responses to the instrument's open-ended inquiry made up this type of data, which was qualitative.

Another set of data was gathered using the same tool post-intervention to assess changes in PSTs' topic knowledge about teach organic chemistry. Focus group interventions were done to supplement the data acquired by the instrument post-intervention; see Appendix H for an interview strategy. This was critical to ensure the accuracy and substance of the claims made in the study and to validate the written responses with a focused group interview. A detailed overview of the data analysis method that took place for this stage of the research is provided in the next section.

3.7.5 Data analysis

Since the study followed the MMR design, the data were largely analysed using mixed-method techniques in the second phase. This technique of data analysis strongly adapts to the pragmatic paradigm (Driscoll et al., 2007). MM analysis according to Onwuegbuzie & Combs (2011) involves the analysis of one or both data types which occurs either concurrently or sequentially. In this phase of the study, the data analysis was largely sequential. Firstly, since the “pure” CK aspects of the construct were assessed separately with an adapted CK instrument, a corresponding marking memorandum (Appendix J) was used to mark PSTs’ responses. Similarly, from the process of developing a valid instrument, a corresponding marking memorandum/guideline was developed, see Appendix M.

After the process of marking both the “pure” CK and the other elements was completed, a corresponding rubric (Appendix O) was used to translate qualitative responses into scalar ordinal data. The designed rubric was structured to cater for the five elements of the construct. Each element has a specific criterion that describes possible progression in the knowledge of content to teach organic chemistry. In the rubric, four response categories are arranged from “poor”, “limited”, and “good” to “outstanding”. Following the performance objectives outlined in Chapter 6, this order outlines the understanding of the subject matter necessary for teaching. On a Likert scale of 1 to 4, these adjectives from "poor" to "outstanding" were placed. Figure 3.3, which was derived from the final version of the rubric, is an example of an extract from the rubric describing the four performance categories for one of the theoretical construct's aspects.

TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	1	2	3	4
Interconnections between the concepts of the fundamentals	At most three concepts are identified relating to the fundamental No concept map is drawn to show links between the concepts The explanation of the nature of the connections is conceptually incorrect	At most four concepts are identified relating to the fundamental The concept map is drawn but with limited linking words to show connections The explanation of the nature of the connections is partially correct The concepts identified are limited to organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to only organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are not limited to only organic chemistry

Figure 3.3: Extract 1 of the final rubric

In the extract shown in Figure 3.3, the progression in the knowledge of content knowledge related to teaching in the element of the interconnections between the concepts that make up the fundamentals is revealed. This included various aspects such as identification of relevant concepts, pictorial representation of the interconnections through the quality of a concept map and written account of how they understand the interconnections between concepts.

Another element of the construct was aligned with the knowledge of the pure substantive CK aspects of the topic. This element was graded separately with the adapted CK tool a total mark of 25 points. The mark obtained by the respondent was then converted to a percentage that was also located on a Likert scale of 1 to 4. Figure 3.4 shows how this allocation of percentages in the continuum was classified indicating the quality of pure content knowledge on the topic.

TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	1	2	3	4
Knowledge of the fundamentals of the topic	There is poor knowledge of the content. Overall content knowledge performance is at 25% and below	There is limited knowledge of the content Overall content knowledge performance is between 25% - 49%	The respondent demonstrates good knowledge of the content Overall content knowledge performance is between 50% - 74%	The respondent demonstrates outstanding knowledge of the fundamental content Overall content performance is 75% and above.

Figure 3.4: Extract 2 of the final rubric

A score of at most 25% indicated poor knowledge of the content and a score of at least 75% indicated outstanding knowledge of the content. The others were allocated in the continuum as shown in Figure 3.4.

The rubric was useful in converting written qualitative responses from the instrument so that they could be processed for Rasch analysis. Then, for this statistical study, the Ministep Winstep Rasch statistical model, version 5.3.1.0, was employed. Bond and Fox (2013) asserted that this program transforms the raw ordinal scores for each item, in this case, scores derived from the qualitative responses of the instrument, into probability measurements that are then put on a linear scale with equal intervals. This suggested that the rubric's "poor" to "outstanding" (or 1–4) scale would be transformed into a linear scale with equal gaps between performance categories. The advantage of such a scale is that it presents the difficulty of constructing elements in rank order as experienced by the participants.

According to Boone and Rogan (2005); Boone et al. (2013) the construct is valid if the mean-square values (MNSQ), also called the relative chi-square range between 0.5 to 1.5. This range implies that the test is productive for measurement (Linacre, 2012). In addition to these, the *z* – standard distribution (ZSTD) values, also called *t*-tests statistics must be within the range of + 2 to -2 for a construct to be valid (Linacre, 2012). In this study, these were also determined through the Rasch analysis to validate the theoretical construct.

In addition, Bond and Fox (2013) pointed out that the Rasch model has the added benefit of calculating two sets of values to help the researcher determine the reliability of a set of measures, i.e. person measure and item measure. This was important for this study as it evaluated if all the items have internal coherency and the same for the persons' responses and whether the items and persons' responses work together to measure a single construct. Thus, the use of the Rasch model in this study provided an analysis of validity and reliability from the quantitative aspect of the study. This responded to the second research question about the validity and reliability of the instrument.

The significant difference between the pre-intervention and post-intervention test scores was looked at to analyze for quantitative gains in the PSTs' knowledge of the content knowledge linked to teaching in organic chemistry. To do this, SPSS was used to run the non-parametric Wilcoxon Signed Rank Test (Pallant, 2011). This statistic is ideal because of its design for the use of repeated measures on two separate but related occasions, that is before and after the intervention (Eftimov & Korošec, 2022). The null hypothesis tested was that *"there is no significant difference in the overall performance of the PSTs measured before and after the explicit intervention*". The responses from this analysis provided answers to the third research question.

In addition to this, qualitative responses from the instrument and focused groups were analysed according to the elements described in the construct. This was important to explore the validity of the construct after the intervention and to confirm and observe quantitative improvement in the knowledge of the construct.

Figure 3.5 below provides a collated overview of the multiphase design explained above.

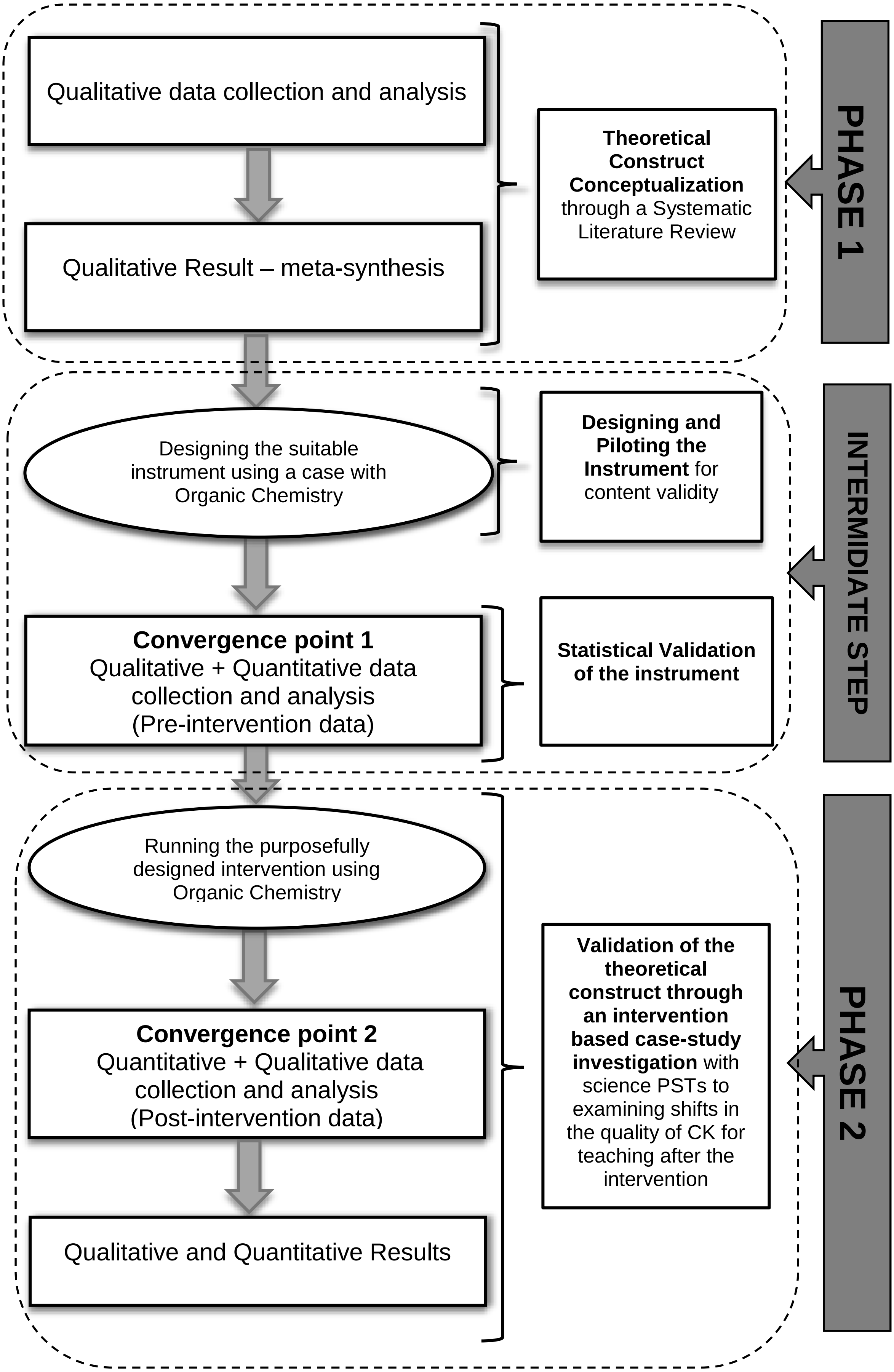

Qualitative data collection and analysis
Qualitative Result – meta-synthesis
Theoretical Construct Conceptualization through a Systematic Literature Review
PHASE 1
Designing the suitable instrument using a case with Organic Chemistry
Designing and Piloting the Instrument for content validity
Convergence point 1
Qualitative + Quantitative data collection and analysis
(Pre-intervention data)
Statistical Validation of the instrument
INTERMIDIATE STEP
Running the purposefully designed intervention using Organic Chemistry
Convergence point 2
Quantitative + Qualitative data collection and analysis
(Post-intervention data)
Qualitative and Quantitative Results
Validation of the theoretical construct through an intervention based case-study investigation with science PSTs to examining shifts in the quality of CK for teaching after the intervention
PHASE 2

Figure 3.5: Flow diagram for the multiphase mixed method research

The next section outlines how research rigour was maintained throughout the study.

3.8 Research rigour

As stated in the introduction, the entire study was divided into two parts. The second phase comprised two portions in each of which the qualitative and quantitative techniques were convergently merged. The first phase was entirely qualitative. As pointed out by Cresswell and Cresswell (2018); Teddlie and Tashakkori (2012), there are concerns about issues of research rigour when employing mixed-method research since it draws from the fortress of both qualitative and quantitative research. As a result, the quantitative parts of this study were considered independently, and they involved concerns with validity and reliability. On the other hand, the trustworthiness and credibility of the data collecting and interpretation procedures were the main emphases of the qualitative elements. I'll start with the latter in the segment after this one.

3.8.1 Trustworthiness and Credibility

While systematic reviews are often regarded as high quality in evidence synthesis, the methodological rigour within which they are conducted is blurred (Menon et al., 2022). However, in this study to increase the methodological rigour a set of standardised steps was explicitly followed as suggested by various proponents of systematic reviews such as Higgins et al. (2012); Menon et al. (2022); Okoli and Schabram (2010). These included a clearly defined review objective, see Chapter 4, section 4.3.2; prespecifying a detailed review protocol using an explicit PICOS strategy, see Chapter 4, section 4.3.3. An exhaustive literature search with clearly defined search items was conducted, see Chapter 4, section 4.4.1, Identified studies were screened and assessed for eligibility, see Chapter 4, section 4.4.2 & 3. These steps were crucial in increasing methodological rigour in this phase.

In addition, as part of rigour "is important to find evidence for the SLR from all sources possible, therefore it is essential to search for resources that will discover grey literature on the topic" (Batten & Brackett, 2021, p. 221). So, in this study, some of the literature references were manually added to strengthen the arguments about the conceptualized construct. In particular, this was done when positioning the construct with the views on powerful knowledge and translations to powerful curriculums.

Furthermore, Menon et al. (2022) asserted the need to assess for potential bias in systematic error in the included studies. To mitigate these potential biases in analysis and arguments, the review findings and synthesis were presented in a series of PCK talks which served as a reference group for critical reflection and constructive feedback. This group was constituted of several esteemed Academics in science education, both nationally and internationally as well as Doctoral students in the same field. In addition to this, the arguments were presented in two conferences, one in a symposium and the other as a conference abstract. Lastly, the findings were also presented in a joint university research project on STEM education for 21st-century citizenship. All these platforms were important in increasing the trustworthiness and credibility of the theoretical claims made in conceptualising the construct describing content knowledge for teaching.

The instrument created and verified in this study was used to collect data in phase 2. Focused-group interviews were undertaken to confirm information from the qualitative data obtained from the instrument to strengthen the validity of the findings and assertions made.

3.8.2 Validity

The are several validity issues in educational research (Cohen et al., 2007). For this study, the focus was on three aspects, i.e. face validity, content validity and construct validity. According to Connell et al. (2018), face validity measures whether the items of each domain are sensible, appropriate, and relevant to the people who use the measurement instrument. So, to cater for this, the pilot study of the draft instrument was conducted with a group of 4th Year B. Ed students with the same specialisation in physical science teaching.

Furthermore, content validity refers to the extent to which the set of items comprehensively covers the different components of the construct to be measured (Connell et al., 2018). In this study, the are two reference groups were put together to improve content validity. The first group was used for item judgement in the instrument construction process. The second group was used in judging the quality of items against the theoretical construct, see Chapter 7 for further details.

In addition, to the above, the second phase also explored construct validity as described by Cronbach and Meehl (1955); Kane (2012). This refers to the extent to which a test or measurement accurately assesses what it's supposed to assess. To establish construct validity, the Rasch fit statistics were used. Rasch software determines the validity of the theoretical construct and the items that make up the construct through statistical indices calculated by the software. According to (Boone & Rogan, 2005; Boone et al., 2013), a construct is valid if all the items or components that make up the construct fall within the conventional statistical range of 0.5 to 1.5 and -2 to +2 for both MNSQ (mean-square) and ZSTD (z – standard distribution) respectively.

3.8.3 Reliability

Similar to validity, dependability is a term that is frequently used in empirical research and can mean a variety of things (Cohen et al., 2007). In this work, instrument reliability was the main focus. Instrument reliability was assessed using internal consistency and item stability (Bannigan & Watson, 2009). When a testing method or instrument is used on a population of people from the same group in a comparable setting, this is referred to as the consistency of measurements to provide the same kind of results (Cohen et al., 2007). In addition to Cohen and colleagues' claim, there are other approaches to gauge internal consistency (Pallant, 2011). Cronbach's coefficient alpha is the statistic that is most frequently utilized in reliability tests. Hence, It is common to see the reliability of instruments used in published science education studies framed in terms of a statistical coefficient known as Cronbach’s alpha (Taber, 2018). This index has been pronounced as ‘one of the most significant and common statistics in research involving test construction. Similarly, in this study, this value was determined for the internal consistency of items. Furthermore, the Rasch analysis provides the internal consistency represented by two reliability indices, viz.: the person separation index (PSI) and the item reliability index (IRI) (Davidowitz & Potgieter, 2016). These were also determined and reported as part of ensuring the reliability of the instrument.

In addition to the reliability measures indicated above, the processes of grading respondents through a rubric needed some internal consistency. To achieve this, before the actual scoring of the written responses, inter-rater reliability was determined between the researcher and the module co-instructor. Three responses were blindly selected for this process.

3.9 Ethical consideration

There is a need for studies to be ethically cleared according to norms and standards set by the ethics committee (Williams, 2000). As per the requirements, this study was ethically cleared by the university under ethics protocol number H19/10/24, see Appendix D for the accompanying clearance certificate. Since the data was generated in a separate institution, there was a need to obtain the gatekeeper's permission. Hence, the Registrar's permission from the host university was also obtained, see Appendix E.

In social science research, there is a need for participants to give consent to be part of the research (Wassenaar & Mamotte, 2012), so the participating PSTs were invited and also asked to sign consent forms. There was no parents' consent solicited as the participants were no longer minors. Participants were explicitly made aware of their voluntary participation in the intervention. They were further informed that they may withdraw at any time they wish to do so. All the true identities of the participants and the identity of the host university have been concealed and participants are referred to by pseudonyms.

3.10 Summary

In closing, this chapter has outlined the overall design of this study. It has clearly outlined the methods of data collection and analysis in each research cycle. These methods were guided by the nature of the question asked in each phase. Since this was mixed-method research, issues of rigour for both qualitative and quantitative were addressed in terms of trustworthiness, credibility, reliability and validity. For the first phase, which is the systematic review, some methodological information was not outlined in this Chapter. Subsequently, the next chapter is a PRISMA technical report on the systematic review and the preliminary synthesis that emerged from the review.

CHAPTER 4 PREFERRED REPORTING ITEMS FOR SYSTEMATIC REVIEW AND META-ANALYSIS PROTOCOLS

This chapter entails a technical report that describes how the process of the SLR was carried out. It is situated within the overall purpose of developing and validating a theoretical framework using construct validity guidelines by Kane (2012). As part of phase 1, this chapter details how the systematic review was carried out as an algorithmic approach to data collection, analysis and synthesis of findings. It outlines the identification, selection, screening, and inclusion of relevant studies towards initial data analysis through a PRISMA checklist requirement. As a technical Chapter, it does not result in the full description of the theoretical construct argued for. Instead, it culminates with the preliminary findings that point to the possibility of hypothesizing a construct that describes typical teacher-related science content knowledge.

4.1 Introduction

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocol (PRISMA-P) statement, was purposefully intended in assisting systematic reviewers to report transparently why and how the review was conducted. It further requires an account of what the reviews did and what they found (Mazéas et al., 2019). Along with this statement, Moher et al. (2015) posited that SLR should be conducted on a protocol that clearly articulates the rationale, hypothesis, and planned methods of the review. For these scholars, a thorough, transparent protocol can facilitate comprehension and evaluation of the review procedures, as well as modifications to procedures and selective reporting in finished reviews (Moher et al., 2015).

In the development of a clear review protocol, three key sections require careful consideration, these are (i) administrative, (ii) introduction, and (iii) methods. Based on the three sections, Mazéas et al. (2019) recommended items that must be considered based on the PRISMA-P checklist, see Appendix Q for the checklist. In the sections below, these are clearly described as part of this technical report on the review process, the first one is on the administrative part.

4.2 Administrative

Four PRISMA-P items were necessary to be highlighted in this section. The review's title, authors, contact information, and the roles they played in the review process are listed first. If the evaluation was conducted before, a statement of revision follows this. The final point relates to the disclosure of any financial backing provided for the review.

4.2.1 Title

The review was titled: “The Conceptualization of the Theoretical Construct Describing Science Content Knowledge Related to Teaching”

4.2.2 Authors

The review was commissioned by two authors with different roles in the Doctoral project. They are:

1) Mr B.P Ndlovu, Wits University, 584432@students.wits.ac.za, PhD student and the primary reviewer.
2) Prof E.M Mavhunga, Wits University, Elizabeth.Mavhunga@wits.ac.za, Supervisor and the secondary reviewer

4.2.3 Amendments

There was no modification to a completed or published procedure in this protocol. The review was based on a new protocol.

4.2.4 Financial Support

This protocol review was part of a Doctoral study financially supported by the National Research Foundation (NRF) of South Africa.

The next section will focus on the introduction of the protocol.

4.3 Review protocol development

4.3.1 Rationale

Literature reviews have established that Pedagogical Content Knowledge (PCK) is commonly accepted as the principal professional teacher knowledge for teaching (Kind & Chan, 2019). This is because of its unique nature that combines content knowledge (CK) and pedagogical knowledge (PK) in sophisticated ways to enable the process of transforming content knowledge for teaching (Hlatshwayo et al., 2022). Thus, the teacher uses their understanding of PCK to transform abstract disciplinary content knowledge into content suitable for classroom practice (Mavhunga & Rollnick, 2013). Along with the plethora of PCK literature, it remains unclear about the nature of the CK needed for developing PCK for teaching secondary school science.

In mathematics, Dreher et al. (2018) highlighted the fundamental differences between CK in a school subject and CK in an academic discipline. According to them, the former and the latter vary in definition, and characteristics such as goals, context and kind of knowledge contained in each. Along with these differences, the prevailing doctrine of disciplinarity (Deng & Luke, 2008) seems to dominate the debate around teacher knowledge of the subject matter content. According to this doctrine, teachers are expected to transform abstract academic discipline CK acquired from mainstream disciplines during their pre-service courses into forms suitable for their classroom practice. The version that they are teaching in schools is therefore not the same in scope and philosophy as the one they generally acquire during PST education programs at an academic discipline. To date, in science education, there is still no articulated theoretical construct that explains the character of CK that should be acquired by PSTs to inform their pedagogical reasoning.

Hence, the requirement for a conceptual justification of a version of content knowledge appropriate for science PST education programs was established in this study. This has to be understood in light of any connections between academic disciplines and school subjects. This version is needed to teach secondary school science and it is not for any other professions in the discipline except for teaching. To realise this conceptualisation the SLR asked the following question:

> *How could a theoretical construct for defining and developing the content knowledge of secondary school science teachers be conceptualized?*

In educational literature, the term "content knowledge" refers to the quantity and structuring of knowledge that a teacher possesses (Vollmer & Klette, 2023). The substantive and syntactic structures of a field, as established by Schwab (1978), are two structures that define this knowledge. As explained by Schwab, this meant that to conceptualize this version of the content, both structures needed to be given attention.

The next section outlines the objectives of the review protocol.

4.3.2 Objectives of the Protocol

The protocol clearly states the question the review will attempt to answer concerning the participants, interventions, comparators, and results (Higgins et al., 2019). One of the features that distinguish systematic reviews from any other traditional reviews is the pre-specification of inclusion and exclusion criteria that is followed in conducting the planned review. This specification helps to ensure careful consideration when planning a review in terms of consistency, transparency, and integrity in the data collection methods, analysis of data, and data synthesis (Meline, 2006). Therefore, for any review, the criteria for inclusion and exclusion, methods, and outcomes to be synthesised are central to the development of the review protocol. For this study, a reference to PICO from the Cochrane Model (Higgins, et al., 2019) was used to outline the selection criteria of the included studies. The major goal of developing this protocol was to information and data that will be conceptually used to respond to the initial research question regarding the type of content knowledge appropriate for secondary school science instruction. In addition, the protocol was aimed to increase rigour in the SLR process.

4.3.3 Inclusion and exclusion criteria

(i) Population

This study considered a variety of peer-reviewed journal articles from multiple disciplines. The sample of records considered articles in natural sciences (physics, chemistry and life sciences). In addition to the pool of studies, papers from geography and mathematics education were considered for inclusion in the review. The main reason why mathematics and geography papers were considered lies in the fact that both these disciplines are very close to the physical sciences (chemistry and physics) content structure. Although the emphasis was largely on secondary education, studies involving both elementary and middle school teachers were also included.

Studies from the economics and management sciences (business studies, economics and accounting) were not part of the review. This was mainly because they are domains in the economics sciences that deal with the science of the economy and its effect and impact on society. In addition to this, science disciplines that do not filter into the secondary school sciences in the South African context were excluded such as medicine, engineering, nursing, etc.

(ii) Interest

The review took an interest in the previous conceptual and empirical studies that examine a special kind of CK related and suitable for teaching secondary school subjects. The common understanding is that CK is important to develop PCK, but not clear which CK is referred to. Hence, the large pool of studies for this review explored differences or similarities between the CK in academic disciplines and school subjects and how the two relate if at all they do. Secondly, studies that explored subject matter for teaching and school subject matter knowledge theorisation were considered. Lastly, interest was also given to studies that explored a specialized kind of material CK for teachers. These papers were carefully drawn from a pool of studies that do not focus largely on PCK literature.

(iii) Comparison

Central to the description and definition of the hypothesised construct was the comparison between academic disciplines and school science. This comparison presented opportunities and possibilities to explore the version of a distinct content knowledge described by a construct.

(iv) Outcomes

The goal of this review was to conceptualize a unique type of CK called by extrapolating the kinds of relationships that exist between academic discipline and school subjects' CK. Secondly. The study aimed to use existing models from similar studies in mathematics and other similar subjects to develop components of the theoretical construct. In Table 4.1 below the inclusion and exclusion criteria used to carefully conduct a comprehensive literature search are summarised:

Table 4.1: Review protocol - summary of the inclusion and exclusion criteria

PICO item	Inclusion Criteria	Exclusion Criteria
Population (P)	Mathematics education/Mathematics Science education/Sciences Geography/earth science Primary/Secondary and ITE	Humanities/ History Physical education Social sciences/economics/ Business Studies/ Vocational Education & Language
Interest (I)	Peer-reviewed Journals Empirical/conceptual Mixed methods/Qualitative studies Special Content Knowledge/SCK Material Content Knowledge Nature of Content Knowledge	Opinion papers/anecdotes Quantitative studies/Statistical studies Pedagogical Knowledge/ Pedagogical Content Knowledge/
Comparison (C)	Academic Discipline and School Subject	Comparison between different disciplines and domains of the sciences
Outcomes (O)	Relationship between academic discipline and school subjects Using the gap to extrapolate possible components of the theoretical construct from the two comparisons	Complexities of the structure of the discipline Approaches to teaching

From Table 4.1, the inclusion criterion considered peer-reviewed interdisciplinary literature covering the field of sciences (physics, chemistry, and geography) and mathematics. The excluded studies form a pool of papers conducted in engineering, medicine, and other technologies etc. since they generally exist outside mainline secondary education except for vocational education in South Africa. Studies from the economics sciences, humanities, and languages were excluded.

In the exclusion criterion, studies that were conducted in higher education only were disregarded, and a paper was included if it was based on primary or secondary education and linked to teacher education. There was no exclusion in terms of the specific countries in which the research was conducted. All international papers were considered for review. The only exception was the language of publishing, only research and articles published in the English language were eligible for inclusion. The review included publications and studies that were published between 1990 and 2019.

Concerning the interest, studies that examined science content knowledge, content knowledge for teachers and pure subject matters were included. The biggest challenge was the use of the term "science knowledge for teaching". Particularly in science education, most studies regarding teacher professional knowledge and "science knowledge for teaching" turns to focus on PCK, PK and to a certain extent, "the relationship" flanked by the SMK/CK and PCK. Such papers were omitted from this review.

The use of the term "discipline" turns out to include studies that are based on student "behavioural" discipline. These were excluded from this review. The study reviewed works that contrast academic fields and school curriculum areas and investigated any connections, or lack thereof, between the two categories of CK. Pure quantitative studies were not considered since the review aims at a conceptual description of the construct. Purely qualitative, mixed method studies and literature reviews were considered for inclusion since this stage was largely constituting a qualitative conceptual argument. The following section outlines the methods of the review process based on the above-described protocol.

4.4 Methods

The third aspect to be given due diligence in conducting the SLR are the methods of identifying relevant sources, data selections, quality appraisal of selected studies and data generation and synthesis (Khan et al., 2003). Hence, in the next sections, the items listed in the PRISMA-P specification will be detailed beginning with the first step of Identifying relevant studies through a comprehensive literature search, followed by an assessment and appraisal of identified studies.

The methods utilized to extract the data and a review of the data will be covered in more detail in the final paragraph of this section. This was a vital step in the creation of new knowledge and the data synthesis process.

4.4.1 Identification of relevant studies

The literature was thoroughly searched to identify pertinent research papers that were included for analysis. To conduct a comprehensive literature search, four databases were searched for peer-reviewed academic journals with specific search items described in the review protocol (*cf.* section 4.3). To complete the search, the EBSCOhost engine was used to broadly search the four databases. Access to these databases and their respective journals was retrieved through the University of the Witwatersrand library student login. The databases searched were (i) Academic Search Ultimate, (ii) Education Resources Information Centre (ERIC), (iii) Teacher Reference Centre and (iv) Education Research Complete

The initial search items used “Academic Discipline and School Subjects” as the main search items concurrently. For Search Identity 1, S1 expanders - apply equivalent subjects, search modes - Boolean/Phrase generated 1251 crude articles, these included conceptual, empirical, reports, reflections, peer-reviewed and non-peer reviewed artefacts and manuscripts. This search was replicated as Search Identity 2, S2, and the same amount of records were generated.

Search Identity 3, S3 – applied Limiters to “full text” yielded 626 articles. For Search Identity, S4 – Limiters to “Date of Publication” – 1995/01/01 to 2019/12/31 and 555 articles were generated. Search Identity, S5 and S6 yielded 0 results because the “references available” limiter was included, this generated 0 results.

Subsequently, this was changed in Search Identity 7, S7 and the date of publication were expanded to “1990/01/01 - 2019/12/31” of the peer-reviewed articles – 31 results were generated for the first selection, see Appendix R for the identified records. Usually, the exhaustive literature search is not completed by algorithmic methods as reported in the paragraph above. Other databases can be manually searched for additional peer-reviewed articles for consideration as suggested by Piper (2013). These are articles that must meet an inclusion criterion predefined in Section 4.3.

To exhaust the search of the literature, Google Scholar was in addition used to identify other relevant studies that would not have emerged from the initially searched databases. Accordingly, in addition to these 31 records from algorithmic search, 9 other records were manually added to the list of articles submitted for the first appraisal of articles, these were extracted manually from other sources identified through Google Scholar. In total, 40 records were finally submitted for the first appraisal.

4.4.2 First assessment of eligibility of initially selected studies

The appraisal of retrieved articles happened in four different stages, these are (i) Identification, (ii) Screening, (iii) Eligibility and (iv) Inclusion of the relevant studies for review. Generally, in systematic reviews, such a process is presented in a form of a PRISMA diagram. Figure 4.1 shows how the number of articles (n) changed from the identification stage to the inclusion stage for analysis whilst conducting quality assessment and appraisal in between.

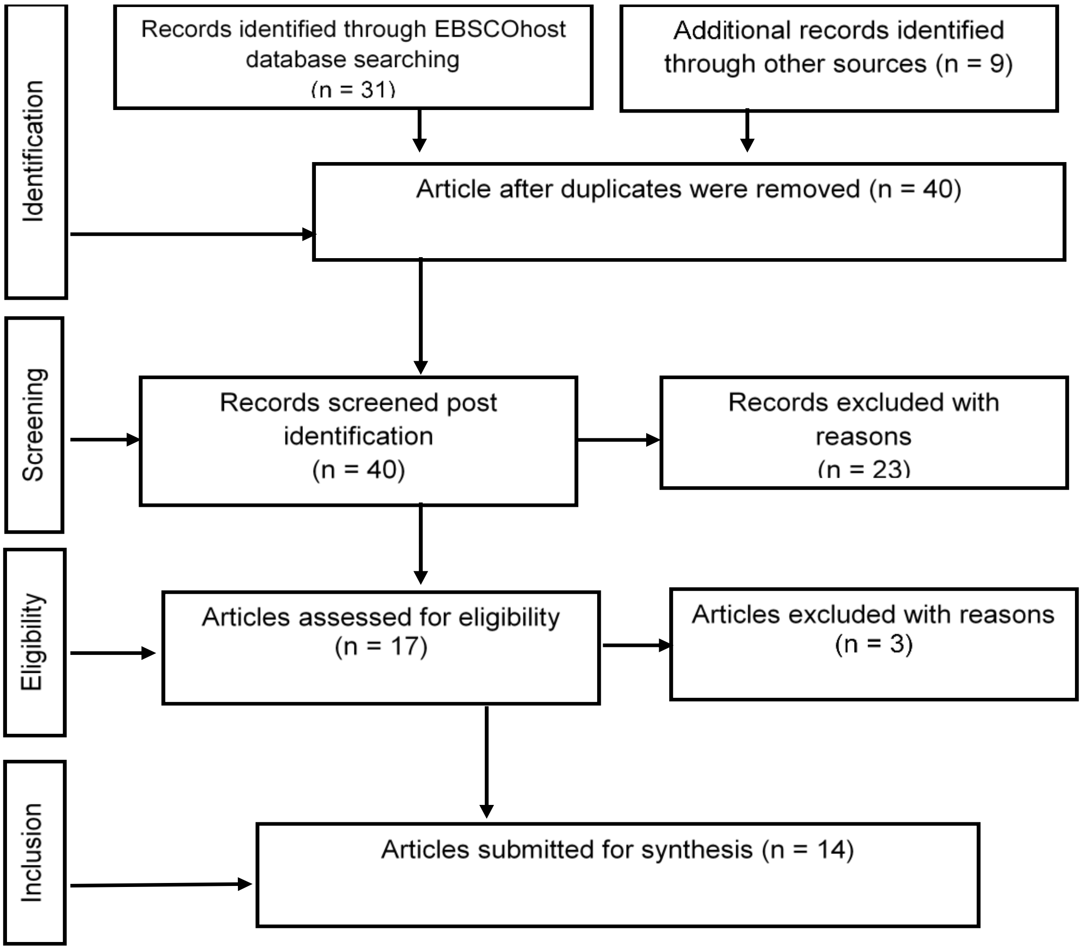


Figure 4.1: PRISMA flow diagram representing data collection and appraisal of studies

From the comprehensive literature search, 40 records were initially selected from a comprehensive search of the literature and submitted for the first assessment of eligibility through screening. These studies included articles generated from both algorithmic search (EBSCOhost) and those generated from the manual search using additional search engines. 31 records were algorithmically searched through

EBSCOhost. The other search engines generated 9 records which were manually added to the sample resulting in 40 records. In this identification, no articles were recorded as duplicates.

The next stage was the screening of the selected articles. This was done to evaluate the first eligibility for consideration according to the pre-set review protocol. For the screening process, both the title of the paper and the electronic abstract were evaluated. The title was critically analysed and thought through to evaluate if it contained the search items prescribed in the search protocol. What served as screening determinants included “academic discipline and school subjects”, the “relationship” between academic disciplines and school subjects, “specialised/special content knowledge for teaching” and, or “teacher content knowledge”. In a case where the title did not provide details for an explicit inclusion, the abstract was carefully read to evaluate if the study was eligible for further consideration.

Post this evaluation 23 records out of 40 were discarded from the review. This is because they included work, which was done in economics and management sciences, history, languages, nursing, pedagogy, feminist, and behavioural studies. In addition to this exclusion, some of these papers were focused purely on science discipline and did not link this to teacher content knowledge or subject matter for secondary/primary school. The other study that was discarded mainly focused on science, technology and mathematics and engineering education outside the knowledge content related to teachers and teacher preparation needs. Thus, post this stage, 17 articles were finally submitted for quality appraisal for inclusion purposes.

4.4.3 Quality appraisal of included studies

The integral part of collecting data for systematic reviews is the quality appraisal of initially selected studies that would be submitted for the final analysis (Erwin et al., 2011; Littlewood et al., 2010). To appraise a study, an article was fully read to evaluate its quality and usability. From the 17 articles read, 3 more papers were rejected as they did not meet the purpose of this review. Hence, these articles were not part of the final quality appraisal process that ensued in this chapter.

The first paper excluded focused on the evolution of geography at schools without drawing from the nature of content knowledge taught at both the school level and PST programs. The second paper excluded did not attempt to conceptualise what happens in teacher education instead it focused on understanding how curricular change is accomplished only on lower and secondary school content knowledge, it lacked links with PST education and training. The last paper discarded was a longitudinal study of about 17 years and it did not attempt to conceptualise content knowledge for teaching, instead, it was a longitudinal paper that focused on how content for teaching evolved in practice.

As a result, a total sum of 14 articles or records was finally submitted for inclusion in the review. Table 4.2 shows an adapted checklist used for appraising the quality of the selected papers and it was adapted from Erwin et al., (2011) work. The first column indicates the criterion used for the quality appraisal of each record. The second column indicates a maximum score for each criterion. The top row shows the allocation of the records ranging from (Rec1 to Rec14), where Rec1 is record 1 or journal article 1 and so on.

For each record, the description in the criteria was scored either a 0 for not clear or a 1 for a clear description in the quality appraisal. The last two rows in the table show the total of all the criteria for each paper out of 15 and indicate the inclusive quality of the record submitted for analysis.

The last row of Table 4.2 displays the global scores allocated across the descriptors of the quality of the paper. The following factors were carefully examined to gauge the calibre of the chosen study. Initially, the study's background and the way it is focused. The second part examined how methods and methodologies used in data collecting and analysis were explicitly mentioned. For conceptual papers, the focus was given to the explicit mention of the review protocol if any that was followed. The third aspect was based on the finding generated by each paper. The interest was in the use of data to justify claims, interpretations as well as coherence in the argument for points and emerging knowledge. The last aspect focused on the discussions and implications that the study generated. The major focus here was on the recommendations for future research, the ability of the author(s) to answer the research question(s) and lastly, contributions to the body of knowledge.

The scores' average value was calculated statistically. These values were used to calculate the average eligibility quality, which was found to be 12.4 out of 15. This value translated to 82.9% of the quality of submitted studies. This was analysed to represent an acceptable quality of the included studies at above 80%.

Table 4.2: A quality appraisal of eligible records

Criteria	Rec1	Rec2	Rec3	Rec3	Rec4	Rec5	Rec6	Rec7	Rec8	Rec10	Rec11	Rec12	Rec13	Rec14
BACKGROUND AND FOCUS														
Problem	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Purpose	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Research Question(s)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
METHODS AND METHODOLOGY														
Qualitative/Mixed Design/Narrative	1	1	1	1	1	1	1	1	1	1	1	1	1	1
data collection plan	1	0	1	0	0	0	1	0	0	0	1	1	1	0
Data analysis plan	1	0	1	0	0	0	1	0	0	0	1	1	1	0
Participant sampling	1	0	1	0	0	0	1	0	0	0	1	1	1	0
Research rigour	1	0	0	0	0	0	1	0	0	0	1	0	0	0
FINDINGS														
Interpretations are supported by data	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Emerging ideas are precise and well-argued.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Results offer new knowledge	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Claims generated are supported well with evidence	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DISCUSSIONS AND IMPLICATIONS														
Recommendations	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Answer(s) to the question	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Contribution to the existing literature	1	1	1	1	1	1	1	1	1	1	1	1	1	1
OVERALL QUALITY	15	11	14	11	11	11	15	11	11	11	15	14	13	11
PERCENTAGE QUALITY	100	73	93	73	73	73	100	73	73	73	100	93	87	73

In Table 4.2, the records were not arranged in terms of their scores. Instead, they are grouped into four categories, which will be explained in the section below. Subsequently, the next section shows how data was extracted, grouped and organised for analysis and synthesis of the findings.

4.4.4 Data extraction and preliminary discussions

Proponents of systematic reviews agree that there is no single and precise method to present and report systematic reviews. How one organises the review report should be logically dictated by the goals of the prevailing review (Siddaway et al., 2019). For example, in this study data was extracted using tables through the Microsoft Excel program to compare and contrast findings. Subsequently, a textual description of the key findings in each category of papers was outlined to point to the emerging conceptualisation of the desired construct.

To analyse the qualitative data, the researcher followed a traditional approach of deductive qualitative data analysis. The first step was for the researcher to be familiar with the content of the articles. This involved thorough reading of the records and the main findings that were generated in each study. Secondly, the researcher grouped the articles according to the main themes or main concepts that were emerging from the thorough reading of the articles. Grouping the article led to a process of organising the article according to meaningful categories. The four categories that emerged from this process are shown in Table 4.3. In addition to the generation of the categories identified, Table 4.3 also includes information about the names of the contributor/s, the publication year, the kind of research each paper fell within, the subject on which each study focused, and the level of education, which is either primary or secondary level. The next step was to integrate the ideas and findings that emerged from different studies to develop a coherent and comprehensive understanding of the research question. This was iteratively done to identify the similarities, differences, or contradictions, if any, amongst the studies and explore how they contribute to the overall understanding of the phenomenon. The overall process led to the generation of three main constructs that are described in section 4.6.

Table 4.3: Summary of the key features and categorization of the included studies.

Category	Author, (Year)	Kind	Subject	Level
Perspectives and foundations for the conceptualisation of Content Knowledge related to teaching science in South Africa	Booi & Khuzwayo (2009)	Empirical	Sciences	Secondary School
Relationship between academic discipline and their related school subject	Stengel (1997)	Conceptual	Curriculum	ITE & Secondary School
	Deng (2012)	Conceptual	Curriculum	Secondary School
	Johnston (2019)	Conceptual	Geography	ITE & Secondary School
	Catling & Martin (2011)	Conceptual	Geography	ITE & Primary School
	Rawding (2010)	Conceptual	Geography	ITE & Secondary School
Theorising the subject matter of secondary school science/ Formation of the school subject	Deng (2007)	Empirical	Science	ITE & Secondary School
	Deng & Luke (2008)	Conceptual	Science & Curriculum	ITE & Secondary School
	Deng (2009)	Conceptual	Curriculum	Secondary School
	Dreher, Lindmeier, Heinze & Niemand (2018)	Empirical	Mathematics	ITE & Secondary School
Special content knowledge for teaching mathematics	Ball, Thames, & Phelps (2008)	Empirical	Mathematics	Primary School
	Chikiwa Westaway & Graven (2019)	Empirical	Mathematics	Primary School
	Sahidin, Budiarto & Fuad (2019)	Empirical	Mathematics	Secondary School
	Speer et al (2015)	Conceptual	Mathematics	Primary – Secondary school

The included studies were initially grouped into four categories to aid the data extraction process. Category 1 consisted of one record that outlined a rationale for reconfiguring the initial teacher education content in the South African context. The second category contained five records (record 2 – record 6). These papers focused on the possible kinds of relationships flanked by school subjects and academic discipline. The third category consisted of four records (record 7 – record 10). These papers explored the theory behind the subject matter knowledge of secondary school subjects. The fourth category consists of four records (record 11 – record 14). These papers focused on CK for teaching, particularly specialised CK for teaching school mathematics.

Secondly, all the papers included were peer-reviewed and extracted from accredited journals/publications or university library press. Two kinds of papers were contained within this review. Six of the studies were empirical research and eight of them were conceptual papers. Four different subjects were considered as explained in the review protocol, these were science, mathematics, geography, and curriculum studies. Two studies were purely conducted on science subjects. One paper had a combination of science and general curriculum aspects. Three papers were generated from geography and they all belonged to one category. Three papers were purely based on curriculum studies and five papers were retrieved from the mathematics education research.

Thirdly, in the last column of Table 4.3, four of these papers purely focused on primary education, one paper linked it to secondary education whilst the other one linked it to ITE. The other nine studies were focused on secondary education. Six of these studies linked secondary school education to the initial teacher education, and only two focused on just secondary school, these were regarded as significant in characterizing the subject matter for teaching secondary school subjects.

At least 13 studies have been conducted between the years 2000 and 2019. Only one study lies in the late 90s, and it has served as a reference study for most of the subsequent studies around the kind of relationship between academic disciplines and school subjects. The preliminary results from the initial analysis of the included studies are highlighted in the following part. This draws attention to the full synthesis of the data in Chapter 5 and concludes this chapter.

4.6 Meta-Synthesis and preliminary findings

Drawing from the papers categorized in Table 4.3, there is evidence that a special kind of CK is needed for those who aspire to teach secondary school science subjects. For example, Booi and Khuzwayo (2019) used the ideas of the practical and critical praxis theoretical framework for curriculum research, development, dissemination, and adaptation to argue for a nested and connected model that emphasises the interconnections between the disciplines of science. These authors used qualitative data from course outlines of six South African universities and corroborated them with in-depth interviews to show the lack of uniformity in the interpretation of the policy on MRTEQ. It was for this reason that Booi and Khuzwayo (2019) suggested a model that depicts interdisciplinary links for content that should underpin teacher education. However, in their model, they did not present components or items that explicitly describe this interdisciplinary nature of content knowledge. They only argued just for discipline-specific links connecting the domains of physics, chemistry, earth and life sciences.

In the second category, the included studies explored the possibilities of relating academic discipline and school subjects. For example, Stengel (1997) focused on curriculum deliberation in teacher preparation to locate her argument. She postulated a variety of possible relationships between school subjects and academic disciplines. For her, the relationship is "*(i) continuous, (ii) discontinuous and (iii) different but related in three ways: (a) school subject precedes academic discipline, (b) academic discipline precedes school subjects (c) dialectical".* Much of the work that continued in these research fields has centred around these permutations by Stengel (1997). Different scholars brought in a variety of interests within these relationships and started reconfiguring these permutations.

For example, Rawding (2010) examined the connections and, or the lack of connections between academic disciplines and school subjects. The focus of his investigation was to locate a discussion on curriculum planning in PST education, using geography as a subject, this was different from Stengel (1997) who was into general curricular deliberations in teacher preparation. On the other hand, Catling and Martin (2011) took a slightly different approach and foregrounded their work on powerful knowledge between academic discipline and ethno-knowledge using the case of geography as both an academic discipline and a school subject. They aimed to explore Young's idea of powerful knowledge to argue for the same status to be accorded between academic geography and school geography. Lastly, Johnston (2019) examined changing geography as a discipline and its effect on geography as a school subject. They highlighted some of the implications these reforms have for PST education.

Both Stengel (1997) and Rawding (2010) did not present a working model to depict their conceptualisation of specific content that should underpin teacher education training. Instead, Stengel (1997) simply examined the variety of possible relationships between academic discipline and their related school subjects. Her interpretation ensued in two ways: firstly, it was the examination of the possible relationships between the two. Secondly, an attempt to interpret the meaning of these concepts as a function of the conceptual relationship between them. Rawding (2010) simply focused on the connections in the subject development. As indicated earlier, this was different from the work of Johnstone (2019) who was concerned about changing the structure of the discipline, its influence on the school subject and its legitimation. Regardless of these various scholarly interests, all these papers agree about the probable connection between academic disciplines and related school subjects.

In the third category of studies, Deng (2007) was interested in describing and theorising subject matter knowledge for teachers and for teaching secondary school science. Firstly, Deng (2007) focused on clarifying the difference between academic disciplines and school subjects building on Stengel's (1997) permutation. in his 2007 seminal work, Deng used Dewey's logical-psychological distinction framework to distinctly clarify the idea that both school subjects and academic disciplines are fundamentally different but related to each other. Five dimensions of looking at this relationship were introduced, these are "*(i) logical (ii) psychological (iii) pedagogical (iv) social and (iv) epistemological dimensions"*. More discussion of these will follow in the next chapter.

Subsequently, Deng and Luke (2008) focused on knowledge classification and theorisation to locate their discussion of subject matter knowledge for teaching or teachers. in this conceptual work, these authors asserted that the subject matter knowledge entails different ways of knowledge classification, these are: epistemological, teleological, methodological, and interpretive or cultural and political. This point was seen as important in assuming a particular curricular position when deliberating about the subject matter knowledge for secondary school science. Subsequently, Deng and Luke (2008) postulated three conceptions of knowledge disciplinary and their epistemological schemes. These are "*(i) disciplinary conception of knowledge, (ii) practical conception of knowledge and (iii) experiential conception of knowledge*". This view was later important in this study as we have blurred the line between these "bits of knowledge" to simply powerful "knowings" and "knows" as described by Carlgren (2020).

In a later study, Deng (2009) used his thesis to demonstrate how a school topic is introduced to schools as a different representation of the content contained in academic discipline materials. According to him, this calls for the application of a theory of content, which is a unique method of choosing, arranging, and framing the content for social, cultural, educational, curricular, and teaching purposes. The underpinning theory of the content must also be understood in order to reveal and realize the educational potential that is inherent in the content, which calls for more than just knowledge of the subject matter covered in school. The following chapter will delve deeper into this idea.

The next category of papers explored a special type of CK required for teaching school mathematics and the operationalisation of the MKFT construct by Ball et al. (2008). The studies in this set were regarded as central to this idea of conceptualising content knowledge for teaching science because of their explicit call for a distinct knowledge of teaching that is content-based and separated from the dominance of PCK.

Firstly, Ball et al., (2008) focused on the identification of domains for mathematical knowledge for teaching using material CK and PCK dimensions. However, their conceptualisation did not consider the differences between academic disciplines and school subjects in mathematics. After that, Chikiwa et al. (2019) illuminated the domains of MKFT to explore their interconnectedness in elementary mathematics. On the other hand, Sahidin et al. (2019) introduced a framework that is conceptual-based following Ball et al., (2008) framework. All these studies did not explicitly take into consideration the gap between content knowledge of the academic discipline and that of the school subject. However, they clinically argued for a special framework for considering CK related to teaching school mathematics.

Lastly, Dreher et al., (2018) used the difference between academic mathematics and school mathematics to hypothesize a special kind of teacher knowledge that takes into consideration the gap between the two. Their work theorises a special construct called school-related content knowledge (SRCK). All these studies have suggested a model for this specialised kind of content knowledge for teaching. Emerging from this set of studies are the key facets that have been empirically validated to describe a model of MKFT and SRCK successively. The following chapter, which conceptualizes a new construct, will go deeply into their meanings and descriptions.

4.5 Conclusion

This chapter has successfully presented a technical report on conducting a systematic literature review following the requirements of the PRISMA-P checklist. This was mainly intended to account for the transparency and credibility of the processes that informed data collection at various steps in the review process. The preliminary analysis emerging from this suggests that three key themes are key in conceptually arguing for the theoretical construct postulated in the study. These are (i) the kinds of relationships between academic discipline and school subjects, (ii) dimensions that relate to academic discipline and school subjects, and (iii) content knowledge for teaching.

As was noted in the beginning, the bulk of this chapter's content was mainly technical and focused on the method of systematic reviews. The conceptualization of the theoretical construct put out in this study is not its pinnacle. However, it has laid a fertile ground to conceptually synthesise the findings from these studies to answer the first sub-research question postulated in this study. Hence, the next Chapter builds from these preliminary findings to conceptualise the theoretical construct describing the content knowledge suitable for teaching secondary school science.

CHAPTER 5 CONCEPTUALIZATION OF A THEORETICAL CONSTRUCT DESCRIBING CONTENT KNOWLEDGE SCIENCE

This chapter presents a conceptual argument that supports the existence of a distinct kind of content knowledge for secondary school science teachers. This version of content is described by an emerging construct that conceptualises content knowledge related to secondary school teaching. This conceptualization draws from the primary data sources collected and accounted for in chapter 4. Further to that, this chapter locates the conceptual argument for the construct within a particular theory of content informed by the latest views of powerful knowledge and curriculum planning. In conclusion, a pictorial model that depicts the curriculum model based on the construct is. This conceptualization constitutes and concludes the first phase of the two-staged process towards theoretical construct validity.

5.1 Introduction

It has been established in this thesis that academic disciplines are fundamentally different from school subjects in various aspects. For example, Deng (2001) used Dewey's logical-psychological structure (Dewey, 1990) to distinguish the two. Secondly, he used Harré's epistemology of science (Harré, 1986) to show that the key ideas in school physics are different from those of the academic discipline in theory type and source analogue. The main concepts or principles that a physics teacher would emphasize in order to help high school pupils understand a certain topic are what the author meant when she said "*important ideas in teaching high school physics*." In the physics discipline, he refers to the topics that a student majoring in physics would focus on learning in courses provided by the university's physics department.

By definition, an academic discipline is a field of learning affiliated with an academic department within a university. They are formulated for the advancement of research and scholarship and the professional training of researchers, academics, and specialists (Deng, 2012). This means that academic discipline in the university is driven by rigorous scientific inquiry.

The main purpose of the first phase of the whole study was to explore ways in which the kind of content knowledge needed to teach secondary school science could be conceptualized differently from academic discipline content knowledge and related school science content knowledge. Hence, this section presents a conceptual argument that describes a novel theoretical construct describing the nature of content knowledge suitable for science teacher education programs and as a base for PCK development. Emerging from the preliminary analysis of the SLR, in chapter 4, three literature constructs or themes were identified towards the conceptualisation. These are:

(i) *"the relationship between academic disciplines and school subjects"*
(ii) *"the dimensions of content knowledge for teaching secondary school science"*
(iii) *"the specialized knowledge for teaching school subjects [mathematics]"*.

In the next sections, each of these literature constructs is unpacked and building implications for the characterizations of the emerging theoretical construct defining content knowledge for teaching science are subsequently discussed.

5.2 Unpacking the building blocks towards a new version of content knowledge

5.2.1 The relationship between academic disciplines and school subjects

The first theme that came out of the review looked at how academic disciplines and corresponding school subjects relate to one another. It was crucial to focus the conversation on typical material content appropriate for teaching science in schools. This topic came up in a group of sources that compared disciplines and educational subjects, considering how they were formed and their epistemological underpinnings. As such, this section used these relationships to compare the nature of content construed by each and how it can be used to describe content knowledge for teaching school science.

According to Stengel (1997), academic disciplines relate to school subjects in three conceptual ways. To begin with, academic disciplines and school subjects are essentially *continuous*. This means that while secondary school students study subjects with concepts and principles that are generally easier, they nonetheless learn the same fundamental ideas about the nature and importance of content that are shared by discipline experts. This was the same notion held by Catling and Martin (2011); Deng (2012) and Johnston (2019).

In addition, Stengel (1997) also acknowledged the alternate view held by proponents who reject the continuous relationship and promote the discontinuous permutation. For her, these proponents argue differently, that "*the impetus for the formulation of school subjects is quite distinct from the impetus for the development of academic disciplines*" (Stengel, 1997, p. 588). As a result of their design, they both serve different purposes in their own epistemological and political existence as epitomised by the views of Noddings (2015). At an earlier point, Deng (2007) also pointed to this discontinuous nature and argued for the need to psychologize the school subjects drawing from the work of John Dewey (Dewey, 1990). This discontinuous nature of the relationship between academic disciplines and school subjects was also acknowledged by other sources included in the review such as Catling and Martin (2011); Johnston (2019) and (Rawding, 2010).

Furthermore, Stengel (1997) posited that continuous relationship emerges from the observations of relationships that are complex, and sometimes sound confusing. The author posited that academic disciplines and school subjects are different but related through three permutations, these are:

(i) "academic disciplines precede school subjects"
(ii) "school subjects precede academic disciplines"
(iii) "*the relationship between these two is dialectical*"

In the first permutation, school subjects are regarded as transformed versions of academic disciplines. This means that it is the discipline first, and then subjects come from the discipline. This view is widely held by several PCK scholars such as Shulman (1987); Kind and Chan (2019). For Shulman (1987, pp. 8-9), "*academic disciplines are the primary source of school subjects because they provide the knowledge, understanding, skills, and disposition that are to be learned by school children"*. Thus, the two are different, yet related and the discipline comes first before the subject. In light of these claims, school science represents a transformed version of the content of its related academic discipline (Geddis & Wood, 1997). This permutation was also viewed to be similar to the continuous model of relationships as argued by Deng (2012). In his view, Deng did not like this idea of school science coming from the academic disciplines and posited that teachers draw from the school curriculum which embodies more than the disciplinary CK.

The second permutation reflects that there are similarities in the development of content in both school subjects and academic disciplines. Further to that, school subjects are considered to mirror those similarities as they ensue from the academic discipline level. This comes through explicitly in Deng (2012), who argued that the school subject provides the starting point for the formation of an academic discipline, and the academic discipline provides the path to understanding the school subject. This suggests that academic discipline comes after the school curriculum. In contrast with the first permutation, this suggests different views by scholars of what is regarded as the starting point.

The third permutation characterises the relationship as being dialectic. This position, as Stengel (1997). According to Dewey (1916) cited in Stengel (1997), there is a need to "*lead students in the direction of what the expert already knows*". This permutation of the dialectic suggests that academic discipline offers norms and reveals potential for the learners' unrefined activities (Stengel, 1997). In his later work, Deng (2012) saw this dialectic relationship as an amalgamation of both the discontinuous model and the "*subject precedes discipline*" model.

Whilst on the third permutation, Catling and Martin (2011) held an alternate view about this. They do agree with academic discipline preceding school subjects and vice versa. However, they argued that "*there is a tension between academic and everyday knowledge [school knowledge] that needs to be resolved through discussion*" (Catling & Martin, 2011, p. 320). Thus, instead of assigning a dialectic relationship, a dialogic connection is a rather more suited description. According to them, teachers operate at a pedagogical level to defuse disciplinary knowledge in the classroom, a view held strongly in the PCK research. Since there is tension between these two powerful pieces of knowledge, teachers need to be able in their pedagogical space to negotiate the connection between these two powerful pieces of knowledge (Catling & Martin, 2011).

Secondly, they further added in their argument that the knowledge held by experts in the discipline and everyday knowledge in school represents two ends of the continuum where each end is informed by its own epistemological existence and political and historical foundations. This argument is illustrated in Figure 5.1 which shows an authority model between academic geography and school geography.

Academic Discipline Geography		**School Subject Geography**
Authority	**Held by both Context**	**Authority**
Powerful Knowledge →	Curriculum as articulation	← Powerful Knowledge
[*The discipline of Geography*]		**[*The younger child With geographical Experience*]**
Academic perspectives of Geography	**Where the pedagogic dialogic interrelationship lies**	Everyday geographical perspectives (ethno-geography)
It is: rational conceptual systematic coherent structured		It is: rational conceptual systematic coherent structured

Figure 5.1: Reproduced authority model for competing powerful knowledge

From Figure 5.1, both ends of the continuum represent powerful pieces of knowledge postulated to be structured, coherent, systematic, conceptual, and rational. Thus, based on this assertion, it is essentially important that as a pedagogical dialogue between these two happens in class, the rational, conceptual, systematic, and coherent structure is not compromised. Whoever mediates from one end of the continuum to the other must be aware of the whirlpools and the tensions that may arise from this dialogic relationship. This is a very important point of consideration in this current work

Lastly, Johnston (2019) collapsed and combined some permutations that Stengel (1997) earlier postulated discreetly. Like Deng (2012), Johnston took the view that the academic disciplines and school subjects form a continuous classification, with the school subject presenting a simpler version of the discipline. This is a linear vertical model. The idea of continuity in Johnston (2019) was however not necessarily similar to the notion held by Catling and Martin (2011) of powerful knowledge. Johnston (2019) viewed the school subject as being less powerful than the academic discipline whereas Catling and Martin (2011) view them as equal and powerful knowledge in a linear horizontal model.

Lastly, Johnston (2019) regarded "*the two as discontinuous, taking very different forms because of the influences on their formation*". He thus concluded that academic disciplines and school subjects share mutual objectives and broader principles, yet they develop differently because of different social, economic and political pressures (Johnston, 2019).

In the next section, emerging insights about this theme are presented.

Emerging insight from the First Theme.

There is a general agreement amongst the studies included in this category that the association between academic disciplines and school subjects is quite complex, with no single, absolute, and sufficient way of relating them (Catling & Martin, 2011; Deng, 2012; Johnston, 2019; Rawding, 2010; Stengel, 1997). This implies that there is no linear way of relating the content embodied in each end without assuming a particular philosophical and curricular position. However, there are emerging common elements that are important clues for building a case for a new version of CK for teaching science.

Firstly, all views seem to acknowledge that school subjects' CK represents a diffused version of the academic discipline CK. Some referred to this difference as a ‘transformed version’ (Geddis & Wood, 1997); a simpler version (Duit et al., 2012) and diffused version (Bednarz & Ludwig, 1997).

Secondly, all versions seem to acknowledge that there is a process of developing one version from and/or in relation to the other, irrespective of which one is considered to be the starting point.

Furthermore, to find a rational ground to describe the kind of relationship between academic discipline content and school subject content, some questions had to be asked. For instance, “what do schools do, and therefore how to prepare the teaching practitioners?” In line with this abstract question, schools have been asked to serve purposes reflected in the four curricular ideologies, these are “*academic rationalism, humanism, social efficiency, and social reconstruction*” (Deng & Luke, 2008). Thus, advocating for a particular curriculum ideology serves to provide answers to the question of what schools do. This further shape a curricular perspective adopted in this study to locate and position this distinct CK version in-between the two different CKs as powerful knowledge.

The most appropriate response to this question was found in Deng (2012). In that piece of work, the author posited that much of what schools do centres on the typical function of diffusing disciplinary knowledge, a “specialised knowledge” that learners cannot simply attain outside the school setup. Hence, disciplinary knowledge provides an indispensable and resourceful framework for looking at schools’ propositional knowledge. This ideology assumes that academic disciplines are viewed as substantive sources from which the school curriculum content is derived. This is an important starting position for the argument for defining a version of CK for teachers in this study. However, while the focus at this point of the argument is on the relationship between academic disciplines and school subjects, the school curriculum is acknowledged as being informed by much more than the disciplinary substantive knowledge.

There are important social, psychological and historical elements at play in a school curriculum. Therefore, this version of CK is built from a perspective that sees academic disciplines and school subjects as related but different, as they have a different impetus in purpose and epistemological structure. They are further seen in a continuum, with each end connected by a dialogic relationship that continuously requires adjustments per the epistemological impetus held by each and also in response to changing new knowledge and social goals (socio-cultural, socio-economical). These adjustments also emerge from the inherent tensions arising from the points of continuity and discontinuity across the two ends of the continuum. So, it becomes necessary for PSTs not to be taught just pure academic discipline content nor the school subject curriculum content as neither is sufficient to handle the complexity seen in the pedagogical practice.

The insights above point to the need for a distinct CK for preparing teachers, that at the very least reflects comprehension of how academic discipline content has been translated into the school subject content. This is not referring to the act of teaching, but the understanding of:

(i) Which aspects of academic disciplinary content knowledge have been imported and which have been left out?

(ii) What tensions and/or differences, therefore, exist that are to be negotiated through a dialogic relation between the two ends?

These two aspects are considered to be the emerging components beginning the build-up towards the full conceptualisation of the version of CK hypothesised in this study. The next section unpacks the second theme that emerged from the studies about the dimension of subject matter

The next section outlines findings about the second emerging theme from the SLR on the dimensions used to describe the relationship between academic disciplines and school subjects.

5.2.2 Dimensions of subject matter knowledge that relate academic disciplines to school science.

Beyond the thoughtful consideration of the kind of relationship that academic disciplines share with a school subject, the systematic review findings also pointed to discussions about the specific dimensions of differences between the two. The works of Deng, dominate this area. Deng (2007) examined Dewey's logical-psychological distinction which brought to view the various aspects that distinguish a school subject from its parent academic discipline. Similarly, his work with Luke, a year later in reviewing the key issues in the classification and conceptualization of knowledge is of high relevance in theorizing the subject matter knowledge for teaching Deng and Luke (2008). In the succeeding year, Deng (2009) explored the formation of the school subject through these dimensions. This foregrounded the meaning of content concerning three aspects "*(i) institutional expectations/aims, (ii) the theory of content embedded in the curriculum framework; and (iii) students' existing knowledge and experiences*" (Deng, 2009).

In 2007, Deng examined the subject matter (content knowledge) for teaching secondary school through Dewey's logical-psychological structure (Dewey, 1990). This structure presupposes "*the subject matter, on the one hand, as determined by the logic of academic discipline, and pedagogical method, on the other hand, as determined by the psychologic of the individual*" (Deng & Luke, 2008, p. 8)

Two propositions emerged from his examination. The first proposition endorsed the above-mentioned finding of the nature of the relationship, that while both types of curriculum content are interrelated, they are fundamentally different. The second proposition is that there are five intersecting dimensions through which the relationship could be magnified. These are "*(i) logical, (ii) pedagogical, (iii) psychological, (iv) social, and (v) epistemological dimensions"* that distinguish one from the other. See Figure 5.2.

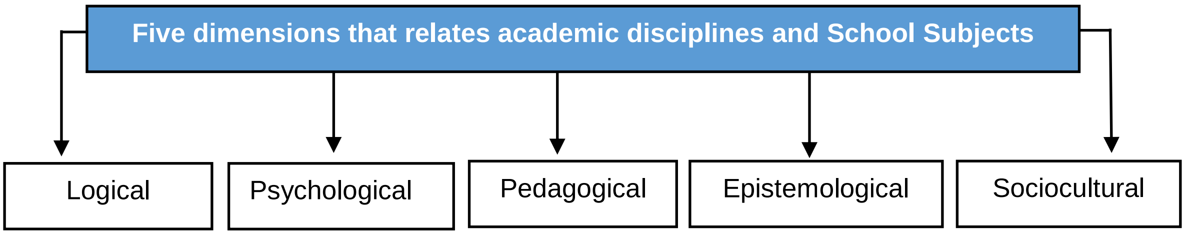


Figure 5.2: Deng's relational dimensions

Subsequently, teachers facilitate content knowledge at the school level, Deng (2007) together with Deng and Luke (2008) posited that knowing the content of secondary school science is at the heart of these five interconnecting dimensions. Each of them is explained below:

(i) The logical dimension

The curricular content that makes up the secondary school subject's landscape is composed of a body of concepts and principles that make up the logical dimension. This is accounted for in the following excerpt:

> *"On the logical plane, knowing the subject matter of a secondary-school science subject entails knowing the concepts and principles that secondary-school students are supposed to know about particular topics in the school science curriculum. These concepts and principles cannot be fully equated with those representing what professional scientists need to know within the sphere of an established academic discipline; they ought to be seen as standing for what scientifically educated adults need to know in order to live and participate in a world increasingly shaped by science and technology. They are selected and formulated primarily for the purpose of teaching and learning, standing for an initial stage of introduction to scientific culture … Knowing the logical dimension also entails knowing the relationships among these concepts and principles. Furthermore, it entails knowing how these concepts and principles relate to the concepts and principles in other secondary-school subjects…*" (Deng, 2007: pg. 521).

There are two parts in the excerpt above, that is the body of facts *(which is not equated to what a professional scientist needs to know)* as well as the interrelations between the concepts that make up the body of facts in science. It must be taken into consideration that the concepts and principles to be taught only stand for the product of knowing, this is what Joseph Schwab called a substantive structure of the content (Schwab, 1978). They do not represent the process of knowing or coming to know, i.e. syntactic structure (Schwab, 1978). The key point driven by the authors is that the subject matter in academic disciplines is related to that of school subjects through a determined 'measure' of the concepts and principles of a discipline and the emphasis on the connections within these concepts. This is an important insight highlighted for noting in our argument for a new version of content knowledge appropriate for science teachers.

(ii) The psychological dimension

This dimension speaks to the developmental considerations of the emergent minds of the learner. For Deng (2007), this involves being aware of how the ideas and concepts to be taught can be developed based on the preferences, life experiences, and prior knowledge of the learners.

(iii) The epistemological dimension

This refers to the ways of knowing, the generation and validation of new knowledge within a discipline. It is an element of knowledge described in Schwab's declaration of the structures of academic discipline as syntactic structure (Schwab, 1978). In science education, the syntactic structure is associated with the knowledge speaking to the knowledge of the inquiry processes such as scientific investigations.

The key point made by Deng and Luke (2008) is that school subjects furnish the way to learning scientific inquiry. While at the school level, the kind of scientific inquiry conducted is introductory, it nonetheless provides the necessary entry into the development towards a full-blown scientific inquiry as experienced in academic disciplines. Here again the issue of a determined measure of scientific inquiry surfaces. To further note, science inquiry as recognized dimension linking the two content knowledge versions.

(iv) Socio-cultural dimension

Society, in general, has expectations about what schools should do. This dimension includes the knowledge of "*what significance the related concepts, key issues, and related issues have for students, society, and the world at large"* (Deng, 2009). Secondly, it includes the knowledge of how might these concepts and issues ascend from countless socio-cultural contexts.

(v) Pedagogical dimension

This refers to the pedagogical aspects of teaching, covered by many teaching theoretical frameworks, particularly PCK as the widely accepted theoretical construct describing teacher knowledge for teaching science. While related to the discussion of this study, its existence as a dimension through which the uniqueness of each content could be discussed is, however, outside the scope of this study.

All these dimensions, taken as a whole, constitute the landscape of the formation of school subjects from the discipline. They together provide an account of how this landscape can be established, formulated, organized, and even linked with other secondary school subjects (Deng, 2007). In addition to the work of Deng and Luke (2008), the work of Dreher et al. (2018) in mathematics education also shared insights into the categorization of the dimensions of difference between academic disciplines and school subjects.

Dreher et al. (2018) conceptualized teacher knowledge for teaching mathematics as School-Related Content Knowledge (SRCK). In doing so, the authors identified three features leading to the full understanding of SRCK, these are

(i) *"curriculum development and fundamental ideas"*
(ii) *"transformation of mathematical content for teaching purposes"*
(iii) *"mathematical background theories"*

These theoretical considerations reveal some synergies with the dimensions described by Deng (2007; 2009) and Deng and Luke (2008). The first theoretical feature is found on the logical plane of the fundamentals of the discipline. The second one is a combination of psychological and pedagogical dimensions that pertains to the transformation of disciplinary mathematics into school mathematics. The last consideration is on the epistemological and the social dimensions of the mathematical background theories.

Dreher and colleagues argued that teachers need specific content knowledge to make connections between academic mathematics and school mathematics. According to them, it is conceptual mathematics about the interrelations between academic and school mathematical content. So, for these authors "*[School Related Content Knowledge]… differs from academic content knowledge as well as from pedagogical content knowledge … and goes beyond school mathematics"* (Dreher et al., 2018, pp. 329 - 330). This is however understood not to mean that this kind of special content knowledge is lesser than any other clinical academic mathematics needed in other mathematical settings beyond teaching.

Emerging insight from the Second Theme.

In summary, this second literature construct reveals that while different to the first one, it is, however, building on it by describing succinctly how the difference between the content knowledge of academic disciplines and school subjects could be described through the five dimensions. The insights that are drawn towards building the conceptualization of the construct defining a version of content knowledge appropriate for science teachers are herein presented.

(i) Accepting that school science is a simplified or transformed version of the academic disciplines – implies that those who teach it, need to know the nature of the makeup of the transformation process. An assumption is held here, that transformation in this case refers to a different form from the meaning of Shulman's pedagogical transformation of disciplinary CK. Transformation here is associated with sifting, picking, choosing and leaving out some things to lead to a simplified version.

(ii) Furthermore, in acknowledging that the transformed version is not the full academic discipline, but a measure, then it suffices to expect those who are to teach the determined measure to understand what constitutes the measure and what does not, and the consequences of the process.

(iii) The distinct content knowledge for teachers is a 'determining measure' of the content in academic disciplines. The 'determining measure' refers to the fundamental concepts and principles of the discipline referred to in the logical dimension described by Deng (2007). This insight builds on the first literature construct alluding to the importance of knowing what is included and excluded when the school subject curriculum is planned.

(iv) The connections between the concepts contained in the 'determined measure of CK' are important.

(v) The exposure of prospective teachers to the syntactic structure of the content, being the scientific enquiry is important.

(vi) In addition to a focus on developing conceptual knowledge and scientific enquiry competencies, consideration for the societal expectations embodied in the goals of education for the country and community are to be included. These provide the context (historical and cultural) in which the substantive and the syntactic knowledge of a discipline may be discussed and taught. It is in these elements that the potential of education is released, as students develop a sense of possibility and active participation in providing solutions to local and global challenges as they hear and identify with previous dilemmas, historical events and discoveries.

(vii) When describing the nature of this construct, the psychological and pedagogical dimensions are not significant as they focus largely on the methods of teaching and not the nature of pure content knowledge and its development.

The next section discusses the last theme about specialised knowledge for teaching school subjects with a particular focus on mathematics as more empirical has been done in this field.

5.2.3 Specialised content knowledge for teaching mathematics

The last literature construct was drawn largely from the mathematics education research that explored the specialised knowledge for teaching. To begin with, Ball et al. (2008) hypothesized and validated a Mathematical Knowledge for Teaching framework (MKTF). In their work, Ball and colleagues developed measures of mathematical knowledge for teaching. Their line of research indicated that at least two empirically discernible subdomains within their framework exist; these are, subject matter knowledge (SMK) and pedagogical content knowledge (PCK).

The components of their framework were later explored by Chikiwa et al. (2019) to illuminate them and their interconnectedness in elementary mathematics. On the other hand, Sahidin et al. (2019) introduced the MKFT in teaching geometry in secondary school and argued for it to be conceptual-based. Speer et al. (2015) on the other hand explored the MKFT components between elementary mathematics and secondary mathematics to show that they differ given the level of operation.

In all the studies mentioned above, there is an agreement about the distinction between SMK items from PCK items. Figure 5.2 shows these domains of the framework located within the two of Shulman's categories of teacher knowledge domains, mentioned earlier. However, for the sake of this work, the focus is given purposefully to SMK (CK) components as they lie in the logical plane described by Deng (2007). These components are Common Content Knowledge, Horizon Content Knowledge and Specialised Content Knowledge

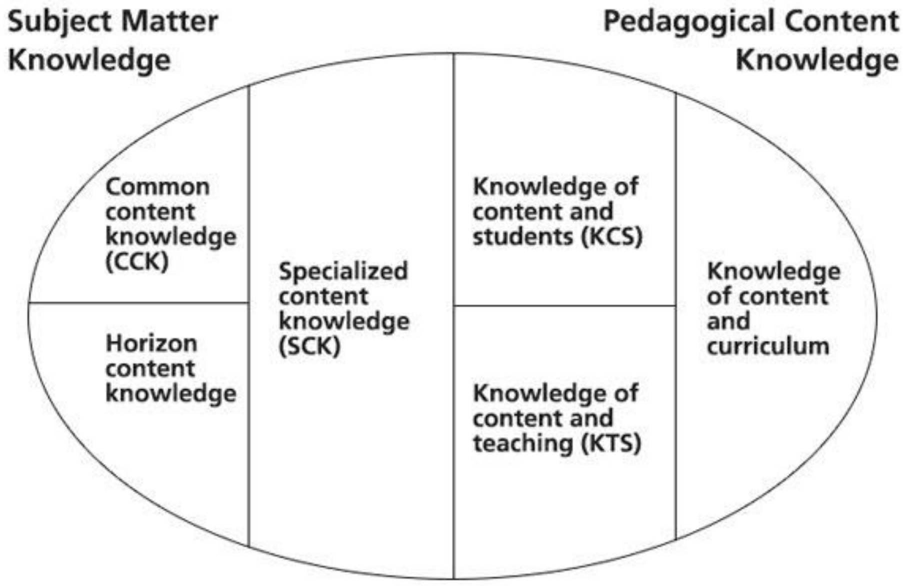


Figure 5.3: Domains of mathematical knowledge for teaching

Briefly, according to Ball et al. (2008), supported by Chikiwa et al. (2019), Common Content Knowledge is defined as mathematical knowledge known in common with others who know and practice mathematics in other settings besides teaching. In supporting this description of Common Content Knowledge, Hill et al. (2008) added that it is viewed as "*knowledge that is used in the work of teaching in ways in common with how it is used in any other professions or occupations that also use mathematics"* (p. 377), hence it is taken to be common.

However, as much as Common Content Knowledge cuts across a larger spectrum of the discipline of mathematics, it must be comprehended within the scope of and the context of teaching. The latter view is held by Bansilal et al. (2014) who asserted that Common Content Knowledge is the knowledge that teachers themselves mediate with the learners and knowing and doing mathematics in ways that help them teach mathematics.

The second component is Horizon Content Knowledge. it represents the knowledge that applies across the landscape of the subject. Ball et al. (2008) described Horizon Content Knowledge as:

> "*…an awareness of how mathematical topics are related over the span of mathematics included in the curriculum. First-grade teachers, for example, may need to know how the mathematics they teach is related to the mathematics students will learn in third grade to be able to set the mathematical foundation for what will come later. It also includes the vision useful in seeing connections to much later mathematics ideas*." (Ball et al., 2008, p. 403)

According to these authors, this facet of content knowledge is neither common nor specialized. Secondly, it is not just about curriculum progression, but rather having a sense of the larger mathematical environment of the discipline, orienting instruction to the discipline, and making judgments about what is mathematically important (Jakobsen et al., 2012). In this study, the interpretation by Speer et al. (2015) is of interest. These authors described Horizon Content Knowledge as knowledge of the mathematics that follows or could follow the mathematics being taught at a particular grade or phase. For a clear understanding, this varies depending on grain size, it can be the knowledge that connects from one topic to another or even concept to concept. In other words, Horizon Content Knowledge encompasses the understanding of how topics or concepts connect or relate to others throughout the subject in the curriculum, this includes the curricular order of topics and reasons for that particular order. In science education, this description is similar to what Mavhunga and Rollnick (2013) called curricular saliency.

The last component under CK items is Specialised Content Knowledge, and it is understood as the knowledge that reveals the key mathematical ideas in class (Ball et al., 2008). This component of CK was introduced to designate a kind of mathematical knowledge not needed for any setting other than mathematical teaching. Further review of the literature revealed that Specialised Content Knowledge refers to the "*mathematical knowledge that allows teachers to engage in particular teaching tasks, including how to accurately represent mathematical ideas, provide mathematical explanations for common rules and procedures, and examine and understand unusual solutions methods to problems*" (Hill et al., 2008, p.378).

All three subject matter content components by Ball and colleagues are linked to the knowledge of teaching endorsed at the logical dimension described earlier in Deng (2007).

Emerging Insight from the Third Theme.

Common content knowledge is considered to describe the "fundamentals of the discipline" in thinking about the CK version appropriate for teaching science. This begins to shed light on the 'measure' of academic discipline content knowledge that is considered appropriate for teaching the school subject. This knowledge consideration of the construct at a logical dimension describes valid propositional facts embodied in scientific concepts, principles, laws, etc. It is called fundamental in the sense that it is taken as the knowledge that all persons who are scientifically inclined should possess. It is fundamental because any other clinical profession that uses science as a discipline builds on it.

Secondly, horizon content knowledge endorses the findings from Deng's work (2007) that emerged in the second literature construct about the "interconnections between the concepts". This knowledge component outlines an account of how the concepts that make a particular topic connected in a broader horizon of the topic, the subject and other subjects of a curriculum. Pulling all the insights derived from the three themes as findings from the systematic literature review, a picture revealing the structural composition of the construct emerges. The discussion on the pictorial representations ensues below.

The specialised content knowledge endorses the teacher's knowledge of what aspects of the discipline are sifted in the formation of the school subject and has been seen as important in teacher preparation. This creates an awareness of the tensions and differences that therefore exist as a result of this extraction process. For this CK version appropriate for teaching science, this denotes a speciality in knowing. Hence such knowledge can be regarded as specialised content knowledge. In the next sections,

In the next section, the synthesis of these findings provides an emerging conceptualisation of the theoretical construct describing the CK version appropriate for teaching school science. This construct is termed Teacher-related Science Content Knowledge (TerSCK)

5.3. The emerging conceptualization of TerSCK

The first theme was about the relationship between academic discipline and school subjects. The nature of the content knowledge conceptualized as TerSCK is derived based on how the academic discipline is related to the school subject and by extrapolations, how the two contents embodied by each relate. This naturally positions TerSCK between the two ends of subject matter content knowledge. In between the continuum, the most attractive nature of the relationship for TerSCK was that of a continuous model by Stengel (1997) combined with the different but related dialogical model by Catling and Martin (2011). This combination appreciated that both serve different educational and social purposes and develop differently. In addition, Linking TerSCK to this kind of a relationship between academic discipline and school subject, logically positioned the content knowledge appropriate for science teachers at the middle of the continuum, see Figure 5.4. This requires teachers to straddle their understanding from the academic discipline for appropriateness for school teaching purposes.

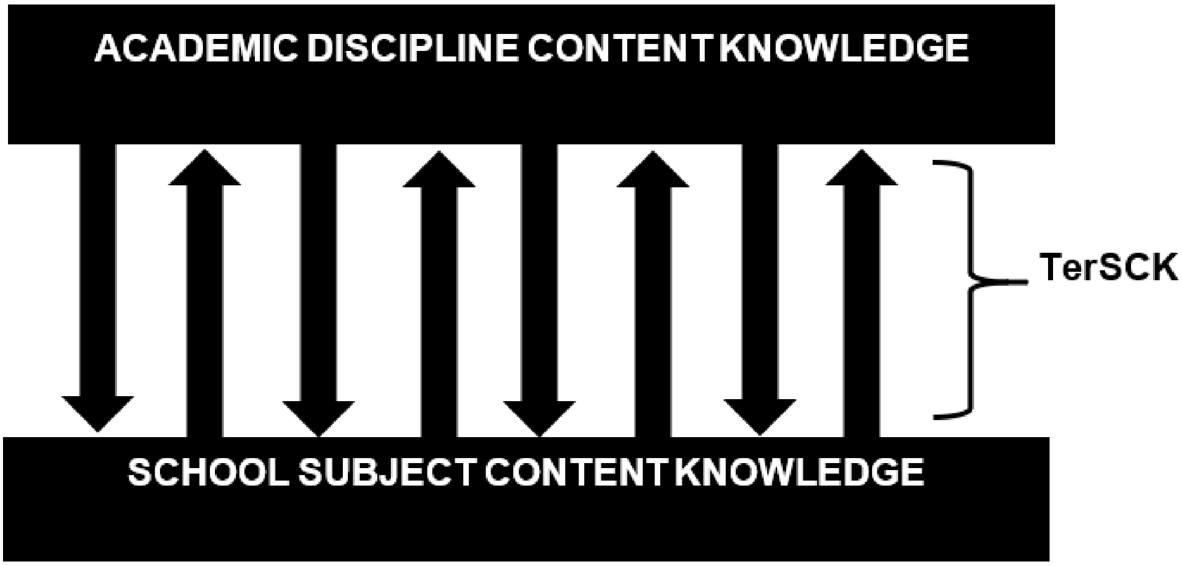


Figure 5.4: Positioning TerSCK between academic discipline and school subject content

The second theme offered a conceptual framework by Deng (2007) from which three content-specific relational dimensions have been adapted for the conceptualisation of TerSCK. These are the logical, epistemological and social relational dimensions. They have been adapted in this study as broad dimensions that describe the nature of TerSCK. Purposefully, the pedagogical and the psychological dimensions have been left out in this conceptualisation as they are more leaning towards the process of transforming content knowledge for teaching purposes. They are linked to the PCK knowledge domains Figure 5.5 shows this relationship through these dimensions.

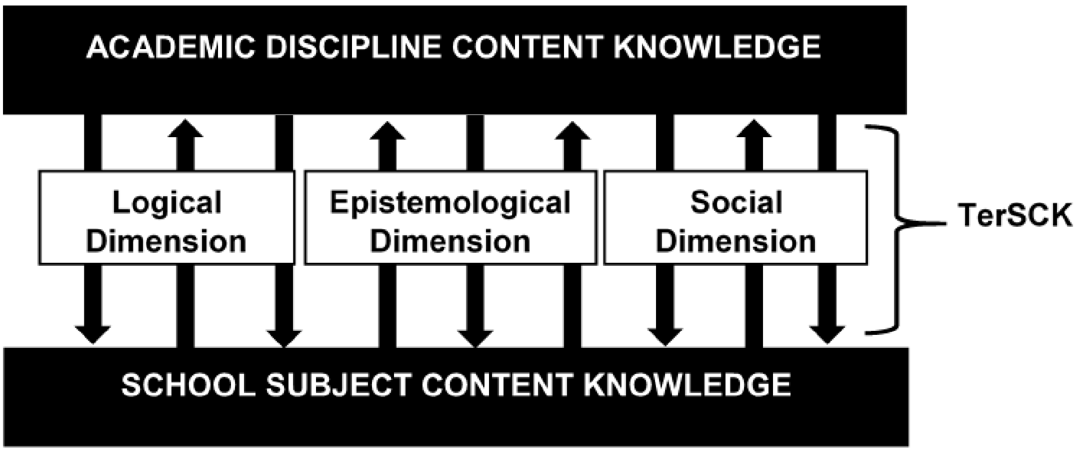


Figure 5.5: Relational dimensions of TerSCK

At the logical dimension, the focus on the discipline's fundamental concepts and principles where the content leading to discipline-based research and new knowledge is left out implies that the distinct content knowledge for teachers is a 'determined measure' of the content taken from academic disciplines. However, the determined measure is to be understood with special attention to the interconnections between the concepts contained within it. Furthermore, it is to include knowledge of the tensions and constraints resulting from the foresaid process of extracting content knowledge from the academic discipline into a school subject. This makes the determined measure different from both the original academic discipline format as well as the secondary school science. It becomes distinct through the meta-knowledge element of understanding the consequences of the extraction process of the fundamental concepts and principles, an aspect that denotes speciality.

At the epistemological dimension, there is a retained emphasis on understanding the syntactic structures used to advance knowledge to be at the present and future forms. This refers to the discipline's ways of inquiry and knowledge generation. At the social dimension, there is an explicit focus to connect the learning of the fundamental principles to current social developments and priorities. In today's society, digitalization and artificial intelligence are the major waves transforming economic activities and social interactions. Education is not to be spared from these reformations and developments.

Emerging from the above insights, TerSCK is redefined as the construct defining the nature of the content knowledge emerging from the continuous and dialogical relationship between the academic discipline and school science subjects, fittingly appropriate for science teacher preparation and professional development. Subsequently, we look at operationalizing TerSCK by translating these constituent relational dimensions into a curriculum for science teacher preparation. This operationalisation needed to occur through translation into a powerful curriculum through a particular theory of content.

5.4 Aligning TerSCK with powerful knowledge and theory of content

Before providing an argument that unpacks what the complete theoretical construct of TerSCK may look like, it is important to lay the groundwork that locates TerSCK within the broader debates in education about curriculum theories and the related theory of content as alluded to in the introduction. TerSCK is embedded within the view of 'powerful knowledge' made explicit by the work of Young and Muller (2013), and Muller and Young (2019) as a curriculum theory. More specifically, the refined focus considers powerful knowledge as "knowns" and "knowings" described by Carlgren (2020).

The idea of powerful knowledge acknowledges the need for specialized knowledge as a means for differentiating our experiences of the world and knowledge within it. It is an idea that is embedded in the assertion that specialized knowledge is emergent and offers a route for human beings to progress their knowledge in a specific field (Young & Muller, 2013).

'Powerful knowns and knowings" extends the idea of powerful knowledge further to blur the traditional differentiation of specialized knowledge as propositional (theory) or practical (skills) knowledge into a new perspective of referring to knowledge as just powerful knowns and knowings (Carlgren, 2020). By considering knowledge as knowns and knowings, not only is the 'knowing that' and 'knowing how' included, but also 'knowing what' which opens up the idea of knowing by the association in a particular context. Knowledge as knowns and knowings considers also the knower and the contexts in which the known is operationalized in some function.

What ties together these versions of knowledge is the shared understanding that powerful knowledge is meant to cultivate humans to unlock their potential to go beyond mere understanding of the current content. Through powerful knowledge, humans develop the competence to be active critical thinkers who are active participants in solving real social challenges and future problems (Deng, 2021). So, understanding curriculum development from the perspective of powerful knowledge places a demand for unpacking the TerSCK theoretical construct beyond just the knowledge of content that is located between academic discipline and school subject versions. It goes further to also unveil and bring to view the kind of cultivating potential that it is positioned to offer teacher education and educators.

In describing the distinction between CK of the academic discipline and that of the school subject, Deng (2009) brought to the attention the theory of content behind school subject matter using the case of *Liberal Studies* in Hong Kong. He argued that it is important for prospective teachers to be exposed to the theory of content behind the subject matter knowledge they are to teach. Translating the described theory of content behind the school subject content will bring to view the full nature of the version of content knowledge for teaching, which is called TerSCK in this study.

So, for this task, the work of Schwab (1973) and (Deng, 2021) that described a curriculum that embodies the notion of powerful knowledge as knowns and knowings in describing TerSCK was useful. (Deng, 2021) has posited that Schwab's model tackled the task of translating scholarly materials, the embodiments of disciplinary knowledge into the curriculum. For this process, Schwab (1973) identified three faces that bring forward a discussion of the theory of content behind curriculum thinking and planning. These are described briefly in the next section.

(i) Purport face

Through the purport face, Schwab referred to the educational potential espoused in a historical account of a past discovery, event, a moral or social dilemma or a scientific report on ways of classification or discoveries (Schwab, 1973). Exposure to such an account is likely to broaden their knowledge horizon, reconsider perspectives, and cultivate moral sensitivity (Deng, 2021).

(ii) Originating discipline face

Through the originating discipline face, Schwab referred to the ways of generating new knowledge or verifications within a discipline, including enquiry and investigations. Exposure to these processes positions students to access the educational potential to develop independence in critical thinking, evaluation of claims, creation of rebuttals and establishing limitations.

(iii) Access Discipline face

Through the access discipline, Schwab referred to the educational potential espoused in the exposure to the different ways in which different disciplines, other than the original discipline, generate and validate knowledge. Such exposure cultivates pragmatic thought and action in knowledge advancements.

For Deng (2021), the above-mentioned three faces form a powerful theory of content that underpins curriculum planning. Its 'power' lies in practically bringing to the fore a perspective on what constitutes the educational potential of content and a set of categories to ascertain that potential. Thus, Schwab's theory of content was applied to the coalescence of insight about what constitutes appropriate content knowledge for science teacher preparation. Figure 5.6, presents a visual way in which the three content-specific relational dimensions of TerSCK link to the three faces.

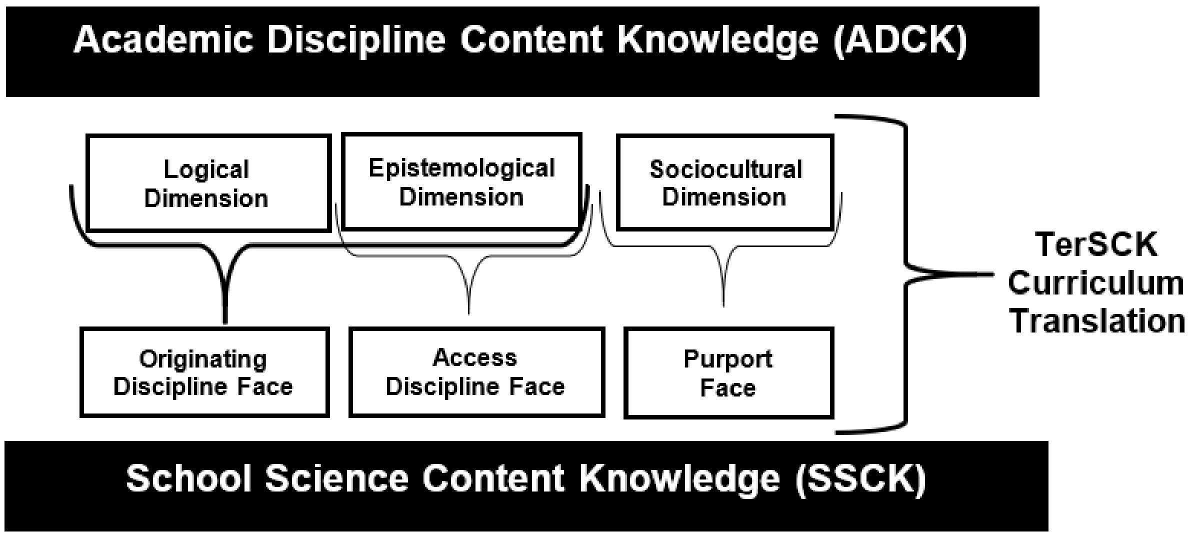


Figure 5.6: Translating the dimensions of TerSCK into a powerful curriculum

The logical dimension could be embodied in the education potential espoused by the originating discipline face. The epistemological dimension could be linked to the education potential espoused in both the originating discipline and the access discipline face. The "determined measure" of content knowledge, mentioned earlier as emerging from the logical dimension, is comprised of the fundamental principles and concepts, the connections across the concepts as well as the understanding of the tensions and limitations resulting from the extraction of the fundamentals from the academic disciplines. This content could be engaged through approaches that promote both their conceptual understanding and critical thinking competence through the enquiry and investigation methods of science.

By having the epistemological dimension of TerSCK including both originating and other disciplines' different ways of knowing, an opportunity for the development of the potential for freedom of thinking and prudent problem solving is being embodied. Lastly, the social dimension of TerSCK is linked to the purport face. This link locks in the opportunity to develop educated citizens who are encouraged to apply their knowledge to social issues seeking alternative solutions and changing destructive pre-set perspectives.

The synergy across the content-specific relational dimensions of TerSCK and Schwab's powerful curriculum faces generated elements of the resulting curriculum for teaching TerSCK shown in Figure 5.7 below.

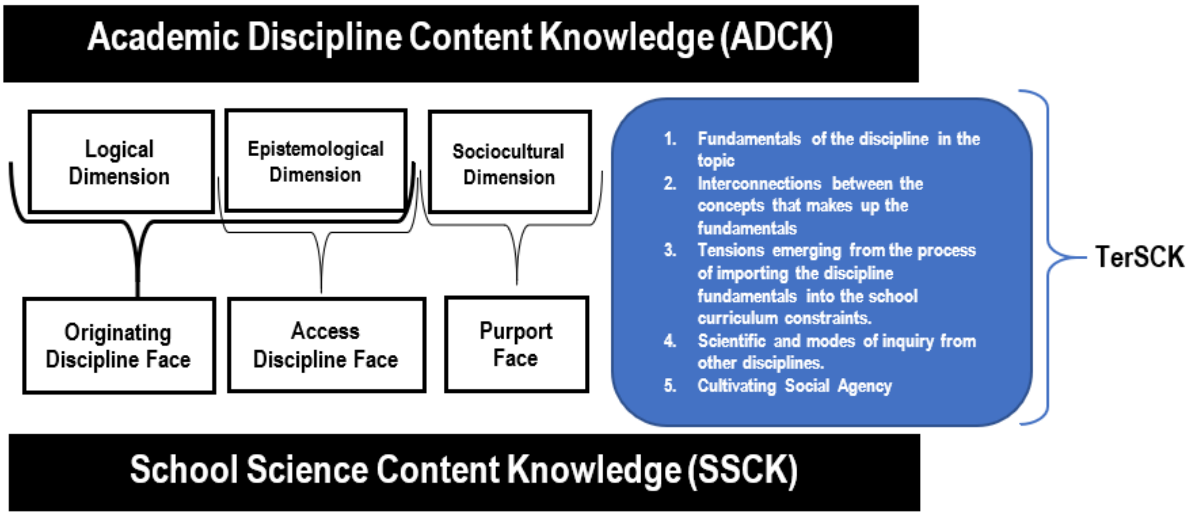


Figure 5.7: Comprehensive TerSCK curriculum model

The above description points to this distinct knowledge having a mediating role across the academic discipline and school science subject. Despite having a mediating role, this remains to be content knowledge and it differs from the pedagogical knowledge aspects which describe the process of knowledge transformation (Shulman, 1986). It is therefore called TerSCK.

5.5 Conclusions

This Chapter completes the first phase of the whole study, which is the qualitative argument that presents a conceptualization of the TerSCK theoretical construct. To begin with, the systematic review opened up the idea that academic discipline content is conceptually different from school science content, as shown by Deng (2012) illustratively using the Harres epistemology of science and Dewey's logical-psychological distinctions. In addition, the review pointed to the prevailing kinds of relationship between academic disciplines and school subjects. Amongst these, this chapter has leaned more on the position taken by Deng (2007) that these two are continuous, and different but related dialogically.

In addition, the results of the review pointed to the logical dimension which encapsulates determined measure of content as fundamentals of the discipline in the topic. This dimension also included the interconnections between the concepts of the fundamentals and the tensions that emerge as the result of importing concepts from the academic discipline to the school subject. This dimension provided the basis for describing the substantive aspects of TerSCK as described in the theoretical framework in Chapter 2. The epistemological dimension opened up to the scientific and other discipline-specific modes of inquiry in knowledge development, rebuttals and verification. Lastly, the social dimension is linked to developing teachers who are cultivated agents of social change through exposure to the historical development of concepts in the discipline. From Deng's framework, both the pedagogical and psychological dimensions were left behind as they are more linked to the knowledge of the PCK.

Beyond the meta-synthesis of the systematic review, this work has also argued for the consideration of powerful knowledge through an explicit theory of content. This was made possible through the translations to the curriculum through the three faces, i.e.: purport face, originating discipline face and access discipline face (Schwab, 1973). Consequently, the conceptual argument was aligned with the views of powerful known and knowing, as described by (Carlgren, 2020) to blur the line between propositional and practical knowledge.

In conclusion, these two sequential processes enabled this chapter to provide answers to the first research question about the conceptualization of the theoretical construct that describes the nature of content knowledge for teaching school science. It is visibly conceptualized distinctly from academic discipline content and the school science content on the following bases. Firstly, it considers a determined measure of content in the academic discipline as fundamentals in the specific topic. Secondly, it focuses largely on the interconnections between the concepts in the discipline. Thirdly, it creates awareness of the whirlpools in teaching concepts by highlighting the tensions and differences emanating from the process of importing the content from the academic discipline to a school subject. Lastly, it is conceptualized through a powerful curriculum that bears the power to cultivate teachers who are agents of social change through exposure to the historical development of concepts in the discipline. As a result of this conceptualisation, TerSCK is defined as content knowledge that enables the process of pedagogical reasoning through the knowledge of five elements. These are:

(i) Fundamentals of the discipline in the topic
(ii) Interconnections between the concepts that make up the fundamentals
(iii) Tensions emerged from the process of importing the discipline fundamentals into the school curriculum constraints.
(iv) Scientific and modes of inquiry from other disciplines.
(v) Cultivating Social Agency

The next chapter uses these five elements to define the performance objectives of the TerSCK theoretical construct. This was done to illuminate the elements of the construct through a piece of curriculum content using a case of organic chemistry. This process was important to develop the content that represents TerSCK leading to the empirical validation of the construct.

CHAPTER 6 DESIGNING THE TERSCK INTERVENTION: A CASE WITH ORGANIC CHEMISTRY

This chapter builds and extends on the results of the conceptual argument presented in Chapter 5 to describe the comprehensive nature of the TerSCK through a piece of curriculum content. It begins by relooking at the key knowledge elements that describe the nature of TerSCK from the conceptualisation earlier. After that, each of the TerSCK elements described in Chapter 5 is taken through the content of organic chemistry to see what it would look like from the content point of view. Included in this chapter is a set of performance objectives for each TerSCK element. These were important for the development of the curriculum content of an explicit TerSCK intervention that seeks to develop the quality of TerSCK in science pre-service teachers. As a result, this chapter presents the structure of the intervention and a brief description of a teaching approach that underpins the intervention, herein called horizontal synchronization.

6.1 Introduction

The previous Chapter has laid the conceptual argument for the theoretical construct referred to as Teacher-related Science Content Knowledge (TerSCK). The model that pictorially represents the construct was also presented with a corresponding curriculum translation process borrowed from Schwab (1973). Further to that, this thesis has been positioned along with the views of powerful knowns and knowing which discourages the distinction of knowledge as propositional or practical. It simply regards knowledge as powerful "knowns" and "knowings" by the knower in a particular context (Carlgren, 2020).

Drawing from the qualitative findings in Chapter 5, the nature of TerSCK was found to be described by five (5) distinct elements. These elements were then situated purposefully with the faces of the powerful curriculum planning model explicated by the seminal work of Joseph Schwab, Schwab (1973) in developing what (Deng, 2021) regarded as a powerful curriculum.

From the conceptualisation in Chapter 5, firstly, TerSCK is defined within a determined measure of "pure" content knowledge appropriate for teaching located at the logical plane. This item is called the fundamentals of the discipline in a specific topic (Duis, 2011). It points to the sufficient amount of subject matter content to be drawn out of the main academic discipline and appropriate for training those who will teach the school science curriculum. Secondly, out of the fundamentals, the interconnections between the concepts were found to be of importance when describing TerSCK, a view strongly coming from the subject matter at a horizon by Ball et al. (2008).

Thirdly, when the content is imported from the academic discipline to the school subject's curriculum, some aspects are left behind. As a result, these constraints create tensions and differences in how we deal with the fundamentals of the academic discipline in the school subject curriculum. So, it was found to be important to expose PSTs to such tensions within their university training. The fourth element relates to the importance of exposure to the epistemologies of the science discipline, particularly the inquiry through which new knowledge is generated and validated (Furtak et al., 2012). Within this exposure, TerSCK argued equally for the inclusion of other modes of inquiry in developing and validating new knowledge through the access discipline.

The last element on the social dimension argued for the consideration of learning the discipline fundamentals from the perspective of the societal needs driven by the previous dilemmas or limitations of the past to realise its cultivating potential. This cultivating power envisages pre-service teachers who will be critical thinkers, developers of knowledge, problem solvers and agents of social change.

Thus, in light of the above elements, this Chapter initiates the second phase of the study, which is the validation of the TerSCK theoretical construct. In this chapter, an example of TerSCK in the topic of organic chemistry is constructed following the five knowledge elements. To do this, the case study research approach in which an intervention is developed to explore the empirical validity of the construct was followed (*cf.* Chapter 3). However, the current chapter will only culminate into a piece of curriculum content and performance objectives that subsequently undergirds the TerSCK intervention. It is the next Chapter 7 that will report on the development of a valid and reliable instrument to capture the quality of TerSCK and argue for its statistical validity through a set of fit statistics and suitable reliability indices.

6.2 Content organized as TerSCK elements in organic chemistry

In the following sections, the notion of TerSCK in organic chemistry is described using the five elements extracted from the previous chapter. In the order of their appearance, these are:

(i) Fundamentals of the discipline in the topic
(ii) Interconnections between the concepts that make up the fundamentals
(iii) Tensions emerged from the process of importing the discipline fundamentals into the school curriculum constraints.
(iv) Scientific and modes of inquiry from other disciplines.
(v) Cultivating Social Agency

To begin it all, the next section describes the content of the intervention illustrative of TerSCK in Organic Chemistry using the five elements of the construct. The first one is on the determined measure of content describing TerSCK – the fundamentals of the discipline in the topic.

6.2.1 Fundamentals of the discipline in a topic

The first element in structuring TerSCK in a topic is to determine the fundamentals. The process of determining the fundamentals of a discipline in a specific topic is not linear and simple since the knowledge of science is dynamic and flexible (Lederman, 2013). However, the work of the American Chemistry Society (ACS) laid the foundation for what is regarded as fundamental knowledge in organic chemistry. In 1972 and 1976, two reports were produced by the organic subcommittee of the ACS. The work of the curriculum subcommittee was largely concerned with the nature of organic chemistry at the introductory level and the interconnections of organic chemistry concepts with other areas of chemistry (ACS, 1972; Bunce, 1976).

Two types of outlines were developed, the topical and the principle outline in both reports. In this work, the topical outline was adopted as it was easy to identify the themes rather than the principle outline which was too exhaustive and lengthy. The topical outline considered was further supplemented with other similar pieces of work done subsequently with the same topic. Firstly, Duis (2011) explored the organic chemistry educators' perspectives on fundamental concepts and associated misconceptions. Further to that, Ashenhurst (2019) explored how concepts build up in an organic chemistry university course. To synthesise the content proposed herein as fundamentals in the topic of organic chemistry the comparative analysis of the works of these authors (Ashenhurst, 2019; Duis, 2011) alongside the topical outline of the ACS was useful.

So, what came out of my analysis in this study was a determined measure of what is regarded as the fundamentals of the discipline of organic chemistry. Table 6.1 summarizes these topical themes and their sub-concepts. In coming to the summary shown in Table 6.1, a few differences were identified across the work of the two authors and the ACS report. In cases where the reports and subsequent articles were not in agreement, those concepts were not included in the list of fundamentals. Such a decision was made concerning the South African Curriculum Statement espoused by the Department of Basic Education (2019). For example, chirality, spectroscopy, and hazards in organic compounds were among these concepts that were not cut across from the report and the subsequent articles and thus were not included in the list of fundamentals.

Table 6.1: Fundamentals of the discipline in organic chemistry

1. **Chemical Bonding in Organic Compounds**
    - Structures
    - 3-D Nature & VSEPR
    - Bond breaking and making in organic synthesis
2. **Nomenclature**
3. **Functional groups chemistry**
    - Hydrocarbons
    - Halogen-containing compounds
    - Oxygen-containing compounds
    - Carboxyl acid derivatives
4. **Isomerism**
    - Structural (chain, positional & functional)
    - Stereoisomerism (geometrical)
5. **Physical Properties of organic compounds**
    - Molecular structure and polarity
    - Boiling point, melting points & vapour pressure
6. **Reactivity & Reaction mechanism**
    - Reactivity series of simple organic compounds
    - Substitution, elimination and addition
7. **Organic Acid-Base Chemistry**
    - Acid-base Theories (Arrhenius, Bronsted-Lowry & Lewis)
    - Organic acid-base strengths

- Organic acid-base reactions

8. Organic Redox reactions

- Oxidation numbers
- Organic reduction and organic oxidation

The choice of the fundamentals in Table 6.1 was also supported by Wheeler and Wheeler (1979) in their work about the introductory undergraduate curriculum in organic chemistry. These authors asserted that:

> *"While the specific topics to be covered in the beginning…. Should include the nomenclature and structure of hydrocarbons, alcohols, ethers, alkyl halides, acids (and their derivatives), aldehydes and ketones. It would be necessary to do enough stereochemistry to understand additions to double bonds, eliminations to form alkenes and nucleophilic substitutions. Fundamental reactions and their mechanisms would include electrophilic addition (halogens, hydrogen halides, and water) to, and hydrogenation of, double and triple bonds, nucleophilic substitution at saturated (SN_I and SN_2) and unsaturated carbon (interconversions of carboxylic acids and their derivatives), Grignard reagents and their reactions with aldehydes and ketones (nucleophilic addition at unsaturated carbon). Reduction of carbonyl compounds to alcohols and oxidation of alcohols should be mentioned"* (Wheeler & Wheeler, 1979, p. 479)

Drawing from the arguments above, the ensuing analysis captured in Table 6.1 represents a reasonable sense of the fundamentals for knowing the content of organic chemistry for teaching purposes. However, acquiring powerful knowledge requires going beyond just a mere acquisition of propositional content seamlessly into also knowing their origins, their applications and their relation to contexts (Deng, 2021).

The second element in structuring TerSCK is to determine how the concepts or themes identified under the fundamentals connect within the topic and outside the topic. Thus, the next section describes how most of these topical concepts in organic chemistry connect using a case of two fundamentals, viz.: functional group chemistry and isomerism. These two fundamentals were chosen deliberately because of their flexibility to allow the discussion of others such as chemical bonding, nomenclature, etc.

6.2.2 Interconnections between the fundamental concepts in the discipline

Pre-service teachers need an awareness that as much as organic chemistry concepts are found within a particular topic, they however do not exist in isolation. They relate and connect to other concepts from other topics within organic chemistry and other chemistry topics. Such knowledge is important to be revealed for the teacher education curriculum to cultivate teachers who look for connections across topics when they teach secondary school science.

Examples of such concept interconnections are presented in Table 6.2 below. Column 2 identifies these concepts and column 3 gives a brief description of the nature of connections. Note that in Table 6.2, only two fundamentals of organic chemistry are considered to reveal these connections, these are (i) functional group chemistry, and (ii) isomerism.

Table 6.2: Interconnections between the concepts in the two fundamentals

Organic Chemistry	**Other concepts Topics**	**Nature of some of the connections**
Functional Group Chemistry - Hydrocarbons - Halogen containing compounds - Oxygen-containing compounds - Carboxyl acids and derivatives	- Chemical bonding – bonds order, length, strength, polarity, sp hybridization & VSEPR theory - Atoms & periodic table - Atomic combination and structures - Molecular formulae - Homologous series - Nomenclature - State of matter, physical properties and intermolecular forces.	The bond order between carbon atoms, atoms or groups of atoms determines the type of functional group in a molecule. The functional group determines the physical and chemical properties of organic compounds The functional group, molecular structure, and geometry determine the homologous series of organic molecules and the dominant intermolecular forces
Isomerism - Structural isomers - Stereoisomers	- Functional groups - Lewis & Couper structures - Molecular formulae and mass - Bond types, Energy and intermolecular forces	Isomers of the same molecules can be identified through different structural formulae, so the knowledge of atomic structures is important for this identification.

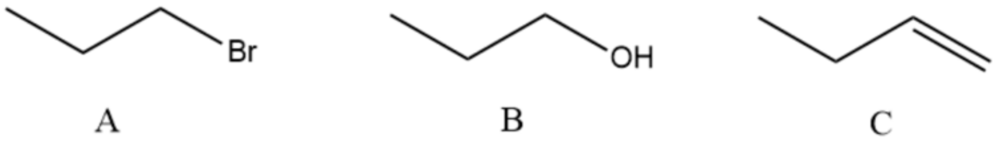
Organic Chemistry	Other concepts Topics	Nature of some of the connections
	- Nomenclature	Isomers have the same molecular mass and different IUPAC names

The links between concepts in key science topics have been given some kind of attention in pre-service teacher education research. However, these are not easy to evaluate at the end of a teaching program. Available literature has employed concept maps in chemistry education to investigate how students articulate the links if any in their understanding of key concepts in chemistry topics (Earl, 2007; Pendley et al., 1994).

However, there is a need to find other innovative ways in which these interconnections can be brought to view during a practicum course as well as during assessment. Trigwell and Sleet (1990) introduced creative exercises (CEs) and argued that they assist learning and help students see links between discrete chunks of information. This in turn may lead to an improvement in their recognition of links between concepts and problem-solving skills (Trigwell & Sleet, 1990).

Recently, Mai et al. (2021) have used CEs as an evaluation tool in an undergraduate first-year organic chemistry course. One of the fundamentals in structuring TerSCK in this thesis is functional group chemistry. The CE designed by Mai et al. (2021) has the potential of illuminating this fundamental for TerSCK purposes, see Figure 6.1.

Consider the following molecules



What can you say about them? List below anything your group can recall.

Think of as many correct, distinct and relavant facts as you can

Figure 6.1: Creative exercise of three organic compounds with different functional groups

Such a CE in Figure 6.1 was used to foster deeper levels of learning and thinking about organic molecules with different functional groups. Trigwell and Sleet (1990) pointed out that a CE of such type can be used in conjunction with concept mapping techniques to highlight key interconnections between the concepts.

In Figure 6.2, a typical response produced by students in response to the CE in Figure 6.1 is shown below. This response was taken from the study by Mai et al. (2021).

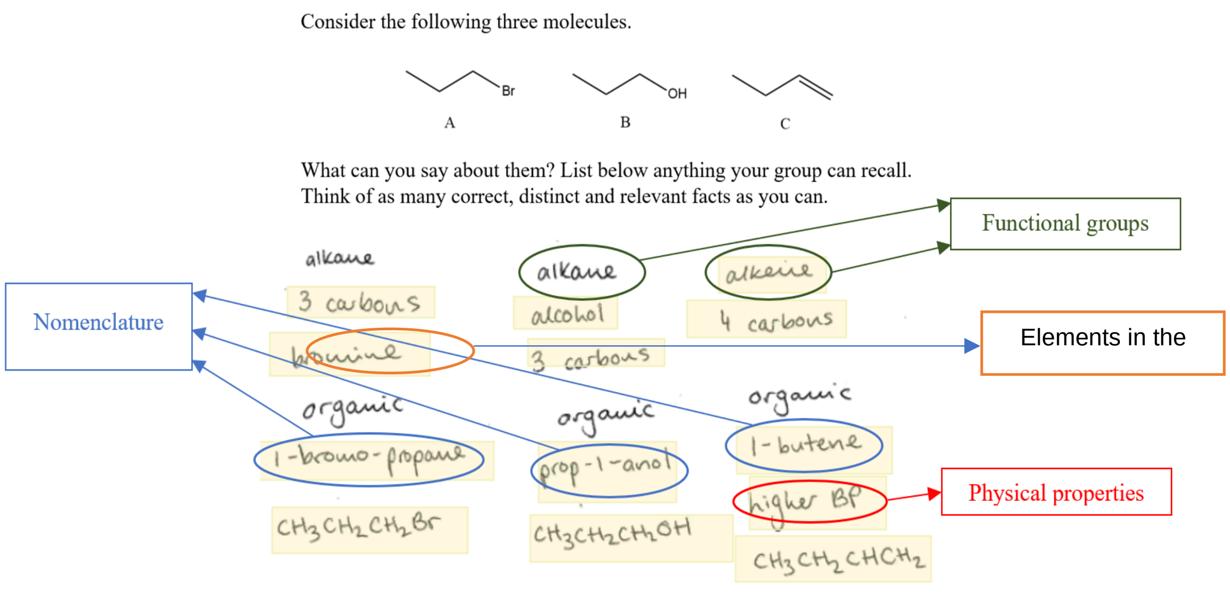


Figure 6.2: Typical students' response to a creative exercise question

Various interconnections can be identified concerning the CE response shown in Figure 6.2. In the knowledge of functional groups chemistry, the nomenclature, homologous series, structural and condensed and molecular formulae are key. Further to that physical properties and intermolecular forces are linked through the mention of boiling point. So, CEs have the potential to make explicit the interconnections between the concepts in the fundamentals. There are other connections not shown in these concepts. For example, alkanes have a special orbital hybridization that results in the formation of a single bond and type of molecular geometry. This is similar to the other homologous series not mentioned in the CE above.

In the next section, the discussion focuses on the two fundamentals to identify some of the tensions and differences in academic and school science.

6.2.3 Tensions emerging from importing the discipline fundamentals into the school curriculum

The third element in structuring TerSCK is the identification of the tensions that arise as a result of importing the content of the academic discipline into the school subject. When the curriculum content of the school is formed, the substantive content of the discipline is imported from the disciplinary level to the school curriculum level. In this transposition, not everything from the scope of the discipline filters down to the school subject. Only a fraction of the content of the academic discipline filters down to the school curriculum. Some of the concepts get to be left behind. These inevitable constraints create tensions and differences between the two ends of the content continuum. Firstly these may engender misconceptions if teachers are not made aware of these during their pre-service teacher education programmes. Secondly, they can present difficulties concerning their teachability, given the limitations of the school curriculum content. The knowledge of the tensions in TerSCK created by the process of importing the discipline's fundamentals into the school curriculum is very close to the knowledge of what is difficult to teach in the TSPCK understanding described in Mavhunga and Rollnick (2013). It is acknowledged in this work that the two knowledge elements are difficult to separate. However, knowing the tensions are embedded in knowing the content rather than in knowing how to transform it for teaching purposes as discussed in TSPCK understanding. Secondly, knowing the tensions also creates awareness from the teacher's point of view about the potential misconceptions that can be engendered rather than the consideration of the difficulty of content from the pedagogical sight.

For example, consider the molecular geometry of organic compounds, predicted through the valence shell electron pair repulsion (VSEPR) theory. The 3-D nature of organic molecules described by the VSEPR theory is not the area of focus in organic molecules, particularly in grade 12 in the curriculum statement. The focus of the VSEPR theory is given to other inorganic molecules such as CO, NH_3, and SO_2 in grade 11. In grade 12, the VSEPR theory is not fundamentally discussed with explicit reference to organic molecules and other concepts of chemical bonding. Further to that, the curriculum limits the discussion of the bond angles. So, students are to exit the schooling level thinking that the structure of the organic molecules is only at a 2-D plane and contains bond angles of 90^0, see Figure 6.3 (a). This assumption is made because the 3-D nature of the organic molecules and the concept of sp - hybridisation is not covered in the VSPER at this level to show that the geometrical shape is a tetrahedral structure with bond angles of 109.5^o, see Figure 6.3 (b). This is but one example of the case with a functional group of alkanes.

Figure 6.3: 2-D and 3-D structural formulae of the methane molecule

Furthermore, there are other constraints associated with the concepts of isomerism. For example, the school curriculum is limited to structural (chain, positional and functional) isomers (Department of Education, 2011). The idea of stereoisomerism is not covered at this level. So, without this information, teachers may engender misconceptions when dealing with compounds like 2-butene. Figure 6.4 uses the example of 2-butene to illuminate this second tension where the two structures can be mistaken as if they are the same. It is therefore important to explicitly expose pre-service teachers to this information through the knowledge of TerSCK

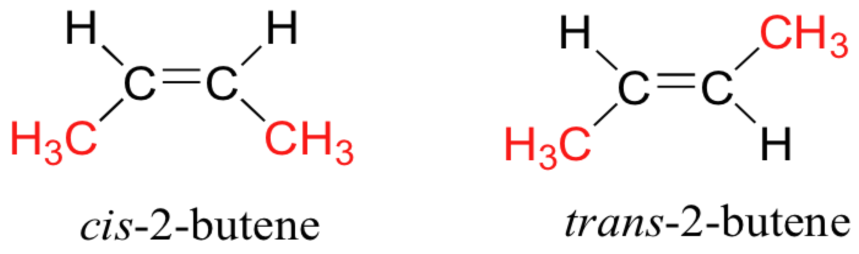


Figure 6.4: Butene cis- and trans-isomers

The knowledge of TerSCK must explicitly focus on these tensions between academic disciplines and school subjects' content in two folds. Firstly, it must highlight the potential misconceptions that could be engendered around these fundamentals. Secondly, it must point out the areas of difficulties regarding the teachability of certain concepts in the fundamentals given the constrained school curriculum. Despite the fact in terms of TerSCK, these concepts are to be covered in the teacher training programme, at the school the teacher may not cover them as such thus needing to be conscious of this and navigate these tensions skilfully.

The next element is the scientific inquiry and possibly other modes of inquiry from the access discipline

6.2.4 The scientific and other modes of inquiry

The fifth element in structuring TerSCK is embracing the inquiry nature of science. The idea of inquiry in science refers to the "diverse ways in which scientists study the natural world" (Marshall et al., 2017, p. 779). Earlier work in practical work identified four typologies that inquiry work can take form in science. These are exercises, experiments, demonstrations and investigations (Tafa, 2014). The most rigorous form of inquiry is an investigation as it aims to reinforce theoretical understanding and learn the ways of the scientists as problem-solvers (Tafa, 2014). So, for TerSCK, the investigative typology following the scientific method would be adopted to describe the scientific inquiry.

In line with this, Furtak et al. (2012) identified four domains of inquiry, these are (i) conceptual, (ii) procedural, (iii) epistemic and (iv) social domains. With regards to this work, the conceptual and the social domains are already incorporated in the fundamentals of the discipline as well as the social dimension of TerSCK respectively.

As a result, the inquiry here will largely consider the other two domains – procedural and epistemic domains. In simpler terms, Nhlengethwa et al. (2021) depicted the procedural domain as the set of activities that are used to generate evidence through the scientific method. The epistemic domain is strongly characterised by an understanding and the character of the processes that underpin the nature of science. For example, data analysis, forming evidence-based conclusions as well as generating and revising theories (Furtak et al., 2012). This domain of inquiry is equally important to bring to view the idea of cultivating potential, that is, the development of teachers who do not view learning as simply the acquisition of existing facts but a process informed by the epistemology of the discipline.

With regards to organic chemistry, these elements can be seen through several concepts embedded in the fundamentals of the discipline, described in section 6.2.1 above. Table 6.3 shows some of these inquiry activities based on the (i) reactivity series of saturated and unsaturated hydrocarbons, and (ii) the boiling points of organic molecules with similar or different functional groups.

Table 6.3: Inquiry element in organic chemistry

Aspect of Inquiry	**Procedural Domain**	**Epistemic/ Conceptual Domain**
Reactivity series of alkanes, alkenes and alkynes	Designing through a <u>detailed scientific method</u> a reaction of hexane, 1-hexene and 1-hexyne with brown bromine water.	- Generate evidence with in-depth explanations, of which reactant will quickly decolourise brown bromine water - Evidence-based conclusion
Boiling points of alcohol	Design through a <u>detailed scientific method</u> a reaction that will investigate the boiling points of pentane isomers: - n-pentane - iso-pentane - neo-pentane	- Generate evidence based on observation to offer in-depth explanations of what affects the boiling points of substances with a similar OR different functional group. Include in your explanation the following concepts: i) Molecular size – chain length

Boiling points of different organic compounds	Design through a detailed scientific method an investigation of the different organic compounds with different functional groups - Acetone - 1-propanol - propanoic acid	ii) Identification of dominant intermolecular forces iii) Strength of the intermolecular forces iv) The energy required to overcome intermolecular forces - Use the findings to make general statements to scientific claims

The examples shown in Table 6.3 do not cover the whole aspects of the inquiry in the knowledge of functional group chemistry since it is a very large section of the topic. They are however chosen to serve as examples of how pre-service teachers can be exposed to understanding a particular piece of knowledge through scientific inquiry, in this case with a strong focus on the procedural and epistemic domains of the scientific inquiry.

To reveal the educational potential, both Deng (2021) and Schwab (1973) posited the need to take advantage of the access discipline in knowledge generation. Within this epistemological dimension of TerSCK, the access discipline opens another window to explore how knowledge is developed and argued for in other disciplines. For example, the medical discipline uses case investigations to solve medical problems. So, in the case of organic chemistry teaching, it is beneficial to expose pre-service teachers to such a modality of inquiry. An example can be seen in the excerpt below.

Cars' **exhaust fumes** include gases such as **carbon dioxide, carbon monoxide** (CO), and **volatile organic compounds** (VOCs). When released into the atmosphere, these gases and such pollutants have drastic environmental consequences

Consider the case of carbon dioxide (CO_2)

Carbon dioxide is formed during the **combustion** of alkanes (octane) inside a **car engine. CO_2** is on e of the greenhouse gases that constributes to a phenomenon known as global warming.

Investigate this the case of CO_2 and the phenomenon of global warming and present working solutions and intervention to mitigate the global warming.

Figure 6.4: Case of car combusting alkanes

With the case presented in the excerpt in Figure 6.4 about the combustion of alkanes, pre-service teachers can be engaged to investigate the phenomenon and its detrimental environmental effects it has. Further to that, they can suggest working solutions and interventions that can mitigate this social and humanitarian dilemma. By so doing, they become cultivated human agents of social change who can solve societal problems.

The last section discusses the last element of the construct found on the social dimension of TerSCK.

6.2.5 Historical development of the content and the cultivating social agency

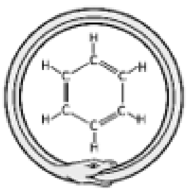
The fifth element in structuring TerSCK is the historical account purporting the development of content in science and the cultivation of social agency embedded in this knowledge element. This study has argued for the need to include the historical development of the content knowledge in science topics. This was in line with the first face called the purport of translations into the curriculum described by Schwab (1973). For Schwab, this is an account of a past event by a piece of history, a moral dilemma or an image of a person or society by a piece of literature or a way of classifying a group of natural phenomena by a scientific report.

The inclusion of this element does not simply consider just the knowledge of the recollection of historical events. However, for TerSCK it reveals the cultivating potential inherent in knowing the development of ideas and concepts in science from a historical perspective. It starts by highlighting a dilemma or a challenge or even the limitation of knowledge at the time. This is followed by the purporting knowledge development or discovery of knowledge from a piece of history through an event, failed experiment, a person, etc in discovering new knowledge.

Using this face, (Deng, 2021) argued that it discloses the cultivating potential in the development of teachers who are knowledge creators and critical thinkers. Table 6.4 shows some of the key historical accounts and discoveries in organic chemistry using Wohler's famous experiment and the case of August Kekule's daydream.

These can be structured as introductory discussions highlighting the challenge or the dilemma of the time and the need for developing new knowledge. This can be used as an agent to show that the development of knowledge in science is not always a straightforward endeavour. It takes human imagination, creativity and sometimes a failed experiment can lead to the discovery of new knowledge in the discipline.

Table 6.4: Historical development of the content in organic chemistry

Challenge/Limitation	Purport face	Knowledge advancement
Very few of the concepts enabled chemists to understand and manipulate the chemistry of inorganic compounds applied to organic compounds.	In 1828 Wöhler synthesized the organic compound urea in the laboratory using the inorganic compound ammonium cyanate. 	- Organic molecules can be synthesized from inorganic matter - Death of the vitalism theory - Discovery of functional groups - Discovery of isomerism
The knowledge of chemical structures was limited. In addition to this challenge, aromatic molecules such as benzene with six carbons and six hydrogens C_6H_6 remained a mystery as to how this organic molecule was structured. A chain structure would not satisfy the valence rules proposed at the time.	Friedrich August Kekulé (1829–1896) hypothesised a theory of chemical structure. He further predicted the aromatic structure of benzene through his dubious daydream story that was biting its tail. 	- Carbon is tetravalent and can undergo catenation in his theory of chemical structures - Discovered the structure of benzene which led to the knowledge of aromatic hydrocarbons - Advancement in the knowledge of isomerism

The information in Table 6.4 is just a piece of some historical account that led to the development of major content and concepts in organic chemistry, especially structural chemistry and isomerism. The idea of bringing new chemical compounds was discovered and many of these are products of scientists' imaginations, exploration, and in some cases, experiments that have gone wrong.

The synthesis of an organic compound from inorganic substances was an accidental discovery by Friedrich Wöhler, a German chemist. In 1828, Wöhler reacted silver cyanate (AgNCO) and ammonium chloride (NH_4Cl) to produce the inorganic substance ammonium cyanate ($NH_4^+NCO^-$). To his complete surprise, he obtained a product that had the same molecular formula as ammonium cyanate but was instead the well-known organic compound urea (NH_2COOH) (Noller & Usselman, 2020). From this unexpected result, Wöhler concluded that organic material can be synthesised from inorganic substances, this falsified the idea of vitalism, a dominant theory of the early centuries in organic chemistry. Secondly, he advanced that atoms could arrange themselves in different ways, and the properties of the resulting molecules were critically dependent on the atomic arrangement. This proposed the existence of isomerism during the 19th century.

On the other hand, due to the limited knowledge of the theory of chemical structures such as benzene, Kekulé proposed that benzene's structure was a hexagonal ring of six tetravalent carbon atoms, each able to form four bonds: one to a hydrogen atom and the others to adjacent carbon atoms (Rocke, 2010). This concept was foreseen by him as "an inexhaustible discovery" and was widely accepted by organic chemists because it predicted the existence of many benzene derivatives that were laboratory synthesized. This in turn advanced the knowledge of chemical structure as well as isomerism (Rocke, 2010)

Exposing PSTs to this kind of historical account lends the idea of TerSCK to carry an educational potential that cultivates teachers to see content beyond just the acquisition of facts. It develops them to become problem solvers, knowledge creators, etc. and this can be realised from the efforts of the previous scientist as agents of cultivation.

Pulling all this together, the next section describes the planned content and the accompanying performance objectives of the intervention that is geared to develop the knowledge of TerSCK through the two fundamentals mentioned in the chapter.

6.3 The performance objectives of the TerSCK intervention

In the following section, all these elements which are postulated above to describe the nature of TerSCK in organic chemistry are put together to present a piece of curriculum that will inform the intervention to validate the construct. Because of the vast nature of organic chemistry postulated above, eight (8) fundamentals of the discipline in the topic are identified (*cf.* Table 6.1). However, since the study is conceptualized within the framework of the Doctoral project, not all the fundamentals will be explored due to feasibility constraints. The intervention will therefore be informed by two fundamentals, which are (i) knowledge of functional group chemistry and (ii) knowledge of isomerism.

These two fundamentals were purposefully selected as some of the other fundamentals can be discussed explicitly along with these two. For example, chemical bonding in organic compounds has direct associations with the knowledge of functional groups. In addition to this, the knowledge of the physical properties of organic compounds can be explored within this fundamental, especially when discussing the trends in boiling points of organic molecules.

Furthermore, the knowledge of the IUPAC naming system under the nomenclature has good associations with isomerism, either structural or stereoisomerism as was the case in this study. So, it was for this rationale that these two were considered for inclusion and consideration in the intervention. These fundamentals will be discussed in a three weeks practicum course set in the “Physical Sciences Education Method 2: Teaching & Learning modules of the third-year Bachelor of Education (B.Ed) programme in one of the South African universities. Table 6.5 summarises the performance objectives of the set TerSCK intervention. These objectives are in line with the five elements of TerSCK and they are illuminated through the two fundamentals selected above.

Table 6.5: Content and performance objectives of the TerSCK intervention

TerSCK elements	Performance objectives
Fundamentals of the discipline the topic	- Classify organic molecules according to their functional groups - Apply the homologous series up to 10 carbon - Use the knowledge of organic nomenclature to name different organic compounds - Interpret, name and use the general, structural formulae, displayed and skeletal formulae of the organic compounds - Describe and explain the different types of structural (chain, positional, functional) isomerism and stereoisomerism (geometrical). - Use the nomenclature of organic compounds to name different isomers
Interconnections between the concepts	- Identify and show how the concepts in the TWO fundamentals in organic chemistry relate to concepts in organic chemistry as we as other chemistry topics - Draw concept maps to describe the nature of connections across the two fundamentals
The tension created by the focus on the fundamentals	- Identify the constraints of the school subject science curriculum against the academic discipline content. - Develop an awareness of the possible misconception that can be engendered by the limitations of the school science. - Develop an awareness of areas of difficulties in teaching that arise from the constraints of the school science curriculum
Scientific and other modes of inquiry	- Understand the scientific enquiry through the procedural and the epistemic domain - Develop the knowledge of the scientific process and all the steps that underpin it planning and undertaking scientific investigations. - Develop the ability to use the epistemic knowledge domain to justify the process of knowledge development in science - Use case studies to investigate effective ways to solve societal problems
Historical development of the content in organic chemistry	- Develop an appreciation that concepts that inform the knowledge of functional groups and isomerism developed through scientists' imaginations, failed ideas or experiments that have gone wrong as well as scientists' imaginations that - Develop elements of cultivation through previous scientists' efforts

The performance objectives listed in Table 6.5 were then used to design a program of teaching in the TerSCK-based intervention.

6.4 Teaching programme and instructional approach of the intervention

As posited above, two (2) fundamentals of the discipline were of interest viz: functional groups and isomerism. In this section, the teaching programme and the content of the TerSCK intervention are outlined with specific activities that guided the discussions of the intervention. It is important to highlight that the TerSCK items were not presented in the order in which they appear in Table 6.5 but they were taught following an integrative approach.

The intervention was geared to run for three weeks, each week has three sessions that run for 1½ hours sessions, these sessions were informed by the timetable of the host university. Subsequently, Table 6.6 details the teaching schedule, intended content and activities in the three weeks intervention. Note that, due to the COVID-19 protocols of the country and the host university's ethical requirements, no physical interaction took place in the intervention. All the sessions were conducted online via the Zoom platform.

Whilst the main aim of the intervention was to improve the quality of content knowledge for teaching, this intervention was not structured in the same way as the traditional interventions reported in the literature such as TSPCK by Mavhunga and Rollnick (2013) and in chemistry content knowledge by Wheeldon (2017). Commonly, these interventions followed a linear synchronization of the content or components of the construct. In the TerSCK intervention, horizontal synchronization was used. In this approach, consideration was made that the TerSCK elements are not discreet but they are interrelated in one way or the other. Thus, the teaching approach used was not fragmented. For example, in a session concepts linked to a particular fundamental were discussed simultaneously with the particular focus on the interconnections and existing tensions between academic science and school science. Similarly, the aspects of enquiry were used to illuminate explicit connections between the concepts whilst fostering the understanding of the fundamentals. For example, how the presence of a particular functional group affects the amount of energy required to overcome the intermolecular forces and thus determines the nature of the physical property of organic molecules such as boiling points, etc.

Unique to this intervention was the highlight of the tension which is created by the process of importing the discipline fundamentals into the school subject content. These discussions were informed by unpacking the curriculum scope within the South African context. This required aspects of interrogating the national curriculum documents to highlight the limitations of the school curriculum. these were discussed explicitly within the scope of the content knowledge of the discipline. These discussions were also embedded in the consideration of teaching particular ideas and averting the potential development of misconceptions in a science classroom. Given the exclusive focus on content and not its teachability, this was seen as a distinct element of the TerSCK intervention from the conventional interventions reported in the PCK/TSPCK literature.

Considering all of the propositions above, the next section outlines the teaching programme that was followed in the intervention with a specific focus on content items.

Table 6.6: Teaching outline of the TerSCK intervention

Week (W), Session (S)	Content discussion	Task
W1, S1	TerSCK pre-intervention test and its online administration	
W1, S2	- Introduction of the TerSCK construct and the discussion of elements that make up the construct. a) Historical development of the concepts in the fundamentals b) Fundamentals of the discipline in the topic c) Interconnections between the concepts of the discipline d) Tensions associated with the focus of the fundamentals e) Scientific inquiry	
W1, S3	- Discussion of key chemical bonding concepts and their relevance to organic chemistry viz: a) Molecular orbital theory b) Sigma and pi bonds c) sp – hybridization and bond angles d) VSEPR e) Bond and molecular polarity f) Intermolecular forces	Inclass-discussions Q&A

Week (W), Session (S)	Content discussion	Task
W2, S1	- Content focus on **halogen-containing** compounds and **hydroxyl group-containing** compounds: a) Functional group chemistry of halide hydrocarbons and alcohols b) Formulae (general, molecular, condensed and structural) c) Nomenclature	Online Content Quiz
W2, S2	- Content focus on **carbonyl-containing** compounds and containing compounds: 1. Aldehydes, ketones, carboxylic acids and their derivatives 2. Formulae (general, molecular, condensed and structural) 3. Nomenclature	Mind map on the knowledge of carbonyl contains molecules
W2, S3	- Investigating the physical properties of the hydrocarbons a) Designing a practical investigation through a scientific method to investigate the boiling points of pentane, hexane and heptane AND the reactivity series of alkanes and alkenes b) Discuss explicit connections between the concepts regarding the effect of intermolecular forces on the boiling point of organic substances	Practical investigation and scientific report on the two experiments
W3, S1	- History and the development of isomerism – Wohlers experiment and Kekule ideas – exploring the cultivation element - Content focus on **structural isomerism** 1. Chain isomers 2. Positional isomers 3. Functional isomers - Nomenclature of the various isomers - Explore the connections that exist in the concepts of isomerism	Online content Quiz on the knowledge of various Structural isomers and their Nomenclature
W3, S2	- Content focus on **stereoisomerism: Geometrical** - Nomenclature of the various geometrical isomers - Discussion of the tensions that are associated with the focus of the fundamental using a case with stereoisomers and structural isomers – use the case of cis- and trans butene	Group work, researching to further identify other tensions that exist
W3, S3	Investigating the physical properties of the isomers: a case with C-5 isomers	Practical investigation and scientific report on

Week (W), Session (S)	Content discussion	Task
	1. Designing a practical investigation through a scientific method to investigate the boiling points of different isomers 2. Compile a scientific report with generalised claims about the observation.	the two experiments
W4, S1	Pulling it all together AND reflections	
W4, S2	Post-test	

6.5 Conclusion

This Chapter was geared to report on the development of a piece of the curriculum content in organic chemistry to show how the elements of TerSCK can be magnified. As much as the elements of the construct are postulated to be distinct, they are however related to one another based on the relational dimension of TerSCK. For example, at the logical plane which entails the knowledge of fundamentals, the interconnections between the concepts in the fundamentals and the tensions that are associated with the focus of the fundamentals.

Secondly, the historical development of the concepts at a social plane is important to show how the logical plane relates to societal needs in the development of the concepts in a particular topic. As postulated earlier, this is paramount in unlocking the cultivating potential of the content in developing critical thinkers, problem solvers, etc.

In Table 6.5, the intervention ran for four consecutive weeks, including running pre and post-intervention tests. The participants who were taken through the intervention were concurrently enrolled in another module that was focusing on disciplinary content knowledge in organic chemistry. Therefore, the intervention did not focus largely on the understanding of the pure content, it however used the distinct elements of TerSCK as the driving agents of the intervention to develop this version of content knowledge for teaching school science.

Whilst the intervention was running, both the country and the university were placed under level 1 restrictions of COVID-19 protocols. The intervention described in this chapter was intended to run as physical contact, however, due to the restrictions, the intervention was virtual. As a result, virtual sessions ran both synchronously and asynchronously. This potentially limited the quality of student discussions in fully realising the TerSCK potential. In addition, there was no actual practical work done in the physical laboratory due to restricted access to the university laboratories. Hence, the planned experiments for investigation purposes were rather presented in a theoretical form, where the participants were given the data to derive aspects of the inquiry as envisaged by the scientific method. To optimise the practical work exposure, participants were also referred to online videos to augment lab exposure. For future interventions based on the TerSCK construct, it is recommended that they are done face to face to fully realise the potential of TerSCK in a specific topic

Before the start of an intervention, a pre-test developed and piloted in this study was administered and graded with a marking memorandum and a corresponding rubric (see next chapter). Post the intervention, the same TerSCK instrument was used to measure the extent to which the PSTs have developed the content knowledge for teaching organic chemistry. Thus, the next chapter reports on the process of developing and validating the TerSCK instrument that captures and measures the quality of TerSCK in organic chemistry, a process leading to the theoretical validity of the construct in this study.

CHAPTER 7 DEVELOPING A VALID AND RELIABLE TERSCK DATA COLLECTION INSTRUMENT IN ORGANIC CHEMISTRY

The previous Chapter 6 used a case of organic chemistry to show how the elements of the TerSCK construct can be illuminated through a piece of curriculum content suitable for teacher education. This chapter emphasizes the need for constructing a reliable and valid data collection tool that can be utilized to determine and measure the prevalence of TerSCK in science teachers. Hence, the chapter reports on the rigorous process of developing and validating a measuring tool for TerSCK as informed by the conceptual argument. The process was important in two folds. Firstly, It provided the statistical basis for establishing TerSCK as a valid theoretical construct and reporting on the reliability and validity of the instrument intended and developed to measure TerSCK in organic chemistry.

7.1 Introduction

The earlier Chapters in this thesis have alluded to TerSCK as a construct that describes CK associated with teaching secondary school science and the base for PCK growth. It has been postulated that it is distinct from the CK of academic disciplines and that of the related school subject curriculum. It is described through the knowledge of five elements. These are (i) fundamentals of the discipline in the topic, (ii) interconnections between the concepts that make up the fundamentals, (iii) tensions emerging from the process of importing the discipline fundamentals into the school curriculum constraints, (iv) scientific and modes of inquiry from other disciplines and (v) cultivating social agency.

To validate this conceptual argument and ultimately the TerSCK construct, the study followed the construct validity process. According to Kane (2012, p. 69), "*it suggests that this be done by laying out an interpretive argument that explicitly states the claims being made, as a chain or network of inferences and assumptions leading from the observed assessment performances to the interpretation and use of the test scores*".

However, in the absence of the suitable tools to measure and portray TerSCK highlighted in chapter 2 of the literature review, the intermediate step asked the following question:

What valid instrument could be used to measure the quality of the newly conceptualised theoretical construct in pre-service teachers?

After an extensive literature review, it was apparent that there were no readily available tools to appropriately measure TerSCK in organic chemistry. Hence, a rationale for new instrument development in this study was made. This followed the intuitive approach used by Rohaan et al. (2009). The steps within this approach were briefly explained in Chapter 3. These are "*specification of the theoretical framework, construct analysis, specification of item characteristics, production of items, the judgement of items, construction of the instrument, and validation of the instrument*". These will be described in depth in this chapter to explain how a valid TerSCK instrument was created. These actions worked together to create an instrument that could measure the newly developed construct and provide an answer to the research question above.

7.2 Instrument Design Methods: The Construct Method

This construct design method was considered suitable for the TerSCK instrument development in several ways. Firstly, it is informed by clear theoretical underpinnings about the construct. This is the case with TerSCK as it is formulated within a particular theory of content that blurs a line between operational and propositional knowledge to just powerful knowns and knowings (Carlgren, 2020). Secondly, the construct design method is informed by construct validity (Cronbach & Meehl, 1955; Kane, 2012), which is fundamental to this research work as it aims to validate TerSCK as a theoretical construct. Thirdly, produces scales that have better psychometric properties compared to the model-based just on intuition and inductive designs (Mellenbergh, 2011).

In the next sections, the process of instrument development is initiated by briefly discussing and analysing the framework in the form of concept analysis as per the requirement of the construct method.

7.3 Specification of the theory and construct analysis

Following the steps used by Rohaan et al. (2009), this section covers steps one and two about the specification of the theory and construct analysis simultaneously. In Chapter 5, the conceptual argument that emerged from the systematic review of literature described the nature of the construct called TerSCK. As postulated in the conceptual phase, TerSCK is a version of content knowledge that is suitable for PST education and a base for PCK development and pedagogical reasoning through the knowledge of five elements. These were mentioned earlier (*cf.* Introduction).

TerSCK is distinct from the academic discipline content that is used in the mainstream sciences such as medicine, engineering and other clinical professions in the discipline of science. It goes beyond the knowledge content to include aspects that are related to the pedagogical practice. Furthermore, it is also different from school science content as it can be acquired through university training or continuous professional teacher development interventions.

The five elements describing the nature of TerSCK are briefly summarised. The first element concerns the fundamentals of the discipline in the topic (Duis, 2011). This knowledge element describes the determined measure of content suitable for a scientifically literate person and sufficient enough for teaching school science. Keep in mind that two fundamentals received the majority of attention in this study, the knowledge of functional group chemistry and knowledge of isomerism, a justification for this choice was made in Chapter 6.

The second element pertains to the interconnections between the concepts of the fundamentals. This component of TerSCK is similar to the knowledge of the content at the horizon described by Ball et al. (2008). It foregrounds an account of how concepts in the logical body of knowledge are linked to one another in a topic as well as other topics across the landscape of the discipline.

The third element concerns the tensions created by the constraints of the fundamentals. This knowledge emanates from the process of importing the content of the discipline into the school curriculum. Some of the content aspects get to be sifted and others filter through. As a result, this creates areas of difficulty when it comes to secondary school science teaching. This could potentially result in the formation of misconceptions in several areas of secondary school education if PSTs are not made aware of it. This knowledge aspect is linked closely to the work of Catling and Martin (2011) about the contesting powerful knowledge between academic content and ethno-knowledge.

The fourth element is about scientific and other modes of inquiry. There is a need to explore the scientific way of knowledge generation, verification or rebuttals in PST education. In addition, it is equally vital to expose science PSTs to other modalities of knowing through access discipline as postulated by Deng (2021), this carries the power to cultivate teachers beyond the knowledge of content.

The last element is the consideration of the historical development of concepts in the topic. This aspect is crucial to unlocking the cultivating potential of content as argued by Deng (2021). This cultivating social agency is seen through the development of PSTs who are critical thinkers, knowledge creators, problem solvers, etc for the current social and natural dilemmas. All these five items taken together describe the knowledge of TerSCK in a specific topic. The description above concludes stages (i) and (ii) of the specification of the theoretical framework and construct analysis respectively.

In the next section, each item was used to produce a set of questions that sort to elicit the knowledge of TerSCK in preservice teachers using the two mentioned fundamentals.

7.4 Specification of item characteristics

Chapter 6 has taken the TerSCK construct through a piece of content in organic chemistry and showed how the elements that make up the construct can be made explicit. This was done to develop the content of TerSCK intervention with pre-service teachers. Out of the eight fundamentals discussed in Chapter 6, this study focused only on two. These were the functional group chemistry and isomerism. The rationale for this choice was given in Chapter 6. Under the functional groups, the focus was given to hydrocarbon, halogen-containing, hydroxyl-containing and carbonyl-containing groups. In isomerism, the focus was on all structural isomers – positional, geometric and functional. This was further extended to include stereoisomerism with a focus on geometric isomers. Hence, the designed TerSCK instrument would capture TerSCK in those selected concepts, not the entire branch of organic chemistry.

To assess and capture the knowledge of the fundamentals, the CK instrument designed and validated by Davidowitz and Vokwana (2014) was adapted to assess the two fundamentals, refer to Appendix I for the adapted CK instrument. The nature of the items in the adapted CK instrument was open-ended questions and MCQ items with a focus on the knowledge of functional groups and isomerism. In the process of adapting the instrument, the questions on the other fundamentals of the discipline were removed. These included items on reactions, mechanisms, intermolecular forces, and physical and chemical properties of organic substances.

Since TerSCK goes beyond just the knowledge of the fundamentals, there was a need to produce other items that will assess these knowledge elements. The second consideration in characterising the TerSCK items was the connections between the concepts that make up the fundamentals. This item is not similar to the notion of prior knowledge as described in PCK literature (Hume & Berry, 2011). It however describes how concepts are connected in a nomological fashion. In the previous chapter, it was argued for the use of concept maps and creative exercises to illuminate these connections. So, the character of the produced items has both the creative exercises and the use of concept maps.

The third consideration in the characterisation was given to tensions created by the constraints of the fundamentals in the school subject curriculum. To evaluate this element, there was a need for items that probe the identification of tensions between school subject content and academic discipline content. In addition, the items also probed the awareness of the resulting difficulties that teachers can anticipate in teaching a particular concept because of how the school curriculum limits the scope of the content derived from the discipline. This knowledge element required open-ended items to solicit pre-service teachers' awareness of these tensions and differences and their implications for teaching.

The fourth element of TerSCK is entrenched in the inquiry aspects. As argued by Furtak et al. (2012), there are different forms of inquiry with the end goal of explaining how scientists generate, verify and refute knowledge in coming to know. TerSCK adopted a scientific method as one of how the inquiry can be illuminated. So, the items produced in this knowledge elements needed to ascertain preservice teachers' awareness of the scientific method such as asking investigative questions, identifying the variables, outlining the procedure for carrying out investigations, collecting and analysing data, and drawing suitable conclusions based on observations.

The last element was characterised by cultivation. This is linked to the historical development of the concepts within a particular fundamental. However, this item is not evaluated based on memorising and retelling the discipline's content development process in history. It is rather designed such that it solicits how the knowledge of the development of concepts in the discipline has cultivated the respondent to be responsible citizens, knowledge developers, critical thinkers and problem solvers. So, the character of this item is in the form of a scenario-based question. The respondents were given the existing natural or social problem and are required to provide possible solutions to mitigate the effects of that dilemma.

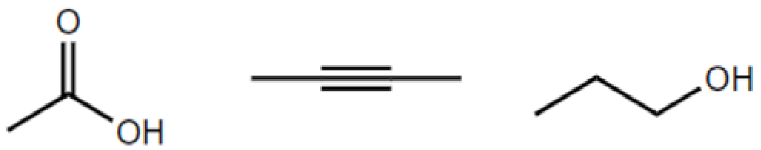
The above description outlines the character of the TerSCK items. The next section describes the process that was involved in the production of items that talk to the character explained above.

7.5 Production of items

After describing the character of the TerSCK items, the subsequent process was to generate a pool of questions that would evaluate each element of the TerSCK construct comprehensively. Firstly, as highlighted before, the first element of the construct is the fundamentals of the discipline. Producing the items for this element was not a grim task, the fundamentals were captured in the knowledge of “pure content” in the discipline. So this study opted to adapt the existing CK instrument developed by Davidowitz and Vokwana (2014) in organic chemistry. So, for this TerSCK element, no new items were produced after the adaptation of this existing instrument. From the existing CK tool mentioned above, all the questions that were not based on the knowledge of functional groups and isomerism were discarded. See Appendix I for the adapted CK instrument.

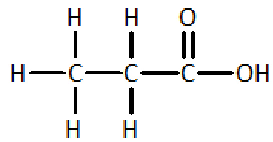
Regarding the second element about the interconnections between the concepts of the fundamentals, three items were produced. These are shown in Figure 7.1. Since the nature of interconnections between the concepts has not been fully explored before in any other previous literature, the initially produced items were then developed by the researcher. The use of creative exercises and concept mapping was found to be valuable in this process. Question 1 in Figure 7.1 was adapted from a creative exercise by Mai et al. (2021). The context of Question 2 was adapted from Davidowitz and Vokwana (2014). It was augmented to assess the knowledge of the interconnections explicitly. Question 3 was taken from an old grade 12 exam question paper and similarly augmented to cater for the desired knowledge of interconnections.

1. Consider the following structures



a. Identify as many concepts/aspects linked to the knowledge of each of the three structures above.
b. Draw a concept map to show how you make sense of the **connections** of the concepts you have identified in (a) above
c. Write a paragraph to describe how you make sense of the connections outlined in your concept map.

2. Structural isomers can belong to different homologous series in other words they could have different functional group.



a. Draw two structural isomers with different functional groups for the compound below and include the IUPAC name for each.
b. Identify a set of FIVE other chemistry concepts that are connected to the knowledge of any form of isomers. In your identification, give a brief explanation of how you see the connection.

3. The students carried out the investigation and generated the following set of results:

Alkanes	Boiling point (^{0}C)
pentane	36
hexane	69
heptane	98
octane	125

a. What pattern can be observed from the set of results above
b. Fully explain the pattern observed you made in 4.4.
c. From the explanation you generated in question 4.5, draw a concept map to show your understanding of **connections** between the concepts used in the explanations.

Figure 7.1: Items produced for the interconnection element of TerSCK

Another distinct element that describes the nature of TerSCK is the knowledge of the tensions that are created by the constraints of the fundamentals. Figure 7.2 shows an extract of three items that were produced for this element of TerSCK. Similar to the interconnections, there were no questions that were readily available to use. Hence, the curriculum policy document, CAPS in physical sciences was used as a resource to establish the limitations of the school curriculum. These were further interrogated against the content in the discipline to see how these limitations create tensions between academic discipline and school science. Question 1 was adapted from Davidowitz and Vokwana (2014). Questions 2 and 3 were taken from the introductory organic chemistry textbook by Ryan and Norris (2014).

1. **Molecules with the same molecular formula can have different structures, this is known as isomerism. There are several kinds of isomerism such as structural and geometric. Answer the following questions about isomers.**

   a) Draw the following isomers for 2-butene, name the compounds that you draw.
   - Positional isomer of 2-butene
   - Structural isomer of 2-butene

   b) Using your knowledge of isomerism, what are the **tensions** associated with the teaching of isomerism at the school level as a result of sifting some aspects from the academic discipline knowledge.

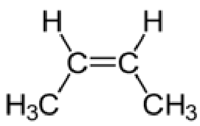
2. **Alcohols are organic compounds that contain a hydroxyl group (-OH) and are described by a general formula $C_nH_{2n+2}O$.**

   a) Draw the structures of:

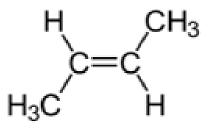
propan-2-ol	1,2propan-diol

   b) With your knowledge of school science, what difficulty do you anticipate in dealing with the two structures when teaching about the knowledge of general formulas?

3. **Consider the following two structures:**



(A)



(B)

   a) Give the IUPAC name for each compound
      (A)
      (B)

   b) Given the scope of the South African curriculum and your knowledge of isomerism above, what difficulty do you anticipate in teaching and making the difference between the two structures clear to learners

Figure 7.2: Items produced for the interconnection element of TerSCK

Generally, the idea in these items was for the respondents to identify that the limited scope of the school curriculum presents challenges (and hence, tensions) in teaching some aspects of the content taken as it is learnt in the academic discipline.

The next items were geared towards scientific inquiry. Figure 7.3 shows two items that were produced to evaluate the knowledge of inquiry in science, particularly following the scientific method. The first item was adapted from the CK instrument designed by Davidowitz and Vokwana (2014). A few items were added by the researcher to augment the initial item, for example, question 1 (a) i. – iv. These were particularly produced to focus on the specific aspects of the scientific method. Question 2 was produced from an introductory university chemistry textbook by Ryan and Norris (2014).

1. Study the following table and answer the questions below:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

a) Considering the first homologous series (alkanes)
   - (i) what is the possible investigative question that you can suggest for this investigation.
   - (ii) Identify the variables in this investigation
   - (iii) What is the general pattern observed in the boiling point of alkanes
   - (iv) Use the knowledge of intermolecular forces, energy required to explain the observed trend in the boiling points of alkanes

b) Why is the boiling point for hexane so much lower than that of hexan-1-ol?

c) Why is the boiling point for methanol so much lower than that of hexan-1-ol?

d) The boiling points for the carboxylic acids are not included. Do you expect their boiling points to be higher or lower than the boiling points of the alcohols with the same number of carbon atoms? Explain your answer.

2. **A group of university students investigated the boiling and of liquid alkanes. Answer the following question based on your knowledge of the scientific process:**
   a. What would be the possible hypothesis for this investigation?
   b. What investigative question can be asked by the student?
   c. Identify the possible variables for this investigation

The students carried out the investigation and generated the following set of results:

Alkanes	Boiling point (°C)
pentane	36
hexane	69
heptane	98
octane	125

   d. What pattern can be observed from the set of results above
   e. Fully explain the pattern observed you made in (d)

Figure 7.3: Items produced for the inquiry element of TerSCK

The next element that TerSCK described is the potential to cultivate pre-service teachers as problem solvers, etc. Two items were produced that speak to this element of cultivating social agency. As postulated earlier, they were presented in the form of a scenario that required the respondent to go beyond just the knowledge of fundamentals and how they have developed but to show cultivation as knowledge developers. Figure 7.4 shows the produced item scenarios. These were also augmented from the university chemistry textbooks (Ryan & Norris, 2014). See Figure 7.4.

1. ***Given the rise in natural disasters experienced in our country and the rest of the world, global warming has been at the center of it all. Global warming is caused by the burning of fuels such as octane that produce carbon dioxide (CO_2) gas. CO_2 is one of the greenhouse effect gases that trap heat in the atmosphere and thus increase the average temperatures of the earth.***

   With your knowledge of science, what practical **solutions** and **interventions** you can implement in your immediate community to mitigate the effects of global warming?

2. **Cars' exhaust fumes include gases such as carbon dioxide, carbon monoxide (CO), and volatile organic compounds (VOCs). When released into the atmosphere, these gases and such pollutants have drastic environmental consequences Consider the case of carbon dioxide (CO_2) formed during the combustion of alkanes (octane) inside a car engine. CO_2 is one of the greenhouse gases that contributes to a phenomenon known as global warming**.

   Investigate this the case of CO_2 and the phenomenon of global warming and present working solutions and intervention to mitigate the global warming.

Figure 7.4: Items produced for the cultivation element of TerSCK

Once all the items were produced, they were collated into one document, see Appendix P for a composite pool of items produced. This was important to initiate the process of the items' judgement. The process of selecting the components created to be included in the TerSCK instrument's initial draft is described in the next section.

7.6 Judgement of items

The process of judging the produced items occurred in two separate phases. First, it was to put together the first draft of the TerSCK instrument. Hence a first reference group of experts was constituted for this purpose, they were two PhD students in chemistry education, a Professor and a Doctor of Science Education. For the second phase, the reference group was increased to have more experts in the field. It was then comprised of three Professors, three Doctors and two PhD students. They were all in the science education field. One of the PhD students was a physical science teacher in secondary school with above 20 years of experience in teaching school science.

The second reference team was asked to judge the items by looking at the correctness of the content, the level of appropriateness, any ambiguities, errors and any relevant aspects for consideration. This was a crucial process in establishing both content and face validity.

Before the first judgement of the items, the theory behind TerSCK was presented to a larger forum of both national and international scholars in science education. This forum is called the "PCK Talks". Each of the five elements of TerSCK was characterised using a piece of content in organic chemistry. This was important to create a shared understanding of the construct before the process of item judgement could ensue. A large number of the members of the reference teams were present. The next section briefly summarised how the first draft was produced.

7.6.1 Initial judgement of items leading to the first draft

As indicated in section 7.4 above, four elements were included in the first draft except for the knowledge of the fundamentals of the discipline, these were in the separate adapted instrument (Appendix I). The first item that was included was the evaluation of the interconnections between the concepts. The reference team considered Question 1 from the set of questions produced for this TerSCK, see Figure 7.1. This was the most suitable item in which three different functional groups were shown in the question compared to questions 2 and 3 which focused on only one type of functional group. Secondly, question 1 included the use of the concept map and the affordances of creative exercise which is argued to be ideal for showing the links between the concepts (Mai et al., 2021).

The next consideration was given to the knowledge of the tensions created by the focus on the fundamentals. Two out of three questions were included as shown in Figure 7.2. These were questions 2 and 3. Question 2 was based on the number of functional groups and the use of the general empirical formula which could be trivial, a case of alcohol and a -diol was used. Question 3 was also included. Under this element, it was the only question which was based on the knowledge of isomerism and how leaving behind the knowledge of stereoisomerism can create tensions in the teaching school curriculum. Question 1 from Figure 7.2 was discarded as it was almost similar to question 3 on isomerism.

Two questions were produced as indicated in Figure 4.4 about the knowledge of the inquiry. The reference team suggested question 1 be considered to evaluate this aspect. Another set of questions indicated as 1 (a) i – iv in Figure 4.4 were considered useful to illuminate the basic aspects of the inquiry. Secondly, question 1 considered several organic molecules compared to question 1 which focussed only on alkanes. Thirdly, question 1 was found to be more open in the sense it had an item that required respondents to predict some physical properties based on the given data. So, it was for these three reasons that question 2 was then discarded from the pool of produced questions.

Regarding the cultivation aspect, two scenarios were presented to the reference group. They were adapted from the university textbook as explicated before, see Figure 7.3. The reference team opted to select the first scenario as it was more accessible to every respondent. This scenario was based on the global warming phenomenon, a dilemma that almost every person can identify with. The second scenario was based on how the structure of the car exhaust is designed to contribute to the partial oxidation of the alkanes. The team took the view that not every respondent would be familiar with this and more time would be required to do investigations to answer the question. This was not going to be feasible for this instrument design purpose.

After all the members of the first reference team reached a consensus about the items produced to be included in the first TerSCK instrument, the initial draft was constructed with all the four elements of TerSCK mentioned above. For a composite first draft, see Appendix K. Subsequently, Table 7.1 summarises each TerSCK element per allocated set of items in the first draft.

Table 7.1: Summary of the items per TerSCK element in the first draft instrument

TerSCK item	Items in the instrument
Interconnections between the concepts	Q 1.1, 1.2, 1.3, & 4,6
Tensions created by the constraints	Q 2.1, 2.2, 3.1 & 3.2
Scientific inquiry	Q 4.1, 4.2, 4.3, 4.4 & 4.5
Cultivation element	Q 5

The next phase was to distribute the first draft to a bigger reference group described earlier. Each member of the reference team of experts judged the items independently and sent their comments to the researcher for consideration. In the next section, the feedback from the experts is summarised leading to the construction of the revised draft of the TerSCK instrument.

7.6.2 Second item judgement towards refining the TerSCK instrument

Based on the four items of TerSCK that were assessed the following feedback was received according to each TerSCK item in the instrument.

(i) Interconnections between the concepts

The initial organic structures were given as only line structures. The experts suggested that it is beneficial to include the condensed structural formula to ease the comprehension of the discussion. Secondly, experts saw a need to first ascertain what the respondents could say about their general knowledge of the organic structures in the questionnaire, so question 1.1 was rather changed to a general question instead of just the identification of concepts right away.

Subsequently, question 1.2 was suggested to probe the concepts linked to each organic structure. Experts saw a need to be explicit here about the specification of "aspects of understanding that could be conveyed/taught by these representations", this was a result of the target population, that is the PSTs.

As means to establish connections, question 1.3 asks the respondents to draw a concept map depicting how they conceptually see the connections from the identified concepts. The last question in this item was to give a written description explaining the nature of the connections identified (See Appendix L for the TerSCK instrument final draft). The next section reports on the issue of the tensions created by the focus on the fundamentals.

(ii) The tension created by the focus on the fundamentals

In this item, two questions were produced according to the two fundamentals, i.e. functional groups and isomerism. Question 2.1 needed to explicitly specify the type of structures assessed. The focus here was on the general empirical formula and as such, it would be more appropriate to use the molecular formula to point to the distinctions. Hence, the question was changed to probe the molecular formula, not the structural formulae of the two alcohols so that respondents could be directed to the area of concern.

Subsequently, question 2.1 was introduced to ascertain if the respondents could identify the problem linked to the use of general empirical formulae across alcohols regardless of the number of functional groups present. Experts highlighted the importance of this question in facilitating the respondents' ability to aptly identify the tension created by the process of migrating academic discipline content to the school curriculum. The subsequent question 2.2 was for the respondents to identify possible areas of teaching that are associated with this particular tension. There was an overarching need from almost all the experts that, a section from the curriculum policy documents be included to point out that this tension is anchored on the school curriculum policy assertion, for example, the following quote was used in rephrasing the question:

> The school science curriculum states that "*organic compounds are restricted… to a maximum of two functional groups of the same type per compound* (DBE, 2011 p 105)" What difficulty do you anticipate in dealing with the two structures when teaching about the knowledge of general empirical formulas?

The second question regarding this item was based on the knowledge of isomerism. The idea here was to use stereoisomerism (which is not part of the school curriculum) to highlight some of the difficulties that can emerge with the lack of consideration of the structural theory of organic compounds in secondary school science.

A case of *cis* 2-butene and *trans*-2-butene was used. In the first draft (*cf.* Figure 7.2), the question required just the IUPAC names of the two isomers and how they can potentially impact teaching the structures of the two organic compounds. The view of the experts was that the two questions cannot unravel the tensions explicitly. As a result, they suggested that question 3.1 should ascertain if the respondents see the two structures as isomers, if so, what kind of isomerism is displayed by the two organic structures. Further to that, question 3.2 was revised to also draw from the curriculum policy document about the scope of isomers:

The school science curriculum states that: "*isomers are restricted to structural isomers: (1) chain isomers (different chain); (2) positional isomers (different position of the same functional group) and (3) functional isomers (different functional group).* (DBE, 2011 p 105)" What difficulty do you anticipate in teaching and making the difference between the two structures clear to learners

Similarly, as in question 2.2, this question needed to draw from the curriculum policy scope to show that isomerism is limited to structural isomers. However, the probe about possible difficulties helps the teacher to be aware that two structures should not be used interchangeably as is the case in the school curriculum. Furthermore, the two structures have significantly different physical properties the position of the alkyl groups on the two ends of the molecule. Lastly, it is not possible to interconvert these two isomers since the double bond cannot be rotated. In both questions 2 and 3, the closing question as questions 2.3 and 3.3 was included through the expert advice to solicit the benefits of knowing about this knowledge item of content for teaching purposes, see Appendix K.

(iii) Scientific Inquiry

Regarding this knowledge item, the initial draft used a set of data to assess if the respondents are familiar with the aspects of the scientific inquiry, these were asked as discreet questions 4.1 to 4.5. The expert views were however different from the initial questions. Since TerSCK is geared toward classroom practice, experts suggested that the question should be open-ended but geared toward assessing if the respondents could design instructions through the inquiry. Instead of the discreet question about aspects of the enquiry, the following question was therefore used in the final questionnaire:

4. A group of science students came across the following data:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
3	Propane	-42	Propan-1-ol	97	Propanoic acid	141
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

In addition to this data, they also learned that:
The strength of the intermolecular forces is connected to the amount of energy required to overcome the intermolecular forces. The amount of energy required thus affects the physical properties of organic compounds.

4.1. Use the case of **compounds with 3 carbons** (propane, propan-1-ol & propanoic acid) and describe how you could use the scientific inquiry (scientific method) to highlight key steps to generate the set of the observed data pattern.

Figure 7.5: Extract based on inquiry in the final TerSCK instrument

The revised question was designed to allow respondents to be flexible in providing answers through the key aspects of the scientific method of investigation. According to the experts, the initial draft did not allow for flexibility regarding the scientific method, the questions that were initially asked were close-ended and required a correct specific answer.

(iv) Cultivating Social Agency

From the conceptualisation of the TerSCK construct, this item was embedded in the notion of cultivation from the historical development of concepts in the topic. In item production, the focus of the question was to use a real-life social or natural problem or dilemma or the challenge of time to find out how preservice teachers can demonstrate their level of cultivation. The expert team was largely in agreement with this notion and the kind of item that was produced in the first TerSCK instrument, see Figure 7.6 for the final item that was included.

Given the rise in natural disasters experienced in our country and the rest of the world, global warming has been proposed as the root cause. Global warming is caused by the combustion of processed fossil fuels such as octane that produce carbon dioxide (CO_2) gas. CO_2 is a greenhouse gas that traps heat in the atmosphere and thus increases the average temperature of the earth.

With your knowledge of science, what practical **solutions** and **interventions** you can

Figure 7.6: Extract based on cultivation in the final TerSCK instrument

The next section is an outline of how then all these judgements were pulled together to construct the final TerSCK instrument.

7.7 Construction of the instrument

After all these processes of specification, production and judgement of items were completed, the revised TerSCK questionnaire prototype was put together. The structure of the prototype was such that the questions were semi-structured across all the TerSCK items. The knowledge of interconnections was itemised in question 1. This was followed by the items on the knowledge of the tensions and differences in academic sciences and school curriculum constraints. These were found in questions 2 and 3 subsequently. The knowledge of the scientific inquiry was itemised as question 4 and lastly, the knowledge on cultivation was itemised as a scenario-based question 5. For the full draft, see Appendix L.

7.8 Piloting the full draft TerSCK instrument

The full draft of the TerSCK instrument was piloted with five B. Ed students in the 4th-year of study. They all majored in chemistry teaching and have completed a content course in organic chemistry and the necessary pedagogies in science education. The purpose of testing this prototype was to make sure that the questionnaire's language was clear, understandable, and simple for PSTs to respond to as a target group.

These 4th-year respondents were not asked to respond only to questions per se, but also to evaluate the complexity of the questions and the need for clarity where necessary. Once all the feedback was received from the pilot respondents, the final draft was put together as a final TerSCK instrument.

Two issues were raised as concerns from the pilot study. Firstly items 2.3 and 3.2 were not clear to the respondents. For example, one respondent highlighted that:

> "…*please Indicate more clearly what kind of confusion you expect here, is it for the teacher or the learner? and what is the benefit of knowing about this tension? – that is what must the teacher do*?

As a result of this feedback, the two items were augmented to be more specific. Item 2.3 and 3.2 were revised as follows:

2.3. The school science curriculum states that "*organic compounds are restricted… to a maximum of two functional groups of the same type per compound* (DBE, 2011 p 105)"

What difficulty in terms of the teachability and the perpetuation of misconceptions do you anticipate in dealing with the two structures when teaching about the knowledge of general empirical formulas?

3.2. The school science curriculum states that: "*isomers are restricted to structural isomers: (1) chain isomers (different chain); (2) positional isomers (different position of the same functional group) and (3) functional isomers (different functional group).* (DBE, 2011 p 105)"

What difficulty in terms of the teachability and the perpetuation of misconceptions do you anticipate in making the difference between the two structures clear to learners?

Figure 7.7: Revised items on tension for inclusion in the final instrument

The revision indicated in Figure 7.7 clearly shows that the focus was on the teaching aspect and not on the learning perspective.

The second clarity was on item 4.1. Here the respondents were requested to define how they could employ the scientific inquiry to highlight key steps to generate the set of the observed data pattern. One of the comments that emerged from the pilot was:

“*It is not clear which form of inquiry is referred to”.*

So, the question was therefore revised to include specifically the scientific method. All the other items were found by the pilot respondent to be clearer to respond to. In addition to these comments, the pilot responses were also used to refine the TerSCK rubric which was developed in conjunction with the marking memorandum and the set performance objective of the intervention. The next section provides information on how the rubric was improved following the pilot research.

7.9 Refining the developed TerSCK rubric

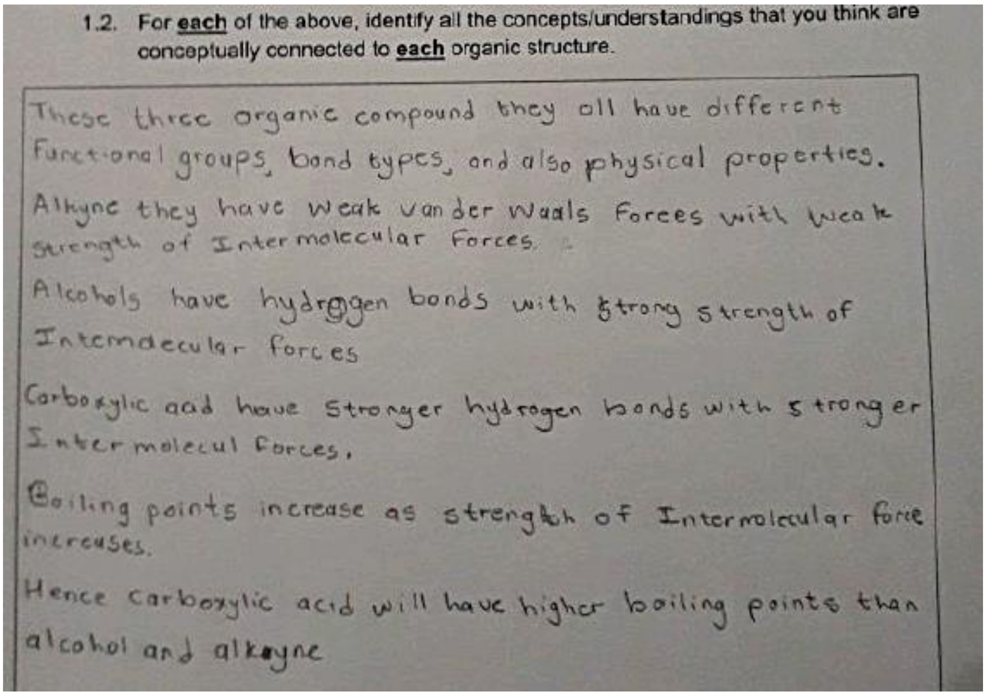
The TerSCK instrument in Appendix L was developed simultaneously with a corresponding TerSCK marking memorandum (see Appendix M) and an accompanying TerSCK rubric (see Appendix O) based on the performance objectives explicated in Chapter 6. The qualitative responses generated from the questionnaire were converted into quantitative scores using the TerSCK rubric with a Likert scale of 1 – 4 indicating the development in the quality of TerSCK. This method is commonly used in several studies that developed instruments to measure professional teacher knowledge such as TSPCK in chemistry, for example, Malcolm et al. (2019) in stoichiometry, Davidowitz and Vokwana (2014) in organic chemistry.

The rubric designed had four categories of performances ranging from poor to outstanding knowledge of TerSCK in each element, see Appendix N for the first version of the TerSCK rubric. The performance descriptions in each element of TerSCK were aligned to the objectives intuitively by the researcher since the construct is fairly new. For example, consider the knowledge of the interconnection between the concepts. Table 7.2 shows an extract from the first version of the designed rubric indicating the progression in the knowledge of TerSCK across the Likert scale of 1 – 4.

Table 7.2: Extract from the first TerSCK rubric

TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	**1**	**2**	**3**	**4**
Interconnections between the concepts of the fundamentals	An insufficient number of concepts are identified relating to the fundamental The concept map drawn shows incorrect links between the concepts The explanation of the nature of the connections is conceptually incorrect	An acceptable number of concepts are identified relating to the fundamental The concept map is drawn but no linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to organic chemistry	A sufficient number of concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to only organic chemistry	A sufficient number of concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are not limited to only organic chemistry

From the five pilot responses, both the researcher and the module co-instructor scored the responses to establish clarity of the performance descriptions. It emerged that the initial rubric was not clear and articulate in separating the responses across the performance categories. For example, see a pilot response in Figure 7.7 against the initial version of the rubric.



1.2. For **each** of the above, identify all the concepts/understandings that you think are conceptually connected to **each** organic structure.

These three organic compound they all have different Functional groups, bond types, and also physical properties.

Alkyne they have weak van der Waals Forces with weak strength of Intermolecular Forces.

Alcohols have hydrogen bonds with strong strength of Intermolecular forces

Carboxylic acid have Stronger hydrogen bonds with stronger Intermolecul Forces,

Boiling points increase as strength of Intermolecular force increases.

Hence carboxylic acid will have higher boiling points than alcohol and alkyne

Figure 7.8: Pilot response on the identification of concepts connected to each molecule

The first version does not quantify the number of concepts identified, it only says an "insufficient", "acceptable" or "sufficient" number of concepts were identified. This posed a challenge in grading. With the help of the module co-instructor, the rubric was revised (see Appendix O) for clarity and articulation. After the revision, the performance descriptors became clearer in separating from poor to outstanding knowledge of TerSCK, see Table 7.3 for the same element of interconnections between the concepts.

Table 7.3 Extract from the revised TerSCK rubric

TerSCK item	Poor	Limited	Good	Outstanding
Likert cale	**1**	**2**	**3**	**4**
Interconnections between the concepts of the fundamentals	At most three concepts are identified relating to the fundamental No concept map is drawn to show links between the concepts The explanation of the nature of the connections is conceptually incorrect	At most four concepts are identified relating to the fundamental The concept map is drawn but with limited linking words to show connections The explanation of the nature of the connections is partially correct The concepts identified are limited to organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to only organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are not limited to only organic chemistry

After revising the rubric, it was easier to locate the response in Figure 7.7 in an appropriate performance category, in this case, it was category 1, indicating poor knowledge of interconnection as at most three concepts were identified, viz: type of intermolecular forces, their relative strength and boiling point. The same was done with all the other TerSCK elements.

7.10 Validation of the instrument

After the pilot, Aithal and Aithal (2020) recommend that the researcher may conduct a full trial test with the envisioned participants for preliminary statistical validation of the instrument. Hence, in this study, the full trial involved giving the final version of the TerSCK instrument to a sizable number of participants, N = 35. Once the responses were collected from this process, they were marked using a TerSCK memorandum designed for this study designed along with the final version. Furthermore, the TerSCK rubric was used to generate ordinal scores from the qualitative responses. However, before the actual grading of the responses from the 35 respondents, there was a need to improve rater reliability. To determine this, both the researcher and the module co-instructor marked three sampled responses. Table 7.4 shows the results of this process.

Table 7.4: Results for determining inter-rater reliability

		Interconnection	Tensions	Inquiry	Cultivation
PST X	Rater 1	2	1	2	2
	Rater 2	1	1	2	2
PST Y	Rater 1	2	1	1	2
	Rater 2	2	1	1	2
PST Z	Rater 1	3	1	1	2
	Rater 2	3	1	2	2

From the independent rating process. It was found that 10/12 cases were scored similarly between raters. This translated to 83% of inter-rater reliability. The two cases of disagreement were deliberated up until an agreement was established by the rater.

To begin with, the knowledge of the fundamentals was assessed using an adapted instrument that supplemented the TerSCK instrument as an addendum. The raw score from this was converted to percentages as explained in the methodology so that they could be located within a Likert scale of 1 – 4. See Appendix S for these scores and conversions.

Table 7.5 summarises the raw scores generated after all responses from the 35 participants were marked and converted using the TerSCK rubric.

Table 7.5: Raw ordinal scores (N= 35) using the TerSCK rubric

Codes	Names	Fundamentals	Interconnect.	Tensions	Inquiry	Cultivation	Person average
PST1	Vishnu	2	2	1	2	2	**2**
PST2	Morgan	1	2	2	1	3	**2**
PST3	Thami	2	1	1	1	1	**1**
PST4	Thando	2	2	2	1	2	**2**
PST5	Maxwell	3	3	1	3	2	**2**
PST6	Nosipho	3	2	2	2	2	**2**
PST7	Lexie	4	1	2	1	3	**2**
PST8	Sabelo	1	1	1	1	2	**1**
PST9	Themba	3	2	1	1	1	**2**
PST10	Nelson	2	2	3	3	3	**3**
PST11	Lettie	1	1	1	3	2	**2**
PST12	Peter	2	1	1	1	1	**1**
PST13	Anita	4	3	2	1	3	**3**
PST14	Alex	3	1	1	1	2	**2**
PST15	Cebo	3	3	2	1	2	**2**
PST16	Jacob	3	3	1	3	2	**2**
PST17	Mfanafuthi	2	1	1	1	2	**1**
PST18	Nomkhosi	1	2	1	1	2	**1**
PST19	Telford	3	2	2	1	2	**2**
PST20	Thembela	3	2	1	1	2	**2**
PST21	Sifiso	2	1	1	1	2	**1**
PST22	Lindane	2	1	1	1	2	**1**
PST23	Bandile	3	3	1	1	2	**2**
PST24	Andile	4	3	3	3	3	**3**
PST25	Mpunki	1	2	2	1	1	**1**
PST26	Luyanda	3	2	1	1	1	**2**
PST27	Odwa	2	2	1	1	2	**2**
PST28	Khulekani	3	2	1	1	1	**2**
PST29	Siyanda	3	2	1	1	2	**2**
PST30	Oretha	3	3	2	3	2	**3**
PST31	Junior	4	2	2	1	3	**2**
PST32	Naledi	4	3	3	3	3	**3**
PST33	Mpho	2	3	2	1	2	**2**
PST34	Asanda	2	3	1	1	3	**2**
PST35	Karabo	2	2	1	2	2	**2**
Average Item Score		**3**	**2**	**1**	**1**	**2**	**2**

On average, the PSTs achieved a score of 3, indicating good knowledge of the “Fundamentals”. Both the knowledge of “Interconnections” and the “Cultivation” scored a 2, indicating limited knowledge of TerSCK whilst the “Tensions” and “Inquiry” scored a 1, indicating poor knowledge of TerSCK.

Across the TerSCK elements, the person averages indicate that 8 (23%) PSTs indicated POOR knowledge of TerSCK. 22 (63%) PSTs attained a score of 2, indicating limited TerSCK knowledge and 5 (14%) got a 3, indicating good knowledge of TerSCK in functional group chemistry and isomerism.

The Rasch statistical model was used to statistically analyse the raw scalar data shown in Table 7.3. According to Boone and Rogan (2005), “*this model converts raw scores for each item into probability measures that can be placed on a linear scale*”. This was the case with the TerSCK score generated. The process was important to assist the next process of determining the statistical validity of the designed TerSCK instrument.

7.10.1 Validity of the instrument

As previously stated, the experts' judgement and the initial pilot study helped to ensure the face validity and content validity of the TerSCK instrument. Hence in this section, we report on the construct validity with the help of the Rasch fit statistics. The fit statistics from Rasch were used. The MNSQ and the ZSTD are valid for ranges of 0.5 to 1.5 and from –2 to + 2, respectively across the measured items for a valid construct (Boone et al., 2013). Figure 7.9 shows these fit measures taken from Rasch.

ITEM STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	ITEM
4	52	35	1.38	.34	.74	-.99	.78	-.46	.71	.65	77.1	71.5	Tensions
5	52	35	1.38	.34	1.49	1.79	1.40	1.04	.61	.65	68.6	71.5	Inquiry
3	71	35	-.39	.29	.71	-1.36	.69	-1.46	.73	.69	68.6	59.4	Interconnections
2	72	35	-.47	.28	.67	-1.61	.72	-1.26	.67	.69	60.0	59.2	Hist & Cultivation
1	90	35	-1.91	.29	1.42	1.66	1.41	1.62	.67	.67	45.7	60.4	Fundamentals
MEAN	67.4	35.0	.00	.31	1.01	-.1	1.00	-.1			64.0	64.4	
P.SD	14.3	.0	1.25	.03	.37	1.5	.33	1.2			10.6	5.8	

Figure 7.9: Item measure and fit statistics for the five items of the TerSCK construct.

According to the data shown in Figure 7.9, the fit statistics were satisfactory for the INFIT and OUTFIT MNSQ and ZSTD values across the five TerSCK items. In the summary of item statistics, it can be observed that the MNSQ INFIT values range from .67 for "Cultivation" items to 1.49 for the "Inquiry" items. The MNSQ OUTFIT ranges from 0.69 "Interconnections" item to 1.41 for the "Fundamentals" item. These are well within the acceptable range of 0.5 to 1.5 as articulated by Linacre (2012).

Secondly, the ZSTD INFIT values range from -0.99 for "Tensions" items to 1.79 for the "Inquiry" items. The ZSTD OUTFIT values range from -0.46 for the "Tensions" items to 1.62 for the "Fundamentals" items. Similarly, these were well within the satisfactory range of -2 to +2.

An MNSQ value of less than 0.5 indicates unexpected answers concerning a person's ability. This according to Malcolm et al. (2019) means that "*respondents were expected to score well on these items but did not"*. In this study, Figure 7.8 indicates that the participants performed as predicted by the Rasch model, there was no MNSQ value equal to .5. Furthermore, the item of "Inquiry" and the "Fundamentals" has an MNSQ fit indices above 1.00. This indicates a large degree of inexplicable variance, however, this does not reduce the measurement of the construct as pointed out by Boone et al. (2013).

Furthermore, Figure 7.9 shows different levels of item difficulty experienced by PSTs. The "Tensions" item in the final column, followed by the "Inquiry" item, was determined to be the most challenging. The item of "Interconnections" was found to be less difficult than the former and the latter. This followed the item of "Hist. & Cultivation". The item of the fundamentals was found to be easiest by the respondents. This was expected as the respondents had already completed a full course in organic chemistry at the 3rd-year level of the B. Ed program.

Figure 7.10 depicts a bubble plot diagram of the PSTs' performance with the items produced by the Rasch software. This plot is important in showing fit indices graphically in the same linear scale. According to Malcolm et al. (2019), "*the fit indices are indicated along the x-axis of the bubble plot and the vertical axis shows the hierarchy of item difficulty and the person's ability measures on the same logit scale*".

This was also shown using a corresponding person-item may, refer to Appendix T for further details.

People have a 50% probability of accurately answering a question with the same level of difficulty on the same scale, according to the position of the bubbles. Higher-ability individuals are more likely to accurately answer questions higher on the scale, while individuals with lower ability measures are less likely to do so. In addition, A visual depiction of the mistake in guessing the respondent's position on the scale is provided by the size of the bubbles (Boone & Rogan, 2005). Figure 7.10 summarises these fit statistics graphically.

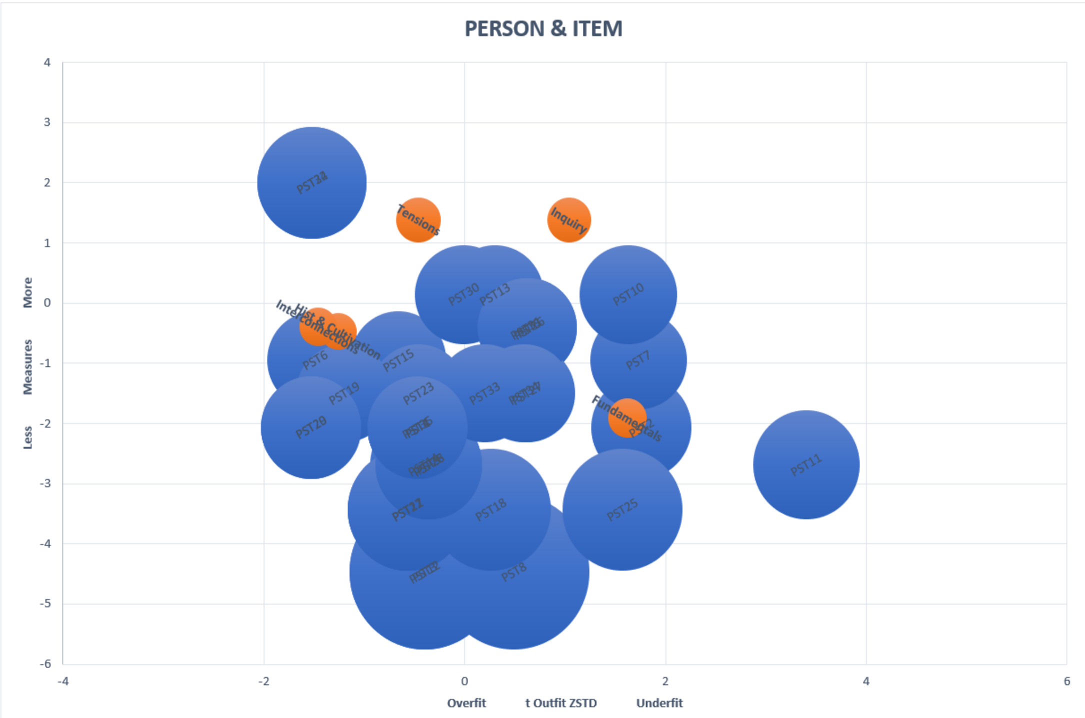


Figure 7.10: Bubble item–person plot for pre-intervention TerSCK items

Similar, to the data presented in Figure 7.9 earlier, Figure 7.10 shows graphically that the items are within the acceptable fit statistic of -2;2 of the t ZSTD. In addition, the bubble plot shows that PST 11 is an outlier. This was expected as the respondent performed below expectation on the easier item "Cultivation" and performed better on the difficult item of "Inquiry" from the raw scores. Furthermore, item difficulty is shown by the position of the items again on the vertical logit scale. The "Tension", "Inquiry" and "Interconnections" items were at the top (above the zero point) and the

“Cultivation” and “Fundamentals” were at the bottom of the logit scale (below the zero point). This graphically indicates the order of difficulty.

From the analysis generated in both Figures 7.9 and 7.10, the good person and item fit statistic provided empirical evidence that the designed TerSCK instrument measures a single construct using the case of organic chemistry and the two fundamentals as examples. Hence, therefore, this is an indication of acceptable construct validity. This kind of validity, taken together with both face and content validity established earlier deemed the TerSCK instrument valid for the two fundamentals. The next section focuses on the reliability of the instrument.

7.10.2 Reliability of the Instrument

Similar to validity, the concept of reliability is widely used in empirical research and it can refer to several things (Cohen et al., 2007). In this section, reliability was determined in terms of the internal consistency and stability of items (Bannigan & Watson, 2009). This is described as “*the consistency of measurements to yield the same kind of results when a testing technique is administered to a population of persons from the same group in a similar context*” (Cohen et al., 2007).

In addition to Cohen and colleagues’ assertion, internal consistency can be measured in several ways (Pallant, 2011). The most commonly used statistic is Cronbach's coefficient alpha. In this study, the analysis from Rasch revealed that this instrument produced a Cronbach alpha value of $\alpha = 0.669$ taken as $\alpha = 0.7$. This was evaluated as being good in reflecting the instrument's internal consistency, as Pallant proposed (2011).

Just like with the case of validity, the Rasch analysis was further utilized to estimate both person and item reliability measures. Figure 7.11 summarises some of these reliability indices based on the 35 persons (respondents) and 5 items (questions based on the elements of the TerSCK construct).

```
--------------------------------------------------------------------------------
| PERSON       35 INPUT       35 MEASURED               INFIT          OUTFIT    |
|            TOTAL     COUNT      MEASURE   REALSE    IMNSQ   ZSTD  OMNSQ   ZSTD|
| MEAN         9.6       5.0        -1.82      .91      .97    -.1   1.00     .0|
| P.SD         2.6        .0         1.58      .20      .75    1.1    .98    1.1|
| REAL RMSE     .94 TRUE SD     1.28  SEPARATION  1.37  PERSON RELIABILITY  .65|
|-------------------------------------------------------------------------------|
| ITEM         5 INPUT        5 MEASURED               INFIT          OUTFIT    |
|            TOTAL     COUNT      MEASURE   REALSE    IMNSQ   ZSTD  OMNSQ   ZSTD|
| MEAN        67.4      35.0          .00      .33     1.01    -.1   1.00    -.1|
| P.SD        14.3        .0         1.25      .05      .37    1.5    .33    1.2|
| REAL RMSE     .34 TRUE SD     1.20  SEPARATION  3.56  ITEM   RELIABILITY  .93|
--------------------------------------------------------------------------------
```

Figure 7.11: Person and item reliability indices

The persons' reliability was 0.65 (65%) separated by a 1.37 index. The items' reliability was 0.93 (93%) separated by a 3.56 index. The instrument is reliable since it has both easy and difficult items, as seen by the excellent item reliability of 0.93. Figures 7.9 and 7.10 supports this inference. According to Bond and Fox (2013), "*the higher the item reliability index the more certain can be placed in the consistency of the inferences made from the development of the instrument*". Hence, the person's reliability index for this instrument at 0.65 indicated an acceptable index above 0.6 as discussed by Bond and Fox (2013). This indicates that there is sufficient confidence in the inferences about assessing a person's ability to use the developed tool.

7.11 Conclusion

This chapter was geared towards developing a valid and reliable instrument for collecting data portraying TerSCK in organic chemistry. This was in line with the objective of the intermediate step in the whole research process. Given the large scope of the topic and the novelty of the TerSCK construct, two fundamentals were chosen to inform the content of this research project. This was crucial in responding to the third research question of the entire study.

The study reported by Davidowitz and Vokwana (2014) was essentially important to assess the knowledge of "pure" content knowledge sufficient enough to teach organic chemistry in South Africa. It was for this reason that the item of the fundamentals in organic chemistry was not included in the development of the instrument, however, it was measured separately with an adapted CK tool which forms part of this instrument development process and that of construct validity processes. For the production, characterization and judgement of the items, the focus was only given to the other four elements of the construct as these were not explored previously in any study.

Following the construct method and drawing from the affordances of the rational methods, the role of the experts was essential in establishing both content and face validity. The Rasch model was employed to produce appropriate fit statistics in establishing construct validity. The TerSCK items were found valid within 0.5 to 1.5 of the MNSQ INFIT and OUTFIT values. Similar to the ZSTD OUTFIT and INFIT values, TerSCK items were valid in the range of -2 to +2. Hence, the instrument was found to be valid.

In addition, the instrument designed to measure TerSCK shows that there is a ranked structure distinguishing the difficulty of each TerSCK item. The item of “Tensions” was found to be the most difficult than the rest of the items. This item of the “Cultivation” was found to be the least difficult item.

Regarding the internal consistency and the stability of the items, the instrument was found to be reliable with an acceptable Cronbach alpha of 0.7. In addition, both the items and persons had good reliable indices of 0.93 and 0.65 respectively. Hence the instrument was found to be reliable. The next stage of this research is to report on ways of validating the TerSCK theoretical construct. This was largely informed by data collected pre- and post-intervention to investigate if this kind of content knowledge could be developed in pre-service teacher training.

CHAPTER 8 DEVELOPING CONTENT KNOWLEDGE FOR TEACHING THROUGH A TERSCK-BASED INTERVENTION

This chapter extends from the work done in Chapter 6 to reports on the effects of the TerSCK-based intervention on PSTs' knowledge of TerSCK in organic chemistry. Qualitative data was collected and translated to quantitative ordinal scores for statistical analysis. Similarly, qualitative data were analysed for mapping up the nature of improvements in the quality of content knowledge related to teaching observed after the explicit intervention that developed TerSCK using two fundamentals of organic chemistry. Before and after the intervention, the validity of the TerSCK construct was evaluated as part of the major purpose of this study. Hence, the findings that are reported in this chapter were useful in responding to the second question asked in Chapter 1.

8.1 Introduction

The previous chapter has established that the instrument developed in this study was found to be valid and reliable to capture and measure the quality of TerSCK in the two fundamentals of the discipline of organic chemistry. Data were generated from PSTs who were purposively sampled. As highlighted earlier, this group of students specialized in physical science teaching and were enrolled in a methodology course that was geared to develop knowledge for teaching school science. Before the explicit intervention that targeted the development of TerSCK through its five knowledge elements, data was collected with a designed and piloted tool. The pre-intervention data was analyzed and was used in two folds. Firstly, to determine the validity of the TerSCK theoretical construct. Secondly, to determine the statistical reliability of the instrument, *see* chapter 7.

In this chapter, the second set of data was collected post-intervention using the same instrument to compare both qualitative responses and quantitative scores for any significant improvement in the knowledge of TerSCK by the same group of PSTs. This comparison has been crucial to determining whether the TerSCK theoretical construct was still valid after the intervention and to investigating the kind of improvement in the level of content knowledge in teaching organic chemistry that resulted from it.

As indicated earlier in chapter 3, this second phase entailed a convergent mixed-method analysis. Therefore, qualitative data collected through the TerSCK instrument was analysed by means of a TerSCK rubric with a Likert scale of 1 to 4, indicating an improvement in the performance categories of TerSCK across each knowledge element. The PSTs' qualitative answers from the instrument were compared for any observable shifts in the knowledge of the construct after the intervention. The set of ordinal scores generated from the rubric was then processed through a Ministep software version 5.3.1.0 for Rasch analysis. This provided for statistical analysis of the quantitative improvements in the quality of TerSCK and the validity of the construct post-intervention.

In addition to this rash analysis, the Wilcoxon Signed Rank Tests were also determined through SPSS to evaluate the statistical difference between pre and post-intervention performance. To begin with, the next section below uses the ordinal set of scores generated before and after the intervention to analyse the observed shifts in the knowledge of TerSCK in the two fundamentals discussed during the intervention. Similarly, the CK scores were generated separately for inclusion in the composite scores. See Appendix S for the CK scores.

8.2 Quantitative analysis of the quality of TerSCK in organic chemistry

To improve the reliability of the rating process, two raters (the researcher and the module co-instructor) scored three sampled responses independently and reached inter-rater reliability of 82% and 92% for pre and post-test respectively. In the post-test scoring, there was only one disagreement out of 12 and hence 92%. In this case, the raters discussed using compelling evidence from the student's responses and against the rubric criterion to reach a consensus.

Table 8.1 shows the ordinal scores produced from PSTs' answers in the pre-intervention and post-intervention tests. In the last column, the scores were averaged to quantitatively map the overall performance across different TerSCK knowledge elements for each PST. The last row shows the average performance in each TerSCK knowledge element by all the PSTs. The shifts were based on the statistically computed average scores for each person and each TerSCK knowledge element. The overall results for the pre-intervention and post-intervention were interpreted using the respective response categories, which range from poor to outstanding understanding of TerSCK in the two fundamentals and reflected the quality of TerSCK described in the rubric.

The estimated averages are used in this research as a stand-in for measuring the TerSCK knowledge's overall and summative outcome. The average scores were typically produced during the analysis as decimals. This restriction on the sensitivity of the rubric scale for Mavhunga (2016) in TSPCK necessitated that the scores be rounded off in the analysis in order to place them appropriately in the corresponding category. To classify the average scores in TerSCK performance categories, they have been rounded off as indicated in Table 8.1.

Table 8.1: Comparison of pre- and-post-intervention ordinal scores

Name	**Code**	**Fundamentals**		**Interconnections**		**Tensions**		**Inquiry**		**Cultivation**		**Person Average**	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Nokulunga	PST1	3	**3**	2	**3**	1	**2**	2	**2**	2	**3**	2	**3**
Morgan	PST2	2	**4**	2	**3**	2	**3**	1	**1**	3	**3**	2	**3**
Thami	PST3	3	**2**	1	**2**	1	**2**	1	**1**	1	**3**	1	**2**
Thando	PST4	3	**4**	2	**3**	2	**3**	1	**1**	2	**3**	2	**3**
Maxwell	PST5	3	**4**	3	**4**	1	**3**	3	**4**	2	**3**	2	**4**
Nosipho	PST6	3	**4**	2	**3**	2	**3**	2	**3**	2	**2**	2	**3**
Lexie	PST7	4	**3**	1	**4**	2	**2**	1	**1**	3	**3**	2	**3**
Sabelo	PST8	1	**4**	1	**2**	1	**2**	1	**1**	2	**3**	1	**2**
Themba	PST9	3	**4**	2	**2**	1	**2**	1	**1**	1	**2**	2	**2**
Nelson	PST10	2	**4**	2	**3**	3	**4**	3	**4**	3	**4**	3	**4**
Lettie	PST11	1	**4**	1	**4**	1	**2**	3	**4**	2	**2**	2	**3**
Peter	PST12	4	**4**	1	**2**	1	**2**	1	**1**	1	**2**	2	**2**
Sonto	PST13	3	**4**	3	**4**	2	**3**	1	**1**	3	**3**	2	**3**
Mongezi	PST14	3	**4**	1	**2**	1	**2**	1	**2**	2	**3**	2	**3**
Cebo	PST15	3	**4**	3	**4**	2	**3**	1	**3**	2	**3**	2	**3**
Jacob	PST16	3	**3**	3	**3**	1	**2**	3	**3**	2	**3**	2	**3**
Mfanafuthi	PST17	2	**3**	1	**2**	1	**2**	1	**3**	2	**3**	1	**3**
Nomkhosi	PST18	1	**2**	2	**4**	1	**3**	1	**3**	2	**3**	1	**3**
Thokozani	PST19	4	**4**	2	**3**	2	**3**	1	**1**	2	**3**	2	**3**
Thembela	PST20	4	**4**	2	**3**	1	**2**	1	**2**	2	**3**	2	**3**
Sfiso	PST21	2	**4**	1	**1**	1	**1**	1	**1**	2	**3**	1	**2**
Lindani	PST22	2	**4**	1	**2**	1	**2**	1	**1**	2	**2**	1	**2**

Name	Code	Fundamentals		Interconnections		Tensions		Inquiry		Cultivation		Person Average	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Bandile	PST23	4	**4**	3	**4**	1	**4**	1	**1**	2	**3**	2	**3**
Andile	PST24	4	**4**	3	**4**	3	**4**	3	**4**	3	**3**	3	**4**
Mpunki	PST25	1	**4**	2	**2**	2	**2**	1	**1**	1	**1**	1	**2**
Luyanda	PST26	3	**3**	2	**3**	1	**1**	1	**1**	1	**2**	2	**2**
Zodwa	PST27	4	**4**	2	**2**	1	**1**	1	**2**	2	**2**	2	**2**
Khulekani	PST28	3	**4**	2	**2**	1	**1**	1	**1**	1	**2**	2	**2**
Ziyanda	PST29	2	**4**	2	**2**	1	**2**	1	**1**	2	**3**	2	**2**
Owethu	PST30	2	**3**	3	**3**	2	**3**	3	**4**	2	**3**	2	**3**
Junior	PST31	4	**4**	2	**3**	2	**2**	1	**1**	3	**3**	2	**3**
Naledi	PST32	4	**4**	3	**4**	3	**3**	3	**3**	3	**4**	3	**4**
Mpho	PST33	2	**4**	3	**3**	2	**2**	1	**3**	2	**2**	2	**3**
Asanda	PST34	2	**3**	3	**4**	1	**1**	1	**2**	3	**3**	2	**3**
Karabo	PST35	2	**4**	2	**3**	1	**3**	2	**3**	2	**2**	2	**3**
Item Average		3	**4**	2	**3**	1	**2**	1	**2**	2	**3**	2	**3**

NOTE:
For each TerSCK element, the bold scores were generated post-intervention. The non-bold scores were generated pre-intervention. (N =35)

Briefly, PSTs showed an overall improvement of a 1-category shift in all the TerSCK knowledge elements. Both the “Interconnections” and “Hist & Cultivation” jumped from a score of 2 indicating limited TerSCK knowledge to 3 indicating good knowledge of TerSCK. The “Tension” and “Inquiry” on the other hand have registered a jump from a score of 1 indicating poor TerSCK knowledge to a score of 2, indicating a limited knowledge of TerSCK post-intervention. The knowledge of the “Fundamentals” registered a shift from a score of 3 indicating good knowledge of TerSCK to 4, indicating an outstanding knowledge of TerSCK in the two fundamentals of organic chemistry.

Furthermore, the last column shows the average TerSCK score across all the elements of the construct per PST. Out of the 35 PSTs who were studied, 6 (17%) of them did not experience any quantitative shifts in their overall performance in TerSCK, see the last column on the average performance. Interestingly, they all maintained a score of 2, indicating limited knowledge of TerSCK pre and post-intervention.

In addition, 26 (74%) of the participating PSTs improved their quality of TerSCK in organic chemistry by one category shift. 5 of the 26 PSTs improved from 1 to 2 indicating a shift from poor to limited knowledge of TerSCK. 18 out of 26 improved from 2 to 3 indicating a shift from limited to good knowledge of TerSCK in organic chemistry. Lastly, 2 of the 26 PST improved from 3 to 4 indicating a shift from good to outstanding knowledge of TerSCK after the intervention.

Furthermore, 3 (9%) of the participating PST registered a shift of 2 in the quality of their TerSCK in the topic of organic chemistry. 2 out of the 3 improve from 1 to 3 indicating a shift from poor to good knowledge of TerSCK. 1 out of 3 improved from 2 to 4 indicating a shift from limited to outstanding knowledge of TerSCK in the topic.

As indicated earlier, the ordinal scores from Table 8.1 were separately analysed by the Rasch software to establish the level of difficulty of the TerSCK elements pre-and post-intervention. According to Boone and Rogan (2005), *"the raw scores at either end of the Likert scale have the greatest margin of error, so the use of Rasch person measures would provide a precise picture of performance in a test"*. As indicated in Chapter 3, this made it possible to determine the reliability and validity of each of the items and the persons using fit statistics, reliability indices, and separation reliability. (Bond & Fox, 2007). In addition, it also allows the construction of person-item maps to examine the level of difficulty in the elements that makes up the construct by "*evaluating the distribution of items along the latent scale*" (Boone et al., 2013).

8.2.1 Establishing reliability of persons and items

Conventionally, a Cronbach alpha is calculated to reflect the instrument's reliability. (Boone & Rogan, 2005). In addition, the Rasch analysis provided two more reliability measures, viz.: items and persons. However, in this analysis, the pre and post-intervention scores were not analyzed separately in the Rasch software. Just like in Ndlovu and Malcolm (2022), the scores were stacked. This meant that although the PSTs who had undergone the TerSCK-based intervention were still considered to be a part of the target group, they were viewed as distinct, and as a result, the post-test results represented different individuals (Linacre, 2012; Wright, 2003). In effect, this changed the sample size from 35 to 70. By this, Ndlovu and Malcolm (2022) asserted that "*the principle of stacking the data was applied to interpret changes in scores, but here each person appears twice (pre and post) to indicate changes in their* *understanding*”. The stacked data's person and item reliability indices are summarized in Figure 8.1.

```
-------------------------------------------------------------------------------
| PERSON      70 INPUT      70 MEASURED               INFIT          OUTFIT    |
|           TOTAL     COUNT      MEASURE  REALSE    IMNSQ   ZSTD  OMNSQ   ZSTD|
| MEAN       11.6       5.0        -.49     .89      1.00     .0  1.00     .0|
| P.SD        3.1        .0        1.90     .23       .59     .9   .68     .9|
| REAL RMSE     .92 TRUE SD    1.66  SEPARATION  1.81  PERSON RELIABILITY  .77|
|-------------------------------------------------------------------------------|
| ITEM        5 INPUT       5 MEASURED                INFIT          OUTFIT    |
|           TOTAL     COUNT      MEASURE  REALSE    IMNSQ   ZSTD  OMNSQ   ZSTD|
| MEAN      162.8      70.0         .00     .23      1.00    -.3  1.00    -.2|
| P.SD       38.1        .0        1.59     .03       .37    2.2   .26    1.1|
| REAL RMSE     .23 TRUE SD    1.57  SEPARATION  6.84  ITEM   RELIABILITY  .98|
-------------------------------------------------------------------------------
```

Figure 8.1: Person and item reliability indices of stacked data

The person reliability was found to be 0.77 (77%) separated by an index of 1.81, this was an improvement from the indices reported before the intervention. The item reliability was found to be 0.98 (98%) separated by an index of 6.84, again this indicates an improvement in the reliability of items from the pre-intervention score. These values were taken to indicate good reliability of persons and items above .7 (Boone et al., 2013). Table 8.2 shows this comparison between pre-intervention scores and stacked data that is inclusive of post-intervention scores.

Table 8.2: Comparison of reliability indices for pre-intervention and stacked data

	Pre-intervention	Stacked data
Person reliability	0.65	0.77
Separation index	1.37	1.81
Item reliability	0.93	0.98
Separation index	3.56	6.84

The next section is focused on reporting on the validity of the score and the construct of TerSCK.

8.2.2 Establishing validity post-intervention

In chapter 7, the pre-intervention scores were used to establish the initial validity of the instrument designed to measure the quality of TerSCK in organic chemistry and ultimately, the construct of TerSCK. In this chapter, the focus is on the staked data to check for the same validity of the instrument and that of the construct. Boone et al. (2013) suggested that when evaluating items and the persons' fit measures, the focus should be given largely on the OUTFIT, particularly the MNSQ values. Briefly, according to them, "*the MNSQ (mean-square) is a chi-square calculation for the outfit and infit statistics. The ZSTD (z-standardized) provides a t-test statistic measuring the probability of the MNSQ calculation occurring by chance*".

Linacre (2012) also pointed out that the OUTFIT statistics are more sensitive to outliers making it easier to recognize and enhance issues of the misfit. In addition, Linacre (2012, p. 622) also highlighted specifically that for reporting purposes, only OUTFIT statistics need to be reported; "*unless the data are heavily contaminated with irrelevant outliers, then reporting infit may be appropriate".* So Figure 8.2 presents the measure order of the TerSCK items and the fit statistics observed.

ITEM STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	ITEM
5	117	70	1.94	.22	1.37	1.95	1.08	.37	.73	.72	58.6	66.5	Inquiry
3	132	70	1.24	.21	.57	-3.01	.63	-1.98	.83	.74	75.7	62.0	Tensions
4	166	70	-.14	.20	.77	-1.49	.98	-.04	.70	.75	62.9	58.7	Hist & Cultivation
2	172	70	-.37	.20	.78	-1.37	.88	-.64	.78	.75	65.7	59.0	Interconnections
1	227	70	-2.67	.22	1.52	2.63	1.44	1.36	.60	.67	50.0	65.3	Fundamentals
MEAN	162.8	70.0	.00	.21	1.00	-.26	1.00	-.18			62.6	62.3	
P.SD	38.1	.0	1.59	.01	.37	2.17	.26	1.11			8.4	3.2	

Figure 8.2 Item measure and fit statistics for the five items of the TerSCK construct.

Just like in the instrument validation stage, PSTs experienced the TerSCK items at different levels of difficulty. The JMLE (Joint Maximum Likelihood Estimation) measure indicates that the "Inquiry" component was the most difficult at the 1.94 index and the "Fundamentals" were least difficult at a measure of -2.67, see the blue box in Figure 8.2. Slightly different from the pre-intervention data that reported the element of "Tensions" as the most difficult in TerSCK.

Examining the OUTFIT statistics reveals that the MNSQ values were well within the tolerable range of 0.5 – 1.5 with the highest fit value at 1.44 and the lowest value at .63. Similarly, the ZSTD values were within the reasonable range of -2 to +2. As advised by Linacre (2012), if the OUTFIT values lie within a tolerable range, the INFIT values are overlooked, see the red box in Figure 8.2. So, both the chi-square calculation and the t-test shows that the TerSCK construct was valid for the stacked data analysis.

8.2.3 Quantitative improvements in TerSCK: Comparing person and item measures

The person-item map in Figure 8.3 shows that there was an observable improvement in the ability of PSTs in answering TerSCK items post-intervention. 27 PSTs (denoted as X, for pre-intervention) were below the mean score and 8 were above the mean score. Post the intervention, 26 PSTs (denoted as Y for post-intervention) scored above the mean, and only 9 were below the mean score this shows an improved ability to respond to TerSCK items measured along the same logit scale. In addition, Figure 8.3 shows the measure order of the item difficulty measured through the same logit scale. This confirms the results discussed in Figure 8.2 about the item difficulty measure. The knowledge of the “Fundamentals” is high up in this logit scale whereas the item of the “Inquiry” is at the lowest.

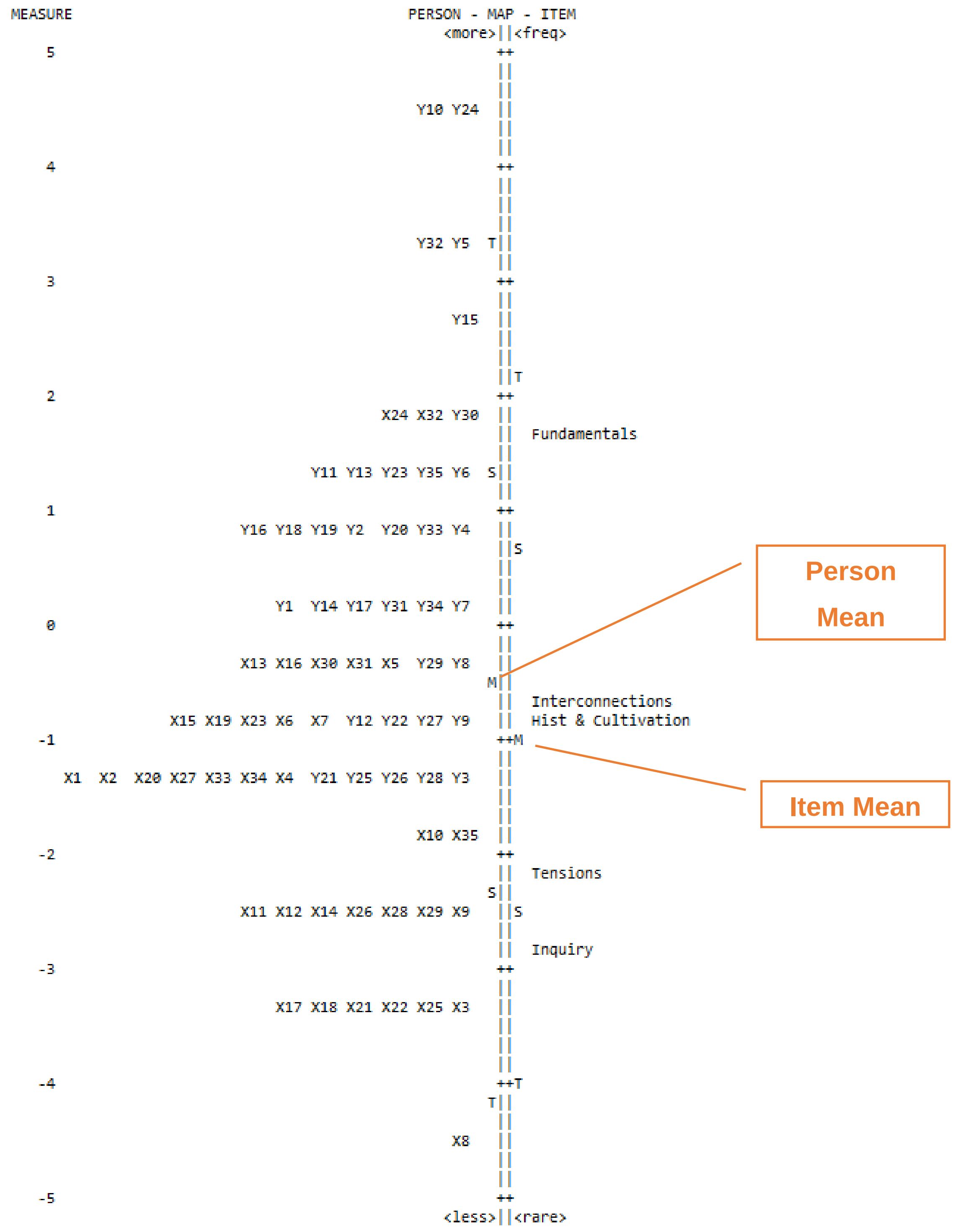


Figure 8.3: Person-item map for stacked data

8.2.4 Significant difference in TerSCK Scores pre and post-intervention

To further evaluate quantitative improvements in PSTs' knowledge of TerSCK in the two fundamentals, the significant difference between the pre and post-test results was examined. To do this, the Wilcoxon Signed Rank Test was applied. According to Taheri and Hesamian (2013). This non-parametric test "*is preferred because of its design for the use of repeated measures on two occasions under different conditions*" (Eftimov & Korošec, 2022). To use this statistical test, a null hypothesis had to be formulated for testing as per the requirements of this statistical analysis.

The null hypothesis made in this study is:

> "*There is no significant difference in the overall TerSCK performance of the pre-service teachers measured before and after the explicit TerSCK-based intervention*".

Figure 8.4 shows the results of the Wilcoxon Signed Rank Tests statistics determined through the SPSS.

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Post Test scores - Pre Test scores	Negative Ranks	0[a]	.00	.00
	Positive Ranks	29[b]	15.00	435.00
	Ties	6[c]		
	Total	35		

a. Post Test scores < Pre Test scores

b. Post Test scores > Pre Test scores

c. Post Test scores = Pre Test scores

Test Statistics[a]

	Post Test scores - Pre Test scores
Z	-5.166[b]
Asymp. Sig. (2-tailed)	<,001

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Figure 8.4: Pre and post-test scores on a Wilcoxon Signed Rank Test

The Wilcoxon Signed Rank Test revealed a statistically significant increase in the overall TerSCK performance of PSTs following participation in the TerSCK-based intervention, $z = -5.166$, $p < .001$, with a large effect size ($r = .87$). For a p-value less than or equal to .05 this means that the results are statistically significant (Andrade, 2019; Taheri & Hesamian, 2013) and we can trust that the difference is not due to chance alone. Similarly, an effect size greater than 0.8 is regarded as large (Pallant, 2011; Plonsky & Oswald, 2014). The effect size, as opposed to the p-value, can indicate the magnitude of a statistically significant difference between the two groups. (Plonsky & Oswald, 2014). In this case, it was found to be large. In conclusion, the null hypothesis was found invalid.

So, there is a significant difference in the overall TerSCK performance of the PSTs measured before and after the explicit TerSCK-based intervention. The observed quantitative shifts can be linked largely to the influence of the TerSCK intervention. In the next sections, the focus is given to the nature of qualitative shifts observed for each TerSCK knowledge element pre and post-intervention.

8.3. Qualitative analysis of the quality of TerSCK in organic chemistry

As pointed out earlier, data was generated through the valid TerSCK instrument as qualitative responses to open-ended questions about the knowledge of functional group chemistry and isomerism. The collected data was analysed following a mixed-method approach. The above sections reported on converted qualitative data to quantitative ordinal scores using the TerSCK rubric. In Table 8.1, the last row indicated the overall performance of the PSTs across each TerSCK knowledge element. The overall raw scores revealed that PSTs experienced a one-category improvement in their knowledge of TerSCK across all the other five elements of the construct.

In the next sections, extracts representing one category shifts from pre-intervention responses to post-intervention responses will be discussed. For each TerSCK element, the performance criterion was described in the TerSCK rubric. Note that, the element of the fundamentals was marked separately from the rubric using a corresponding memorandum. The raw marks were converted to percentages so that they could be located on the Likert scale of 1 to 4. Figure 8.5 shows an extract of the rubric used for this analysis.

TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	1	2	3	4
Knowledge of the fundamentals of the topic	There is poor knowledge of the content. Overall content knowledge performance is at 25% and below	There is limited knowledge of the content Overall content knowledge performance is between 25% - 49%	The respondent demonstrates good knowledge of the content Overall content knowledge performance is between 50% - 74%	The respondent demonstrates outstanding knowledge of the fundamental content Overall content performance is 75% and above.

Figure 8.5: TerSCK rubric extract on knowledge of the fundamentals of the topic

For example, if a PST obtains a score of 15/25, this translates to 60% which is 3 and it indicates good knowledge of the fundamentals of the topic. So, this was done for all the participating PSTs, pre and post-intervention. Table 8.1 indicates that on average, PST shifted from good to outstanding knowledge of the fundamentals.

8.3.1 Qualitative shifts in the knowledge of interconnections

This knowledge element of TerSCK entails an awareness that as much as organic chemistry concepts are found within a particular topic, they however do not exist in isolation. They relate and connect to other concepts from other topics within organic chemistry and other chemistry topics. On average, the participating PSTs experienced a category shift of 2 to 3 from pre to post the TerSCK intervention. This indicated a shift from limited to good knowledge of TerSCK in organic chemistry. Figure 8.6 shows the extract of the TerSCK rubric that was used to rate PSTs' responses

TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	1	2	3	4
Knowledge of the interconnections between the concepts of the fundamentals	At most three concepts are identified relating to the fundamental No concept map is drawn to show links between the concepts The explanation of the nature of the connections is conceptually incorrect	At most four concepts are identified relating to the fundamental The concept map is drawn but with limited linking words to show connections The explanation of the nature of the connections is partially correct The concepts identified are limited to organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to only organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are not limited to only organic chemistry

Figure 8.6: TerSCK rubric extract on the knowledge of interconnection

Below is a response from Nosipho responding to the first part of the question that probed the knowledge of interconnection. When asked to identify the concepts that are linked to each structure, the response by Nosipho identified three concepts that were linked to the structures given, these were homologous series, nomenclature and general formulae, see Figure 8.7.

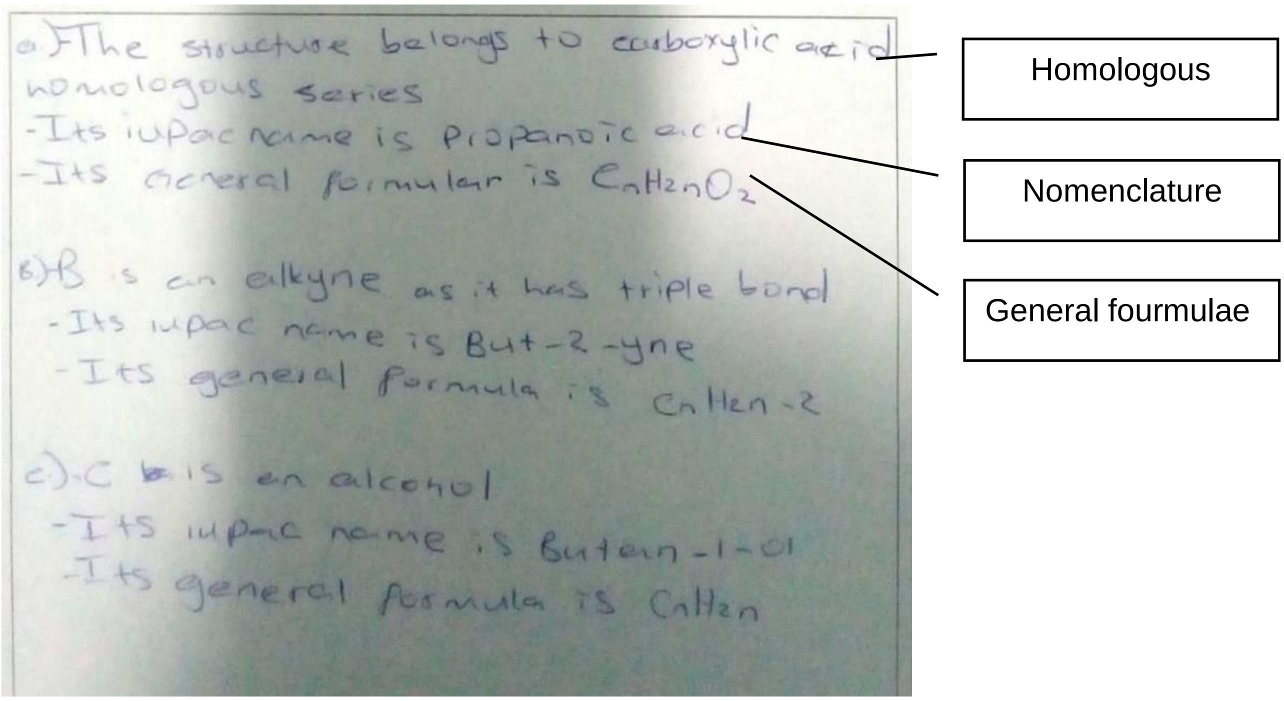


Figure 8.7: Nosipho's pre-test response to concept identification

Further to that, when asked to draw a concept map, Nosipho was limited to the concepts identified above, see Figure 8.8. The response was scored a 2 given that there was no clear indication of how the concepts identified were linked. Instead, the understanding was limited to how the alcohols react with carboxylic acids in the preparation of esters. In addition, some connecting ideas show that the knowledge of organic chemistry was partly incorrect. For instance, Nosipho indicated that the elimination of oxygen would lead to the production of an alkyne.

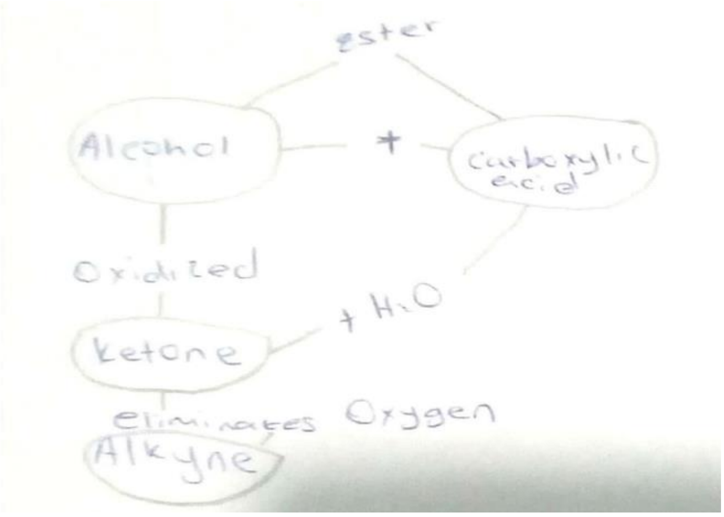
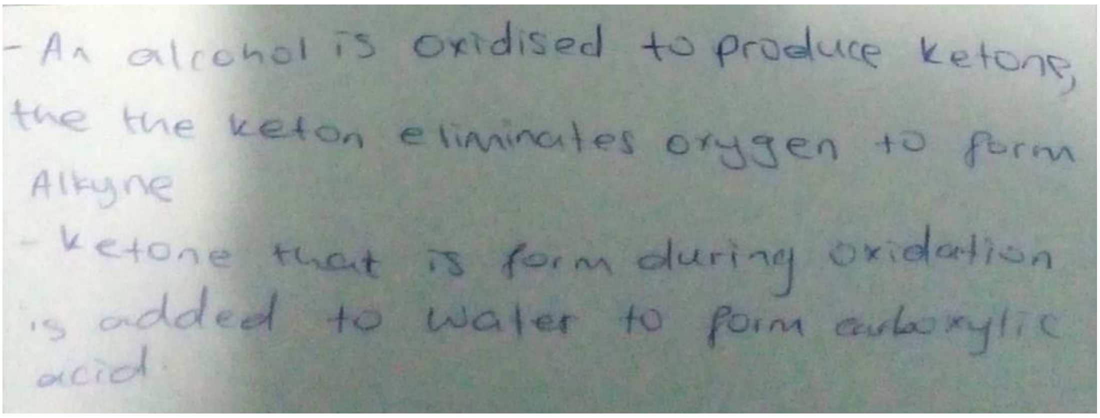


Figure 8.8: Nosipho's pre-test concept map

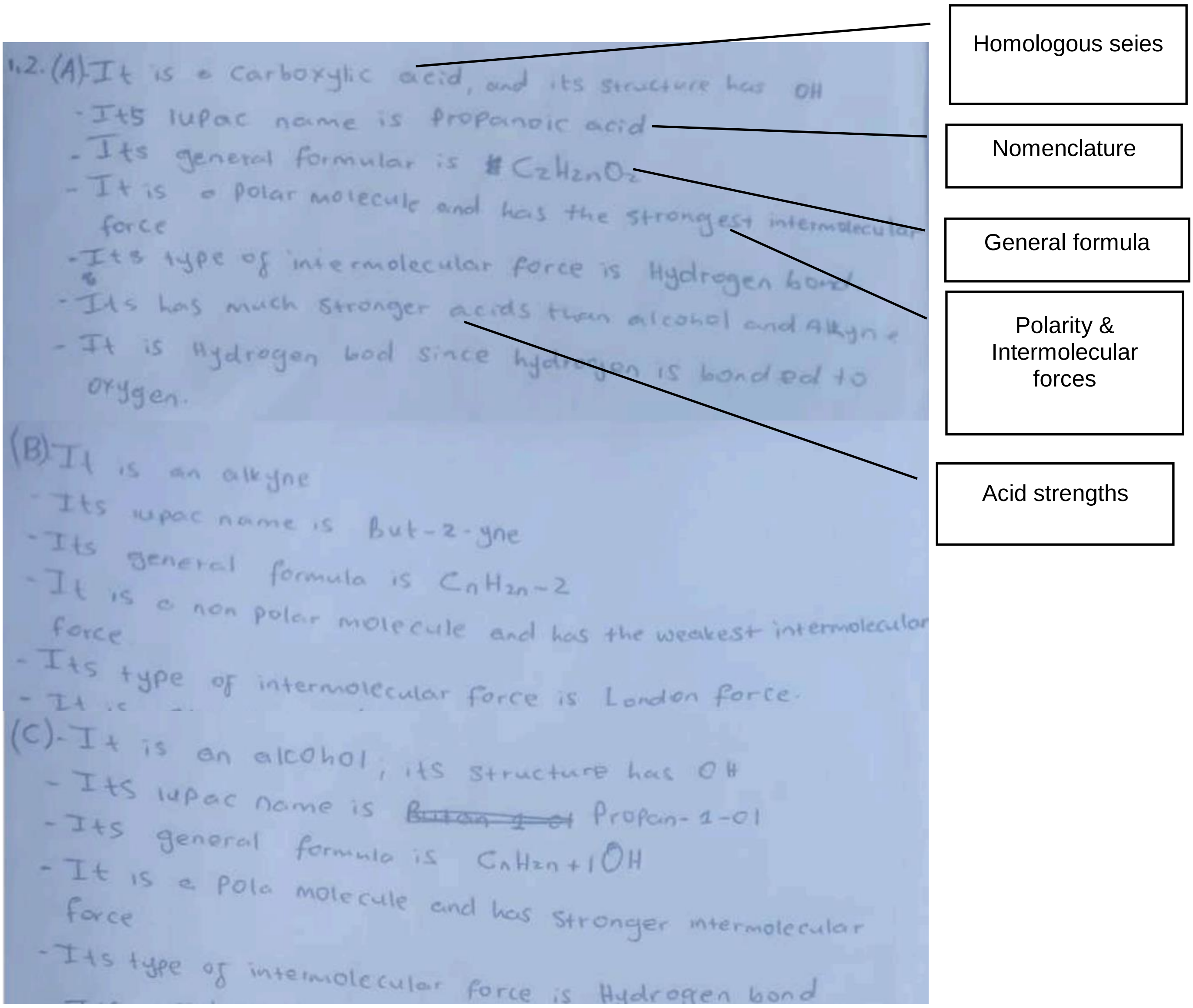
This response indicated limited knowledge of interconnections. Nosipho managed to identify at least 3 concepts however failed to pictorially represent how the identified concepts relate. The idea of just linking alcohols and carboxylic acids in terms of esterification stems from how these were generally taught in high school. This was confirmed after interviewing Nosipho. Furthermore, the concept map represented an incorrect reaction. i.e. alcohols are oxidised to ketone instead of aldehydes. As a result, the textual explanation of the concept map was also partially incorrect, see Figure 8.9. All of these responses revealed a limited knowledge of TerSCK on the topic.



- An alcohol is oxidised to produce ketone, the the keton eliminates oxygen to form Alkyne
- ketone that is form during oxidation is added to water to form carboxylic acid.

Figure 8.9: Nosipho's pre-test explanation of the interconnection

However, post the intervention Nosipho scored a 3, indicating good knowledge of interconnections in the topic. Firstly, more than four concepts were identified for each structure. These concepts are reflected on the right side in Figure 8.10. These include homologous series, the nomenclature, general formula, polarity and intermolecular forces and acidity of organic molecules.


1.2. (A) It is a Carboxylic acid, and its structure has OH
- Its Iupac name is Propanoic acid
- Its general formular is # $C_2H_{2n}O_2$
- It is a polar molecule and has the strongest intermolecular force
- Its type of intermolecular force is Hydrogen bond
- Its has much stronger acids than alcohol and Alkyne
- It is Hydrogen bod since hydrogen is bonded to oxygen.

(B) It is an alkyne
- Its iupac name is But-2-yne
- Its general formula is C_nH_{2n-2}
- It is a non polar molecule and has the weakest intermolecular force
- Its type of intermolecular force is London force.

(C) It is an alcohol, its structure has OH
- Its iupac name is ~~Butan-1-ol~~ Propan-1-ol
- Its general formula is $C_nH_{2n+1}OH$
- It is a Pola molecule and has stronger intermolecular force
- Its type of intermolecular force is Hydrogen bond

Figure 8.10: Nosipho's post-test response on concept identification

In addition to the choice of concepts shown in Figure 8.10, Nosipho was able to draw a concept map that outlines the nature to which the identified concepts are linked, see Figure 8.11. Even though the concept map lacked clear connecting words, the response was given a score of 3, for good TerSCK knowledge because it was found to have identified a sufficient number of concepts.

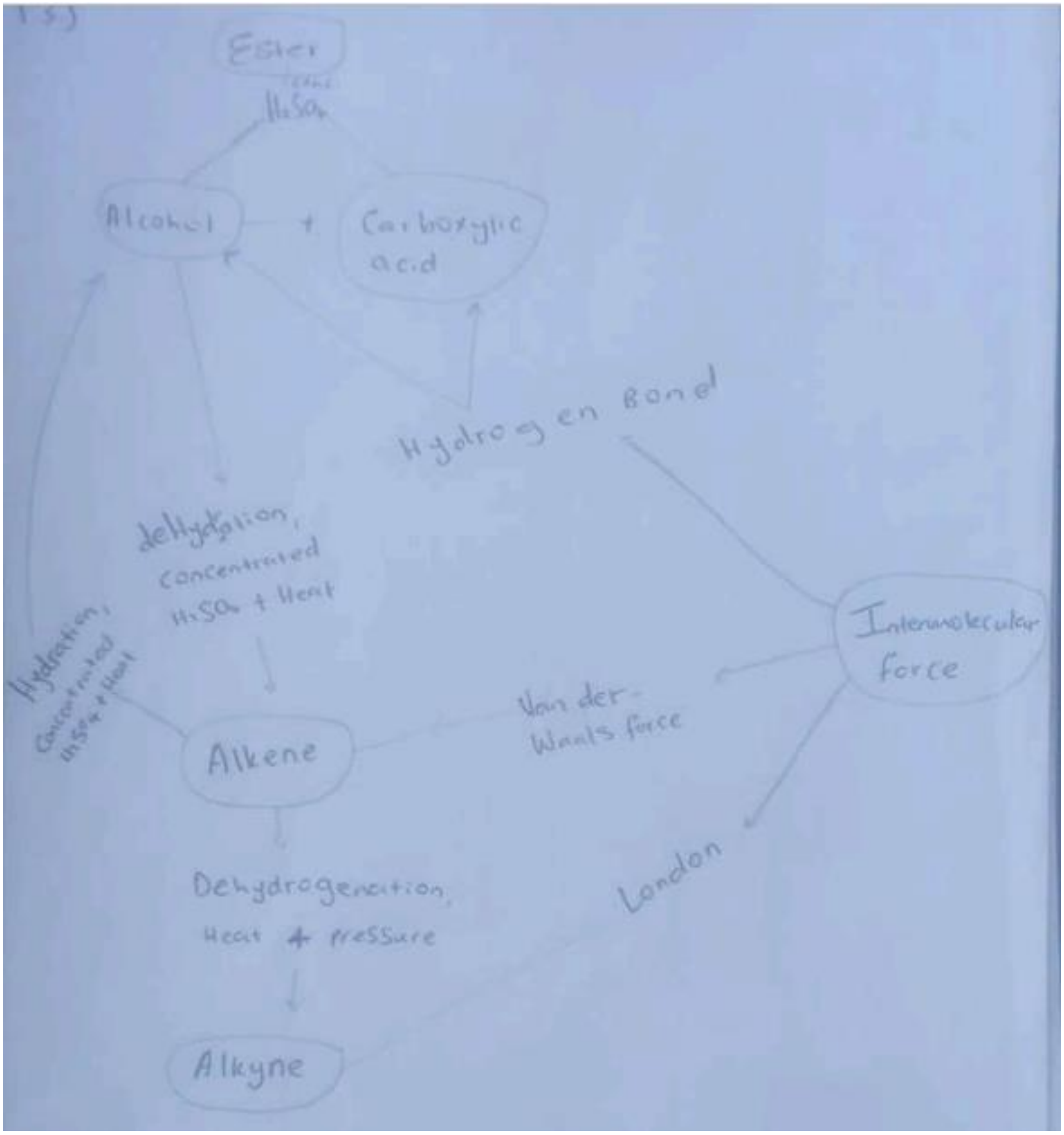
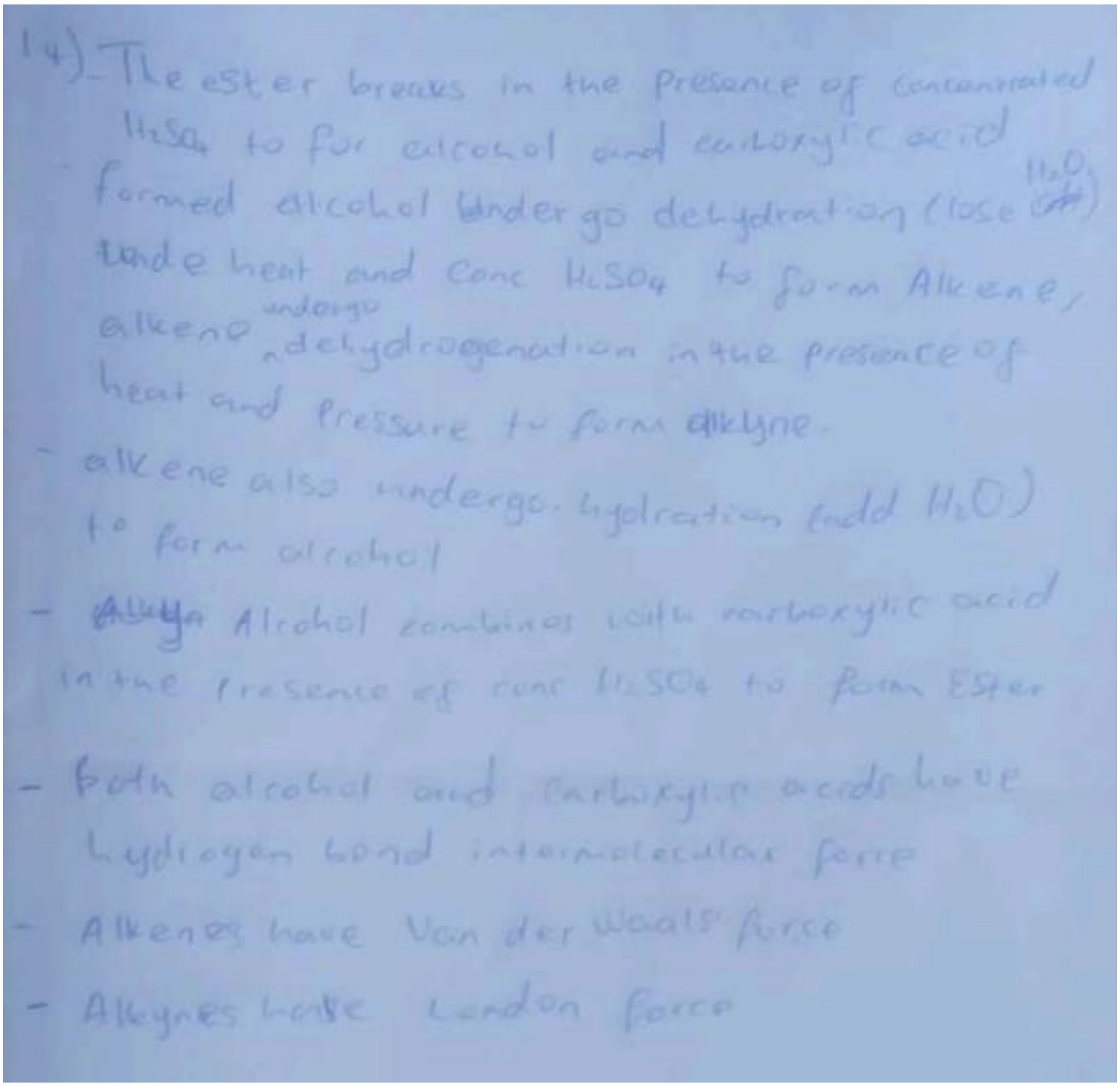


Figure 8.11: Nosipho's post-test concept map

When asked to provide a textual explanation of the nature of the connections, Nosipho explained correctly the links between the concepts, see Figure 8.12. In as much as the explanation given in Figure 8.12 was correct, the response was given a 3 since not all the concepts identified in the first part were fully explained in this textual account. However, Nosipho makes a deliberate effort to link the kind of homologous series to a particular type of intermolecular force. In addition, she links the two structures, i.e. alcohols and carboxylic acids in the production of esters. It was for this reason that the response was then given a 3.



14) The ester breaks in the presence of Concentrated H_2SO_4 to for alcohol and carboxylic acid
- formed alcohol undergo dehydration (lose H_2O) unde heat and Conc H_2SO_4 to form Alkene,
alkene undergo dehydrogenation in the presence of heat and pressure to form alkyne.
- alkene also undergo. hydration (add H_2O) to form alcohol
- Alcohol combines with carboxylic acid in the presence of conc H_2SO_4 to form Ester
- both alcohol and carboxylic acids have hydrogen bond intermolecular force
- Alkenes have Van der Waals force
- Alkynes have London force

Figure 8.12: Nosipho's pre-test explanation of interconnections

The next section will show one category shift in the knowledge of the tensions created by the constraints of the fundamentals.

8.3.2 Qualitative shifts in the knowledge of tensions

The overall raw scores indicated that PSTs experienced a one-category shift from 1 to 2. This shift indicated an improvement from poor to limited knowledge of the tensions created by the process of importing the fundamentals of the discipline to the school subject. Figure 8.13 shows an extract from the TerSCK rubric that describes the knowledge progression in this element of the construct.

TerSCK Item	**Poor**	**Limited**	**Good**	**Outstanding**
Likert Scale	**1**	**2**	**3**	**4**
Knowledge of the tensions associated with the focus on the fundamentals	The respondent shows no awareness of the tensions created by importing academic discipline content into the school curriculum	The respondent identifies the tension/limitation but cannot justify it by drawing from an explanation construed in the fundamentals The respondent does not link the tension/limitation to explain what potential difficulty is anticipated in teaching the concept	The respondent identifies the tension/limitation and correctly justifies it by drawing from an explanation construed in the fundamentals The respondent links the tension/limitation identified to explain the anticipated difficulty in teaching the concept	The respondent identifies more than one tension/limitation and correctly justifies them by drawing from an explanation construed in the fundamentals The respondent links the tensions/limitations identified to explain the anticipated difficulty in teaching the concept

Figure 8.13: TerSCK rubric extract on the knowledge of tension

When Thembelani was asked to identify the tension using the case of alcohol and -diol, before the intervention, he responded as follows, see Figure 8.14. The sample response was scored a 1 for poor TerSCK knowledge as Thembelani showed no awareness of the potential tension or differences arising from the careless use of the general formulae in the school curriculum versus the understandings in the academic discipline.

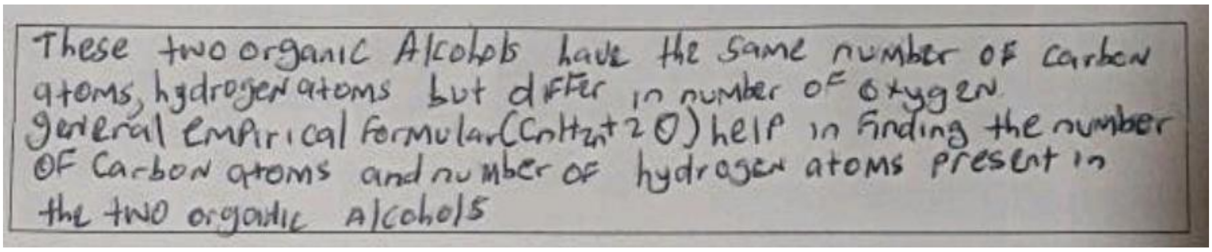
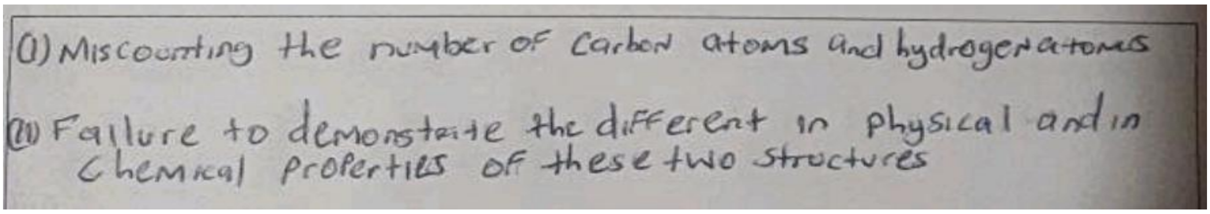

These two organic Alcohols have the same number of carbon atoms, hydrogen atoms but differ in number of oxygen general empirical formular($C_nH_{2n+2}O$) help in finding the number of Carbon atoms and number of hydrogen atoms present in the two organic alcohols

Figure 8.14 Thembelani's pre-test response on tensions identification

Furthermore, PSTs were asked to identify areas of difficulty that may arise as a result of the tension resulting from the constrained school curriculum content. Figure 8.15 shows a response from the same PST.


(i) Miscounting the number of Carbon atoms and hydrogen atomes

(ii) Failure to demonstrate the different in physical and in chemical properties of these two structures

Figure 8.15: Tembelani's pre-test response on potential difficulty linked to the tension

The response provided by Thembelani indicates that he had no idea about any potential difficulties that can be linked to the constraints of the school curriculum content. Hence, this was scored a 1, indicating poor knowledge of TerSCK

Post the intervention, Thembelani showed an improved understanding of this knowledge element. When responding to the same questions, he was able to identify that the general formula of the alcohols does not apply to both structures. see Figure 8.16. When dealing with the knowledge of the general empirical formula in the curriculum, there has to be a consideration of the number of functional groups present in the molecule. This limits the sloppy use of the general formula.

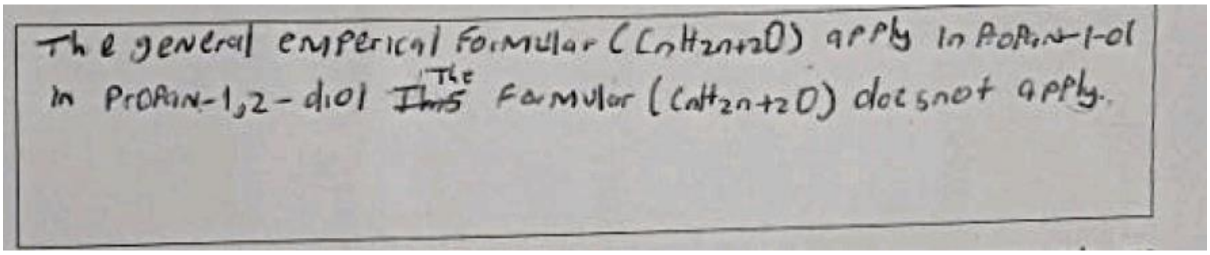

The general emperical formular ($C_nH_{2n+2}O$) apply in propan-1-ol
in propan-1,2-diol ~~This~~ The formular ($C_nH_{2n+2}O$) does not apply.

Figure 8.16: **Tembelani's post-test response on tensions identification**

This response was accorded a score of 2 indicating a limited knowledge of TerSCK. As much as Thembelani identified the tension or the limitation, he could not explain the potential area of difficulty linked to the knowledge of tension or the limitation, see Figure 8.17.

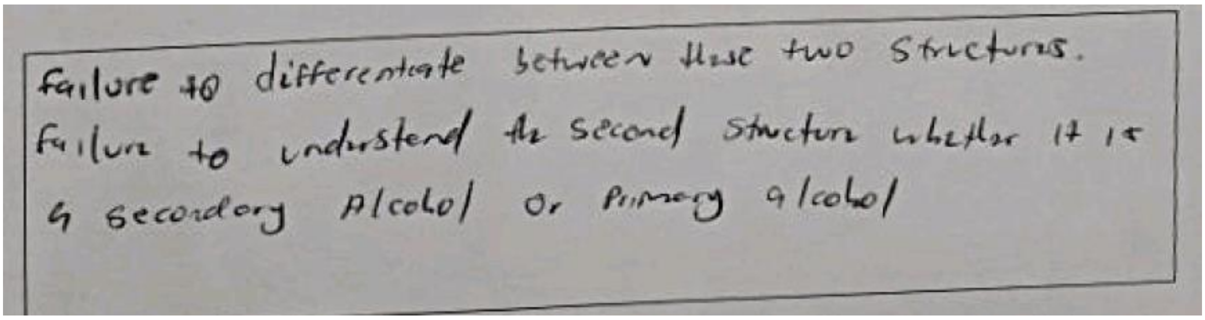

Failure to differentiate between these two Structures.
Failure to understand the second Structure whether it is
a secondary Alcohol or Primary alcohol

Figure 8.17: **Tembelani's post-test response on potential difficulty linked to the tension**

There were two aspects of tensions that were evaluated, these were the functional group and isomerism. The extracts above were based on functional groups and below is an extract based on the knowledge of isomerism. Similarly, on average, PSTs showed poor knowledge of this TerSCK element before the intervention.

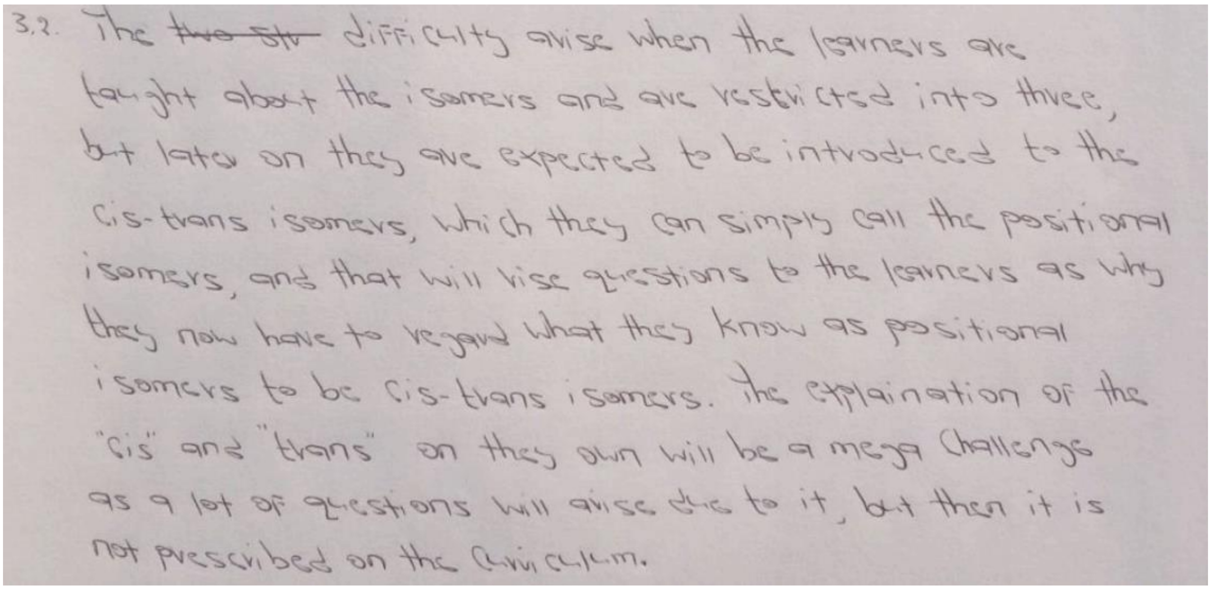
When asked if the two organic structures shown in the TerSCK instrument were isomers, Sabelo said they are isomers but mentioned an incorrect type of isomerism, which is positional isomers. However, post-intervention, Sabelo identified the correct type of isomerism, which is cis-trans isomerism. Before the intervention, when asked to identify the potential area of difficulty in dealing with the two structures in the school curriculum. Sabelo responded in a manner that indicated no awareness of the tension between school curriculum constraints and academic discipline content. See Figure 8.18 for a pre-test response.

They have same number of carbon and hydrogen no difference in functional group same parent chain is the same.

Figure 8.18: Sabelo's pre-test response on potential difficulty linked to the tension

In the response in Figure 8.18, Sabelo only described his observation based on the atomic composition of the molecules, the type of the functional group present and the chain length. Such a response indicated no awareness of the tension. Thus, he was given a score of 1 indicating limited knowledge of TerSCK linked to this fundamental.

Post the intervention, for the same question. Sabelo identifies the tension/limitation but could not justify it by drawing from an explanation construed in the fundamentals, see Figure 8.19. In addition to this, the response in Figure 8.19 indicated no link between the tension and potential areas of difficulties in teaching such as the development of misconceptions in learners.



3.2. The ~~two str~~ difficulty arise when the learners are taught about the isomers and are restricted into three, but later on they are expected to be introduced to the cis-trans isomers, which they can simply call the positional isomers, and that will rise questions to the learners as why they now have to regard what they know as positional isomers to be cis-trans isomers. The explaination of the "cis" and "trans" on they own will be a mega challenge as a lot of questions will arise due to it, but then it is not prescribed on the curriculum.

Figure 8.19: Sabelo's pre-test response on potential difficulty linked to the tension

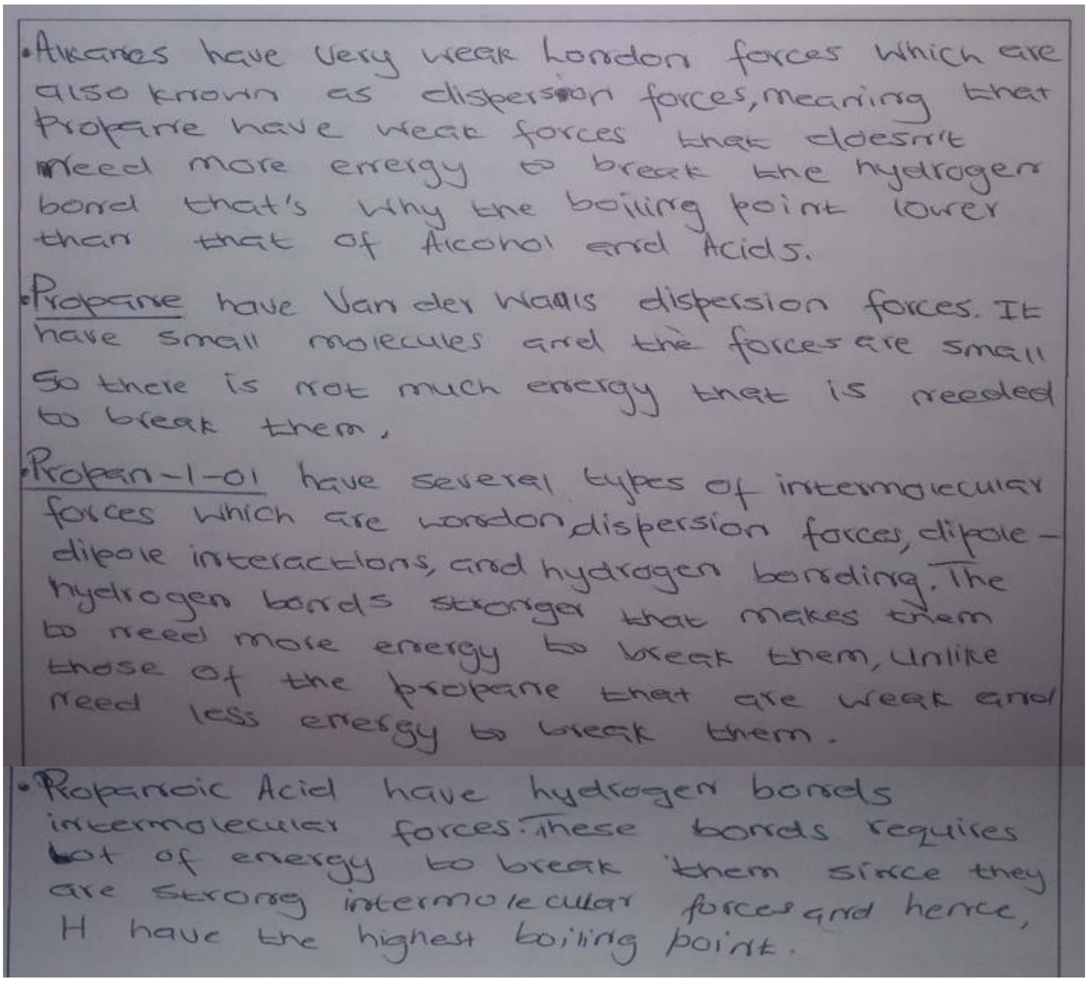
8.3.3 Qualitative shifts in knowledge of the scientific inquiry

This knowledge element involves how scientific knowledge develops to its present form through its various forms of scientific epistemology. The focus of this work was largely on the knowledge of the scientific method that reinforces rigorous scientific investigations and practical work. For this item, PSTs were presented with a set of data and were asked to design a suitable investigation informed by the set of results given. In their responses, they were expected to show their knowledge of the key aspects of carrying out an investigation. Figure 8.20 shows an extract of the TerSCK rubric that was used to evaluate PSTs' responses.

TerSCK Item	**Poor**	**Limited**	**Good**	**Outstanding**
Likert Scale	**1**	**2**	**3**	**4**
Knowledge of the scientific inquiry (Scientific method)	There is no evidence of the knowledge of the scientific inquiry The response lacks all aspects of the knowledge of the scientific method	There is basic knowledge of the scientific inquiry The respondent can hypothesize, ask investigative questions, identify all the variables involved in the investigation	There is good knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation AND draw correct observations from the presented data. The respondence draw from the scientific body of knowledge to justify observed patterns with minor conceptual errors	There is good knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation AND draw correct observations from the presented data. The respondence draw from the scientific body of knowledge to justify observed patterns with no conceptual errors

Figure 8.20: TerSCK rubric extract on the knowledge of inquiry

Quantitative data in Table 8.1 revealed that on average, PSTs experienced improved overall performance in this knowledge element. They registered a shift from a score of 1, indicating poor TerSCK knowledge to a score of 2 indicating limited knowledge of TerSCK.



• Alkanes have very weak London forces which are also known as dispersion forces, meaning that Propane have weak forces that doesn't need more energy to break the hydrogen bond that's why the boiling point lower than that of Alcohol and Acids.

• Propane have Van der Waals dispersion forces. It have small molecules and the forces are small so there is not much energy that is needed to break them.

• Propan-1-ol have several types of intermolecular forces which are London dispersion forces, dipole-dipole interactions, and hydrogen bonding. The hydrogen bonds stronger that makes them to need more energy to break them, unlike those of the propane that are weak and need less energy to break them.

• Propanoic Acid have hydrogen bonds intermolecular forces. These bonds requires lot of energy to break them since they are strong intermolecular forces and hence, H have the highest boiling point.

Figure 8.21: Zodwa's pre-test response on the knowledge of Inquiry

Using the rubric, the response in Figure 8.21 was scored a 1 indicating poor knowledge of the inquiry. Zodwa was completely unaware of the aspects that pertain to a scientific method. All that the response did was to recall the kinds of intermolecular forces between the molecules of propane, propanol and propanoic acid and how these affect the amount of energy required to overcome these forces. This was an interesting observation and Zodwa was followed up with an interview to solicit why such a response. It was discovered that how this section was taught in secondary school had an influence.

Interviewer: *Remember the question of the scientific method?*

Zodwa: *Yes… that was so confusing for me*

Interviewer: *What informed your answer to the question on the scientific method?*

Zodwa: *To be honest, I really don't know…. [deep sigh] but I, no actually I remember now, my physics teacher [high school teacher] used to say to us… this is how you respond to these questions during exam… yeah*

The interview excerpt above reveals that the high school experience influenced how Zodwa responded to this question. She was completely unaware of the aspects of the scientific method.

However post the intervention, Zodwa was given a score of 2 indicating a limited knowledge of TerSCK in this component. For example, given the same question, Zodwa had an idea that investigating a phenomenon through a scientific begins with a question, and linked to the question is the hypothesis that should be backed up or falsified by appropriate observations. See Figure 8.22 for the post-test response.

The response shown in Figure 8.22 was scored a 2 for limited knowledge of inquiry on the basis that the PST identified three aspects of inquiry, that is ask an investigative question, make observations and confirm the hypothesis. A score of 2 was given even though the question asked was not necessarily an investigatable question.

Question

What is happening to the values of the boiling point from Alkanes to Carboxylic acids having 3 number of carbons.

Observe

At the start the boiling point is smaller on the alkanes, it increases in alcohol as the number of hydrogen bonds increases and more energy to break the bonds and it ~~is~~ is bigger in carboxylic acid as we need more energy to break the bonds.

Hypothesis

The boiling point of ~~of~~ the compounds increases as the number of hydrogen bonds increases.

Figure 8.22: Zodwa's post-test response on the knowledge of Inquiry

Post the intervention, Zodwa was also interviewed on her responses. In as much as she has improved by a one-category, the lack of laboratory exposure was a challenge for the intervention. this was created by the restrictions due to COVID-19 regulations.

Interviewer: *Do you think you understand the scientific method now?*

Zodwa: *Well, a bit…*

Interviewer: *Yes… [probing for more response]*

Zodwa: *I wish we had the opportunity to do practical work like the lab work, maybe I would understand this well*

In the next section, the focus is given to the knowledge of cultivation potential embedded in knowing the historical development of the concepts that make up the fundamentals.

8.3.4 Qualitative shifts in the cultivating potential of content

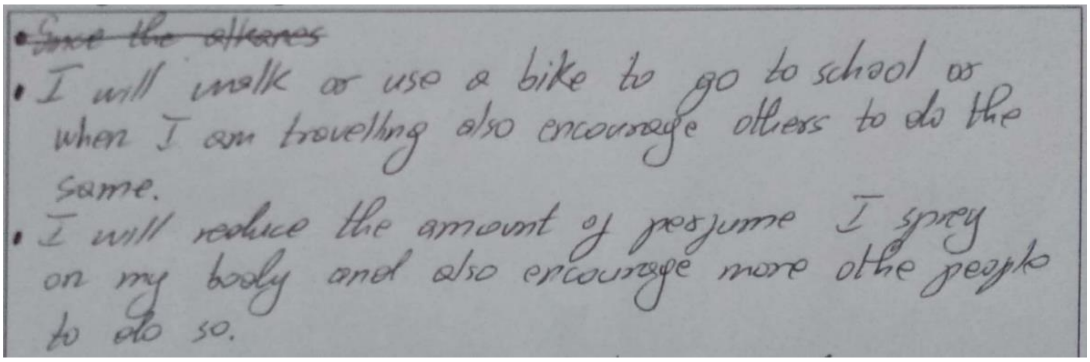
This last knowledge element was largely construed by evaluating if PSTs were cultivated after the TerSCK-based intervention. PSTs were given a real-life scenario linked to the knowledge of one of the fundamentals and asked to provide practical and feasible solutions to their immediate communities about the phenomenon. Figure 8.23 shows a section of the rubric that was used to grade PSTs' knowledge of this item.

TerSCK Item	**Poor**	**Limited**	**Good**	**Outstanding**
Likert Scale	**1**	**2**	**3**	**4**
Historical development of content and its cultivating potential.	There is no evidence of cultivation through the knowledge of TerSCK The response does not offer practical societal solutions and interventions to real-life problems	There is a basic level of cultivation through the knowledge of TerSCK The response offers solutions and interventions that are impractical to real-life problems There is no link with the existing knowledge of the fundamentals	There is a sufficient level of cultivation through the knowledge of TerSCK. The response offers solutions and interventions that are impractical to real-life problems There are explicit links with the existing knowledge of the fundamentals	There is a good level of cultivation through the knowledge of TerSCK The response shows the ability to offer practical solutions to real-life problems There are explicit links with the existing knowledge of the fundamentals & there is evidence of new knowledge emerging

Figure 8.23: TerSCK rubric extract on the cultivating potential of content

The analysis of raw ordinal scores shows that on average, PSTs registered a shift of one category in the knowledge of TerSCK in this component. Before, the intervention, Table 8.1 shows that an average score of 2 was attained by PSTs, indicating limited knowledge. Post the intervention a score of 3, indicating good knowledge of TerSCK was registered by PSTs.

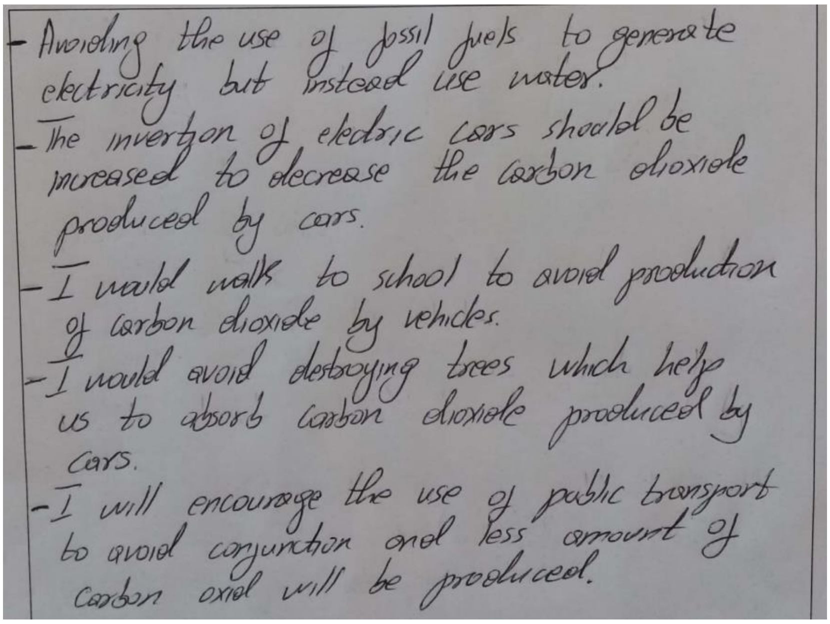
Jacob scored a 2 pre-intervention as he indicated limited cultivation. The solutions offered are not linked with the knowledge of the existing fundamentals. For example, why use a bike and not a car? What will be the effect of using less perfume, is this applicable to ozone layer-depleting perfumes or all perfumes? All these interventions were not backed up by existing knowledge in the discipline, see Figure 8.24



~~[illegible]~~
- I will walk or use a bike to go to school or when I am travelling also encourage others to do the same.
- I will reduce the amount of perfume I spray on my body and also encourage more othe people to do so.

Figure 8.24: Jacobs's pre-test response on the cultivating potential of content

However, post the intervention Jacob scored a 3, indicating good evidence of cultivation through TerSCK. When asked the same question, he was able to offer solutions that were essentially practical but quite difficult to achieve. In addition, Jacob made an explicit effort to link what is learnt in the fundamentals to back up his interventions. For example, the invention of electric cars is preferable since conventional cars produce carbon dioxide after the catalytic oxidation of octane in the exhaust. This is similar to his third point that conventional vehicles produce carbon dioxide. In addition, he draws from the knowledge of photosynthesis to assert that trees are needed as they use up carbon dioxide gas. In essence, Jacob is explicitly aware that carbon dioxide is one of the major contributors to global warming as a greenhouse gas, see Figure 8.24.



- Avoiding the use of fossil fuels to generate electricity but instead use water.
- The invertion of electric cars should be increased to decrease the carbon dioxide produced by cars.
- I would walk to school to avoid production of carbon dioxide by vehicles.
- I would avoid destroying trees which help us to absorb carbon dioxide produced by cars.
- I will encourage the use of public transport to avoid conjunction and less amount of carbon oxid will be produced.

Figure 8.25: Jacobs's post-test response on the cultivating potential of content

8.4 Discussion and conclusions

This chapter was geared toward exploring ways in which the construct of TerSCK could be validated. This was the main purpose of phase 2 of the research. Firstly, the pre-intervention data was provided for the validation of the tool and the initial validation of the construct. In this chapter, the TerSCK intervention was conducted to investigate the development of content knowledge for teaching and ultimately investigate if the construct is still valid post-intervention.

As indicated, the focus was given to two fundamentals in the topic, these are (i) functional group chemistry and (ii) isomerism. As part of this validation process, this chapter reported on the quantitative and qualitative improvements in the quality of PSTs' CK related to teaching organic chemistry after the intervention

The Rasch offered a two-way solution for the statistical analysis. Initially, it was determined that the person and item reliability indices were good, measuring 0.77 and 0.98, respectively. Second, Rasch also provided for the TerSCK theoretical construct validity in terms of its fundamental elements. This was done with the stacked data after the intervention. The MNSQ OUTFIT values were analysed and found to be acceptable between 0.5 to 1.5. Similarly, the ZSTD OUTFIT values were acceptable between -2 to +2. As advised by Boone et al. (2013), this analysis was based on OUTFIT values rather than INFIT since outfit values are more prone to outliers in the data. The reported fit statistics indicated that TerSCK was found to be valid before and after the intervention.

The analysis of raw ordinal scores revealed that in general PST experienced a one-category shift in the overall knowledge of TerSCK elements. To evaluate the significance of these quantitative observations pre and post-intervention, the Wilcoxon Signed Rank Test indicated a statistically significant increase in the overall TerSCK performance of PSTs post-intervention. The test statistics showed that these were significant at $z = -5.166$, $p < 0.001$, with a large effect size of $r = 0.87$. This indicates that these quantitative observations were not by any chance but as a result of the explicit intervention.

In addition to the quantitative improvements described above, PSTs also experienced the TerSCK items at different levels of difficulty. For example, they experience the knowledge of the fundamentals to be the least difficult whilst the knowledge of the scientific inquiry was found to be the most difficult. As such, focus group interviews were conducted to confirm these findings and ascertain the contributing factors to the observation. Indeed, PSTs confirmed that the knowledge of the fundamentals was found to be easier to deal with, upon further probing as to why this was the case Thokozani responded as follows:

> *Interviewer:* *What are the reasons that made you find it easier to answer questions on the fundamentals?*
>
> *Thokozani:* *Fundamentals mean the pure chemistry questions… right?*
>
> *Interviewer:* *Yes…*
>
> *Thokozani:* *Oh…. in fact we [were] also doing a chemistry module [content course] that also deals with some of the content in the intervention, so we were getting taught twice the same thing.*

The interview extract above reveals that PSTs who were enrolled in the methodology course in which the intervention was located also enrolled in a content module that dealt with aspects of organic chemistry. This subsequently enabled them to find the knowledge of the fundamentals (pure content) to be the easier TerSCK element to deal with. On the contrary, the knowledge of inquiry was the most difficult to develop. Upon further interviews, the following was solicited:

> *Interviewer:* *Which aspect of TerSCK have you found to be difficult*
>
> *Mfanafuthi:* *I think the aspect of investigations and tensions were not easy to understand*
>
> *Interviewer:* *Why do think this was the case?*
>
> *Mfanafuthi:* *Most of the practical work, we have not done it because we do not have access to a laboratory. I*

think the fact that we were theorising about these investigations also was a problem for us to understand this aspect

The interview transcript above reveals that Mfanafuthi had challenges with the elements of both inquiry and tension. This is in line with the quantitative analysis of the item measure from the Rasch analysis (*cf* Figure 8.2 and 8.3). One of the major contributing factors in teaching the practical aspects of the intervention was the COVID restrictions. The intervention was offered online synchronously and asynchronously, hence this limited the extent to which PSTs engage with the full potential of TerSCK.

In addition to the above discussions, participating PSTs were asked to reflect generally on their views about TerSCK exposure through the intervention. One of the reflective questions was: "Do you think TerSCK is different from the main content course you have done, if so, how?" See Appendix U for a reflective schedule.

Andile: yes, I think it is different because the content course focuses mainly on the content to be mastered and covered; very limited connections between concepts are stressed, limited misconceptions are brought forward and highlighted; very minimal stress (if any) on the history of science and its evolution which is actually the opposite of what is done in the TerSCK program

Bandile: Yes, TerSCK teaches us how we can transmit the content to learners and the misconceptions we may cause when teaching whilst the main content course is all about learning advanced concepts so that we can be better suited for teaching, but it doesn't teach us how we can transmit what we know.

The two responses by both Andile and Bandile indicate that they generally felt that TerSCK was different from the version of the content they experienced from their module about pure chemistry. The notion of interconnection was largely emphasized by both respondents as being explicit. This knowledge of the topic at a horizon is important for PCK developments in terms of curricula saliency that deals with the "*teachers' awareness of the place of a topic in the curriculum framework*" (Ndlovu & Malcolm, 2022). Andile highlighted the idea of exposure to historical events in the discovery of content in the topic of the intervention and pointed to the notion that it is limited, if any, in pure content courses. Such feedback points to the notion that TerSCK is indeed different from the academic discipline content knowledge.

Similarly, the same question was asked about the version of school science content knowledge against TerSCK. Andile indicated that he has experienced TerSCK to be different from the school curriculum and the respondent quoted a few elements that distinguish it from the school curriculum.

> *Andile:* *… it is very different from what we covered at school as our teachers currently in our schools teach learners for a pass with very minimal stress or importance as to whether the learners understand how things are done and why they are done in that particular way, let alone the idea of linking different concepts and highlighting the misconceptions that learners should be aware of and prevent*

In light of the above, the study claims that TerSCK developed via an explicit-based intervention. The next chapter provides further discussions and knowledge contributions made in this study as a final chapter.

CHAPTER 9 Further discussions, conclusions and recommendations

This Chapter pulls it all together. It begins by highlighting the overview of this whole research study. It revisits the critical questions flowing from the key research objective that has guided this project. The chapter's main emphasis is on the study's contributions to new knowledge in the field. There are two strands of contributions that the chapter touches on. These are theoretical contributions and methodological contributions. In addition, the chapter also gives a critical reflection on the research design processes that guided this study. These include a reflection on the process of systematic literature review that informed the conceptualization of the new construct TerSCK in the first phase and the development and running of the TerSCK intervention to validate the construct. The chapter also discusses certain study limitations, and it finishes by noting the implications and suggestions made by this work for theory, practice, and future research in the area.

9.1 Introduction and overview of the study

This study has raised a concern about the lack of clarity on the nature of content knowledge suitable for use in developing science PSTs through initial teacher education programs as the base for PCK development. It has argued along with Deng (2012) that the subject matter contained in academic discipline and school subjects is different due to their social, political and philosophical impetuses. As a result, it postulated that neither the academic discipline nor school subject content is suitable for PCK development. Building from this argument and other works of Deng, this study postulated that the content knowledge for teaching is a different version that denotes speciality for teaching school science and refers to it as Teacher-related Science Content Knowledge (TerSCK).

The primary goal of this study was therefore towards developing and validating a theoretical construct that defines a type of content knowledge suitable for teacher education and as a base for PCK development in science education. To realise this purpose the study was structured into two major research phases. The first phase entailed the conceptualisation of the construct through an SLR of studies that have explored the field. Building on the existing debate about the distinction and relationship between academic disciplines and their correlating school subjects, a new version of content knowledge was conceptualized as a theoretical construct describing a version of content knowledge geared for pre-service teacher education programmes termed Teacher-related Science Content Knowledge (TerSCK). The second phase entailed the statistical validation through quantitative means of the conceptual argument of the first phase. The two processes were in line with the requirements of construct validity as described in Kane (2012).

Chapter 1 established the primary research question that formed the basis for this investigation, which is:

> *In what ways the content knowledge suitable for teaching secondary school science can be developed and validated as a distinct theoretical construct from academic discipline and school subjects' content?*

The main research question was unpacked through a set of three sub-research questions. These are:

- (i) How could a theoretical construct for defining and developing the content knowledge of secondary school science teachers be conceptualized?
- (ii) How could the newly conceptualized theoretical construct be validated?
- (iii) What valid instrument could be used to measure the quality of the newly conceptualised theoretical construct in pre-service teachers?

The findings in this study presented new knowledge contributions in two major areas of the field, i.e. theoretical and methodological. So, In the next sections, I discuss these findings and the emerging contributions starting with the theoretical contributions of this study.

9.2 New knowledge contributions

9.2.1 Theoretical contributions

This study contributed two salient theoretical inputs to the body of knowledge in understanding content knowledge suitable for pre-service teacher education programmes. These are the (i) positioning of TerSCK in between the science academic discipline and the school subject content knowledge whilst taking a relational role between the two, (ii) ways in which the broader dimensions of the TerSCK construct could be translated into an operational curriculum for teacher development programmes. The two contributions are unpacked below.

Firstly, this study provided an understanding that the content knowledge intended for teaching secondary school science could be conceptualized distinctly from both the academic discipline and school subject content. This was described as a theoretical construct called TerSCK. To do this, a comprehensive consideration had to be made in exploring how both academic disciplines relate or do not relate to corresponding school subjects. The works of Catling and Martin (2011); Stengel (1997); Johnston (2019) were alluring in this consideration. There are several models through which the two relate or differ, *see* Chapter 5.

For the conceptualization of TerSCK, the combination of the “discontinuous” model by Stengel (1997) with the “different but related dialogic” model by Catling and Martin (2011) was more appealing. In this chosen model combination, the academic discipline and school subject content are positioned as different entities on the opposite ends of a content continuum but relate to each other through a dialogue that is sensitive to the contemporary goals and needs of society. In light of this model, TerSCK is positioned between these entities, in the middle of the continuum and reflects a dialogic relationship between the two ends. This positioning concedes to the differences between the two ends of content in the continuum and it subsequently provides for the relational role that ought to be played by the teacher concerning the operationalization of content in school subjects.

In addition, it implies a teacher’s role as enabling the discernment of the elements of the academic disciplinary content knowledge that have been imported and those left out in forming school subjects. Furthermore, it points to a need for the teachers to comprehend what tensions and/or differences are created by the process of the importation of content from the academic discipline to a school subject. This for TerSCK needs to be negotiated through a dialogic relationship between the two ends. In this study, this view on content knowledge denotes speciality, and accordingly, it is considered one of the specific elements of the CK appropriate for science teacher education training.

From the broader positioning of TerSCK described above, the works of Deng (2007, 2009) offered a conceptual framework that describes the relationship between the two ends through five relational dimensions that speak to the difference by both the nature of the content and its teachability. From the five relational dimensions in Deng's framework, this study extracted three of the content-specific dimensions, to describe the nature of TerSCK leaving out those speaking to the difference by teachability. These were the *logical, epistemological* and *social dimensions.* For more details on the descriptions of these dimensions, see Chapter 5.

The pedagogical and psychological dimensions were not considered on the basis that they have an element of the transformation of content for teaching purposes (Geddis & Wood, 1997), a knowledge speciality that is largely explored in PCK literature. In addition, the psychological dimension had some epistemological influence on the logical dimension that called for a determined measure (only the fundamentals) of content from the discipline thereby inherently taking into consideration the cognitive difficulty of content to be taught at a school level. Figure 9.1 pictorially shows this theorization.

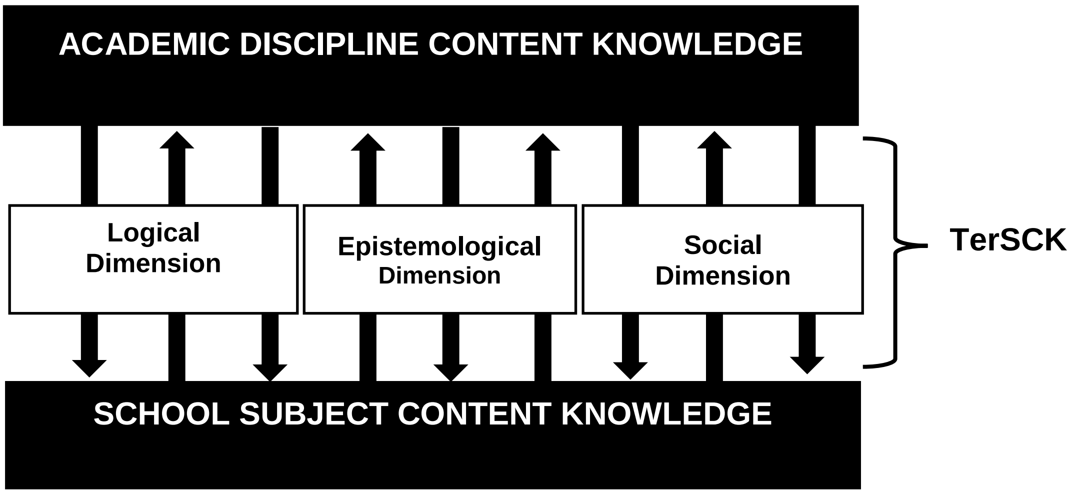


Figure 9.1: Relational dimensions of TerSCK

So, for TerSCK at the logical dimension, the focus on the discipline's fundamental concepts and principles where the content leading to discipline-specific research and new knowledge is left out, infers that the distinct content suitable for teacher education is a 'determined measure' extracted from academic discipline content. This is to be understood with special attention to the interconnections between the concepts confined within it.

Furthermore, it includes the knowledge and awareness of the tensions and constraints resulting from the process of extraction. These germane considerations differentiate the determining measure from both the original academic discipline format and the scope of the school subject.

At the epistemological dimension, the emphasis is on understanding the syntactic structures used to advance knowledge to be at its current and future potential forms. Particularly, this pertains to the discipline-specific ways of inquiry and knowledge generation, verifications and knowledge rebuttals as described by Bullock (2009).

At the social dimension, the focus is to connect the learning of the fundamental concepts and principles to the current social developments, dilemmas and priorities. In today's society, digitalization and artificial intelligence are the major waves transforming economic activities and social interactions (Hussain, 2021). Hence, the content knowledge enterprise is not to be spared along these reformations and the social dimension makes room for this link with society, cultures and technological advancements.

The second theoretical advancement of this study was the translation of the TerSCK dimensions into a powerful science teacher education curriculum using a nuanced theory of content. This translation aligned TerSCK with the notion of powerful knowledge (Carlgren, 2020; Hordern et al., 2021). Powerful knowledge, and by reference powerful curriculum, refers to knowledge that carries the power to cultivate human capacity beyond the mere acquisition of content (Deng, 2021). Building on the work of Schwab (1973), "*The Practical 3: Translations in Curriculum*" introduced three faces for this process. These are the *purport*, *originating discipline* and *access discipline* (Deng, 2021). For a description of these faces, see Chapter 5. A careful analysis in this study revealed that these faces are in sync with the chosen three content-specific relational dimensions of TerSCK.

Hence, it has been postulated that the logical dimension could be embodied in the education potential espoused by the originating discipline face. The epistemological dimension could be linked to the education potential espoused in both the originating discipline and the access discipline face. The “determined measure” of content knowledge, mentioned earlier as emerging from the logical dimension, is comprised of the fundamental principles and concepts, the connections across the concepts as well as the understanding of the tensions and limitations resulting from the extraction of the fundamentals from the academic disciplines.

This content could be engaged through approaches that promote both their conceptual understanding and critical thinking competence through the enquiry and investigation methods of science. By having the epistemological dimension of TerSCK including both originating and other disciplines’ different ways of knowing, an opportunity for the development of the potential for freedom of thinking and judicious problem solving is being embodied through multi-disciplinarity. Lastly, the social dimension of TerSCK is linked to the purport face. This link locks in the opportunity to develop educated citizens who are encouraged to apply their knowledge to social issues seeking alternative solutions and changing destructive pre-set perspectives.

Figure 9.2 shows the resulting model of the TerSCK curriculum. The first layer shows the broader dimensions of TerSCK. These are shown to be in sync with the translations of the curriculum faces. On the model's right-hand side, the five elements of TerSCK are shown emerging from these dimensions and curriculum faces.

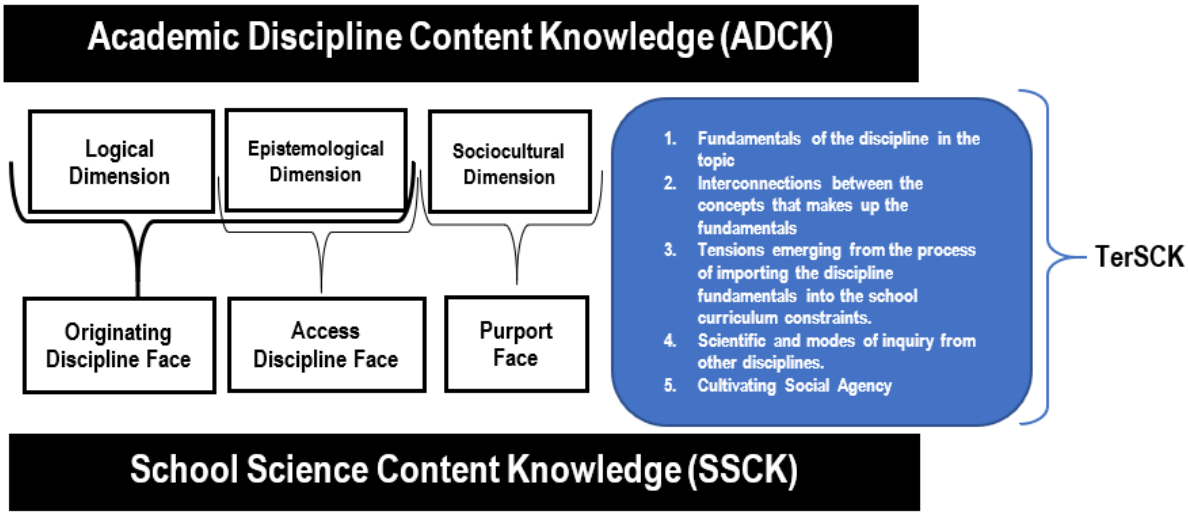


Figure 9.2: TerSCK curriculum model

The theoretical contributions highlighted above respond to the first research question. That asked:

> *How could a theoretical construct for defining and developing the content knowledge of secondary school science teachers be conceptualized?*

In responding to the question, TerSCK is viewed theoretical construct describing distinct content knowledge from academic discipline and school subject content. It is positioned between the two ends of the content continuum and built from the knowledge of three content-specific relational dimensions viz: the logical, epistemological and sociocultural dimensions. TerSCK is aligned with the theory of content that translates to a powerful curriculum through three faces, the purport, originating discipline and access discipline.

The synergy across the content-specific relational dimensions of TerSCK and powerful curriculum faces generated elements of the resulting curriculum model for teaching TerSCK. These elements were (i) fundamentals of the discipline in the topic, (ii) interconnections between the concepts that make up the fundamentals, (iii) tensions emerging from the process of importing the discipline fundamentals into the school curriculum constraints, (iv) scientific and modes of inquiry from other disciplines, (v) cultivating social agency, see Figure 9.2.

The next section explores the methodological contributions of this study towards the TerSCK instrument development process and the TerSCK-based intervention.

9.3 Methodological Contribution: Instrument development and the intervention

Methodologically, this study has contributed two significant inputs to the field of science education research. Firstly, it developed a new valid and reliable instrument that can be used to measure the quality of content knowledge related to teaching school science using two fundamentals in organic chemistry. Secondly, the study presented ways in which this version of content knowledge could be developed through an intervention situated in a teacher education programme. These contributions were essential in responding to the second and third research questions. The two contributions are unpacked below:

9.3.1 An instrument to measure the knowledge of TerSCK

The instrument to measure the quality of pre-service teachers' TerSCK was developed as part of the process of validating the TerSCK theoretical construct using the construct validity approach (Kane, 2012). While it was not part of the original objectives, it was however needed as an essential element of the methodology followed in this process, hence the inclusion of the intermediate step in the research project. Since TerSCK is a novel construct that has not been explored in any empirical work, the construct validity design method was to evaluate the reliability of the instrument. However, the process of developing a tool in this study drew from the affordances of the rational design method (Oosterveld et al., 2019) to cater for aspects of concept analysis, item production, and scale construction in instrument development, see Chapter 6. Integrating the rational design method and the construct validity design was one of the methodological inventions of this study in two folds. Firstly, the production of the new data collection instrument. Secondly, the innovations in integrating two different design methods of test construction in one study.

To begin with, the instrument developed by Davidowitz and Vokwana (2014) was essentially relevant and a starting point to measure the knowledge of "pure" CK in organic chemistry, herein referred to as the fundamentals of the discipline in the topic, see Appendix I. The development of items reflecting the other two relational dimensions of TerSCK (epistemological and social) was developed with constant inputs from the reference team of experts in the field (Parratt et al., 2016). This was in line with the requirements of the rational method described by Oosterveld et al. (2019). After the first draft was collated and the content validated, the instrument was piloted with 5 4^{th}-year PSTs and 3 postgraduate students in science education, who were not part of the upcoming intervention to strengthen content validity. The scale construction that informed the process of developing the TerSCK rubric was guided by intuition and the performance objectives spelt out in Chapter 6. Refinements to the performance descriptors of the rubric were further made as the grading process ensued during inter-rater reliability check.

This methodological contribution of the instrument development process responded to the third research question that asked:

> *What valid instrument could be used to measure the quality of the newly conceptualised theoretical construct in PSTs?*

Several kinds of validity were explored in this process. These are content, face and ultimately construct validity. The reference team of experts and the pilot study ensured the content validity of the instrument. However, for the construct validity, Rasch analysis was used to generate appropriate fit statistics in establishing TerSCK construct validity. All the TerSCK items were found valid within 0.5 to 1.5 of the MNSQ values. Similar to the ZSTD values, TerSCK items were valid at the range of -2;2. Hence, the instrument was found to be valid according to (Boone et al., 2013). In addition, the statistical analysis for validating the tool showed that there is a ranked structure that distinguishes the difficulty of each TerSCK item. The item of “Tensions” was found to be the most difficult than the rest of the other TerSCK items and the “Cultivation” item was found to be the least difficult item at the point of instrument validation.

Regarding the internal consistency and the stability of the TerSCK questions, the instrument was found to be reliable with an acceptable Cronbach alpha of 0.7 (Vaske et al., 2017). In addition, both the items and persons had good reliable indices of 0.89 (89%) and 0.64 (64%) respectively as posited by Lightfoot et al. (2021).

This was one of the project's methodological contributions to the development of a novel, accurate tool for measuring TerSCK in organic chemistry. As one of the second methodological contributions of this study, I describe the intervention that focused on the development of TerSCK in PSTs in the next section.

9.3.2 The intervention targeting the development of TerSCK in science teachers

This study has also developed an explicit intervention that was geared to develop the quality of TerSCK with pre-service teachers, see Chapter 6 for more details on the intervention, its content and instructional approach. The case of organic chemistry was used to develop the content of the intervention through two fundamentals, i.e.

functional group chemistry and isomerism. This intervention was located in a methodology course of the 3rd – year PSTs who majored in Physical Science teaching.

Developing and running this intervention contributed to describing how PSTs developed their specialized knowledge capacity to teach organic chemistry in secondary school and to investigate the validity of the construct before and after the intervention. This methodological contribution of a TerSCK-base intervention responds to the following research question which asked:

How could the newly conceptualized theoretical construct be validated?

The question above was investigated in two folds. Firstly to determine if there was any statistical significance in PSTs' TerSCK performance before and after the intervention. Secondly, it was the focus on the observed qualitative shifts in the quality of PSTs' knowledge of the construct post-intervention. Before and after the investigation, the validity of the construct was also tested with different sets of data.

Two statistical programs were used for this analysis, the Rasch software and the SPSS. The former provided for the analysis of person and item fit statistics towards construct validity and the reliability indices of both persons and items before and after the intervention. The latter provided for a non-parametric test to evaluate if there was any statistical difference between pre and post-test scores.

The Wilcoxon Signed Rank Test in SPSS tested the null hypothesis made in this study. The null hypothesis tested was that *"there is no significant difference in the overall TerSCK performance of the pre-service teachers measured before and after the explicit TerSCK-based intervention*". This test falsified the null hypothesis as it revealed a significant increase in the overall TerSCK performance of PSTs from pre-intervention to post-intervention results. The test statistics showed that these were significant at $z = -5.166$, $p < 0.001$, with a large effect size of $r = 0.87$. This indicates that these quantitative observations were not by any chance but as a result of the explicit intervention that targeted the development of TerSCK.

From the qualitative analysis, PSTs improved their quality of TerSCK in the knowledge of functional group chemistry and isomerism after the intervention. In general, they improved their knowledge by one category shift described by the TerSCK rubric from "limited" to "good" knowledge of the TerSCK elements. The element of the "Fundamentals" improved from "good" to "outstanding" knowledge of TerSCK. Both the knowledge of "Interconnections" and "Cultivation" improved from "limited" to "good" knowledge of TerSCK. The knowledge of "Tensions" and "Scientific inquiry" improved from "poor" to "limited" knowledge of TerSCK in the two fundamentals.

The focused group interviews corroborated an observation that PSTs experienced the knowledge of TerSCK elements at different levels of difficulty. The element of the "scientific inquiry" was the most difficult to develop after the intervention meanwhile the fundamentals of the discipline were the easiest to develop. This was slightly different from the pre-intervention performance where PSTs found the knowledge of "Tensions" to be the most difficult.

9.4 Critical reflections on the research design process

This section reflects on the research design followed for the conceptualization and validation of a new theoretical construct to inform the challenge of distinguishing the appropriate content knowledge for teacher development.

9.4.1 Conducting a systematic review

Systematic literature reviews are generally rigorous and they are a methodology that requires good expertise to handle the amount of secondary data that is readily available. The first phase of this study was to conceptually argue for the theoretical concept that is describing the idea of TerSCK, a construct theorised for science education. There was a paucity of studies in this field and as a result, we had to be interdisciplinary in our search parameters and consider inclusion from disciplines such as mathematics and geography and to a certain extent curriculum study. Limiting the search items to "academic discipline" and "school science" presented challenges for the conceptualisation of TerSCK. It was through my supervisor's suggestion that we also manually add other literature that goes beyond just the initial search identities and look into how we can conceptualise TerSCK beyond this point. In particular, to realise the educational potential (Deng, 2011; Verloop et al., 2001) of TerSCK, we had to find a theory of curriculum that could translate into a powerful curriculum. As such, we had to define and align with the notion of powerful knowns and knowings by Carlgren

(2020). So, digging further into the scholarly work by Deng was very beneficial as we unravelled a plethora of theories of content and amongst those was the Schwabian approach to developing a powerful curriculum. This helped to strengthen the arguments made in Chapter 5 and inform the formation of a powerful curriculum through the knowledge of TerSCK.

Much of the conclusions that were drawn from the conceptualisation stage were also presented in several communities of practice forums such as the PCK Talks, Regional conferences and two international forums for critical feedback and final checks. This was valuable in crystallising the claims made in this project. So, the research design for conceptualisation was useful in starting the process of TerSCK description.

9.4.2 Developing the TerSCK instrument

The process that developed the TerSCK instrument was largely reliant on the expertise of the teacher educators, especially those who are working in the Higher Education sector. There was only one member of the reference group who was coming from the secondary school level. The researcher missed an opportunity of including more of these experts who have in-depth knowledge of the school curriculum. Their insights would have strengthened the validity of the test items.

9.4.3 Developing and running the TerSCK-based intervention

The main focus of the intervention was to develop the content knowledge for teaching secondary school science through the elements of TerSCK. This intervention was developed in line with the performance objectives articulated in Chapter 6. Because of the vast nature of the fundamentals of the discipline in organic chemistry, a careful choice was made to focus on *functional group chemistry* and *isomerism* as they were largely overlapping with other fundamentals in the topic such as chemical bonding, nomenclature, etc.

The intervention was designed to run in person. However, it ran while the country and universities were still operating under the adjusted COVID-19 restrictions. This posed two challenges. Firstly, pre-service teachers were engaged synchronously and asynchronously with the content of the intervention, as such the full engagement between the researcher and the participants was minimal. The sessions were conducted through Zoom and some pre-service teachers would have network issues and not engage fully. With the help of the module instructor, we were able to engage some pre-service teachers beyond the Zoom interface and all the sessions were recorded and uploaded on the module site.

Secondly, TerSCK has an element of scientific inquiry, in particular, the scientific method as one of the modalities of inquiry. This required students to be engaged with the laboratory work in person. So, the restrictions limited the full exploration of this TerSCK element. As such, this was the element of TerSCK that was reported to be difficult by preservice teachers to develop after the intervention. This observation was further confirmed by follow-up interviews with the informants, *see* Chapter 8.

In addition, it would have been very ideal for the participants to keep a reflective journal where they would reflect on the quality of TerSCK and their learning experience emerging from the exposure to the intervention. Given an opportunity to do this work, the researcher would include this data set. In addition, in repeating this kind of work, another set of TSPCK responses in organic chemistry would be collected pre and post-intervention to provide insights if the development of TerSCK tacitly develops TSPCK.

9.5 Limitations

The study had some limitations that prohibit the generalization of findings made. Firstly, only two fundamentals out of the eight were explored. So, the findings are only based on the knowledge of functional group chemistry and isomerism, these cannot be generalised for other fundamentals within the organic chemistry topic. Secondly, the study used a case of PSTs in one South African university. It is important to note that the findings of my study must be viewed in the context of the particular intervention they relate to in order not to be generalized to other instances of similar interventions elsewhere.

9.6 Conclusions and Recommendations

The positioning of TerSCK between academic discipline and school subjects successfully considered TerSCK as a distinct version of content from the two far ends. This provides the space and capacity for teachers to learn to straddle them in their training by themselves in real practice. Considering the three relational dimensions was important to help this conceptualisation separate TerSCK from PCK. However, this proved to be difficult to make as PCK is largely linked to subject matter content (Kind & Chan, 2019; Rollnick et al., 2008). The idea of discarding two of Deng's relational dimensions (the pedagogical and psychological dimensions) was one attempt to distinguish TerSCK from PCK, while evidence points to their interrelatedness. Therefore, TerSCK was distinguished from PCK for purposes of structuring purposeful development as a precursor for the development of PCK.

To show how content knowledge is generally handled in science pre-service teacher education today, like Khoza (2022), we pointed to the ambiguity about the scope covered with some anecdotal references to the first and some to the second-year curriculum of mainstream science. While a similar understanding was reached in understanding the nature of the content knowledge for teacher preparation being a *determined measure*, the rationale is now based on the structure of the content rather than a reference to academic years. The *determining measure* emerging from this position refers to the exposure of the fundamental concepts and principles of the academic discipline in ways that magnify the connections within concepts, and a mindful awareness of the tensions and differences that emerge from the process of separating the fundamentals from the rest of the substantive structure of academic discipline content. This is distinct from merely choosing a discipline academic level to benchmark the content appropriate for teacher training.

In addition, when content courses in the mainstream academic faculties are introduced, historical developments in the discipline are usually highlighted. Taber (2019) has pointed out the insufficiency of these accounts for the education version of the academic discipline subject. Regarding TerSCK, consideration of these historical accounts through the purport faced by Schwab (1973) increases the educational potential embodied in a curriculum. Emphasis is to be placed on the potential to cultivate informed agency to judicious thought and action arising from the exposure to these accounts rather than a focus on precise recollection of the sequence and timing of events. This is not to say these are redundant, however, it is the difference concerning what is important for the purpose associated with the goals of a powerful teacher education curriculum for powerful teaching outcomes (Young & Muller, 2013).

This study has successfully developed an illustrative piece of the TerSCK curriculum using a case of organic chemistry and focused on two key fundamentals (functional group chemistry and isomerism). It has further drawn on this conceptualization to design an instrument that could capture and measure the quality of TerSCK.

The content knowledge described by TerSCK is intended for science PSTs only, and it may serve as the foundation for PCK and its related grain size, TSPCK. Given that it is meant to be taught in a classroom, no other clinical scientific professional practitioner may be interested in the subject matter portrayed by TerSCK. This is because of its unique feature such as the careful consideration of the tensions between the two ends of the curriculum content, the interest in the interconnections between concepts and the deliberate inclusion of historical development of contents as means for cultivation. The advancement of the substantive and syntactic structures of content knowledge of science as a field has been carefully examined, although it is tied to educational elements. Although TerSCK is not pure academic science, it has the same status as the knowledge obtained through traditional university instruction. For teacher development, TerSCK has two salient implications. Firstly, PGCE programmes would need to include specific courses for developing TerSCK appropriate for teaching school sciences. Secondly, the development of TerSCK requires the use of a model for initial teacher training in which the content courses (i.e. developing Ter SCK) are offered by those with a formal teaching qualification.

9.7 Further research

Given the limitations of this study, it is recommended that larger studies can be conducted and include all the fundamentals of the discipline in the topic to explore the nature of TerSCK in the topic. In addition, there is a need to conduct similar studies with other chemistry topics to explore the validity of the TerSCK construct. such studies can also explore other domains of sciences such as physics and biology to explore the notion of TerSCK in pre-service teacher education training. Such further research can open up comparative studies that explore the nature and development of TerSCK across various topics and domains of science.

9.8 Final pierce

The distinction between academic disciplines and school subjects is seen as an important area for theorising about profession-specific content knowledge for teachers. Theorising about profession-specific content knowledge for teaching should not be informed by a mere matching exercise to disciplinary or school subject content but by how these two entities relate. In addition, teaching is a clinical profession that should cultivate communities, hence teachers need to be cultivated first as social agents and TerSCK has shown that this potential can be realised.

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APPENDICES

Appendix A: Exhaustive search protocol

Search ID#	Search Terms	Search Options	Last Run Via	Results
S8	academic discipline and school subjects content knowledge for teaching	Limiters - Full Text; Scholarly (Peer Reviewed) Journals; Published Date: 19950101-20191231 Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	31
S7	academic discipline and school subjects	Limiters - Full Text; References Available; Scholarly (Peer Reviewed) Journals; Published Date: 19900101-20191231 Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	0
S6	academic discipline and school subjects	Limiters - Full Text; References Available; Scholarly (Peer Reviewed) Journals; Published Date: 19950101-20191231 Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	0
S5	academic discipline and school subjects	Limiters - Full Text; Scholarly (Peer Reviewed) Journals; Published Date: 19950101-20191231 Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	31
S4	academic discipline and school subjects	Limiters - Full Text; Published Date: 19950101-20191231 Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	555
S3	academic discipline	Limiters - Full Text Expanders - Apply equivalent	Interface - EBSCOhost Research Databases	626

	academic discipline and school subjects	Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	
S2	academic discipline and school subjects	Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	1,251
S1	academic discipline and school subjects	Expanders - Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Basic Search Database - ERIC; Education Research Complete; Open Dissertations; Teacher Reference Centre	6711

Appendix B: Checklist for quality appraisal of records

Criteria	Max Score	Record 1	Record 2	Record 3	Record 4
BACKGROUND AND FOCUS	**3**				
Problem	1				
Purpose	1				
Research Question(s)	1				
METHODS AND METHODOLOGY	**5**				
Qualitative/Mixed design/Narrative	1				
data collection plan	1				
Data analysis plan	1				
Participant sampling	1				
Research rigour	1				
FINDINGS	**4**				
Interpretations are supported by data	1				
Emerging ideas are precise and well-argued.	1				
Results offer new knowledge	1				
Claims generated are supported well with evidence	1				
DISCUSSIONS AND IMPLICATIONS	**3**				
Recommendations	1				
Answer(s) to the question	1				
Contribution to the existing literature	1				
OVERALL QUALITY	**15**				
PERCENTAGE QUALITY					

NOTES:

- **A record is scored a 0 if it doesn't meet the criterion**
- **A record is scored a 1 if it meets the criterion**

Appendix C: Methodology course outline

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

School of Education
Science and Technology Cluster
COURSE OUTLINE

Name of the Module	Teaching and Learning in Physical Sciences; Method 2	
Module Code	EDPS334	
Module Coordinator	**Mr B.P Ndlovu**	
Contacts	Campus	Edgewood
	Building	Main Tutorial |GF|CU142
	Email:	NdlovuB7@ukzn.ac.za
	Contacts	031 260 3444
Lecturer	**Dr L Kolobe**	
Contacts	Campus	Edgewood
	Building	Main Tutorial |GF|
	Email:	Kolobe@ukzn.ac.za
	Contacts	031 260 3785

AIMS OF THE MODULES

This module aims to provide students with a broad-based sound knowledge that equips the graduate with the knowledge of theories and methodologies of the discipline to enable them to demonstrate initiative and responsibility in an academic and professional context within an inclusive education framework. In particular, it will assist students in developing an awareness of the various teaching and learning strategies in Physical Science education; to make students aware of the kinds of misconceptions learners; to develop assessment skills; to develop skills in selecting and using resources in science teaching and to engage in professional reflective practice.

LEARNING OBJECTIVES OF THE MODULE

Upon completion of the module, the student should be able to:

- Demonstrate the knowledge and understanding of the various misconceptions and explore different ways of changing such misconceptions
- Demonstrate knowledge and understanding of the different teaching and learning strategies in science education

- Demonstrate the knowledge of various resource-based learning (types of resources, use of selected resources; for example, simulations).
- Demonstrate the knowledge and understanding of various aspects concerning assessment
- Demonstrate the ability to apply teaching strategies to correct misconceptions
- Demonstrate the ability to use appropriate lesson types for different topics
- Demonstrate the ability to use different resources in their teaching
- Demonstrate the ability to implement appropriate assessment strategies for different topics
- Demonstrate the ability to reflect meaningfully on their professional practice

CONTENT OF THE MODULE

Chemical Reactions; Mechanics and Waves will be used as a context for developing an understanding of how physical science is taught in the new Curriculum and Assessment Policy Statement (CAPS). The following aspects would be addressed

- Teaching and learning strategies in physical sciences
- Resource-based learning
- Assessment
- Identifying and addressing alternative (mis)conceptions
- Reflections on professional practice

COURSE MATERIAL

1. Physical Science FET CAPS Document
2. Section 23 of Grade 12 Abridged Section 4 CAPS
3. Copies of Physical Sciences SIYAVULA Textbooks (Grade 10 – 12)
4. Reading as outlined in the sessions below; these will be found in the

STUDENT RESPONSIBILITY

1. The course will be running on learn2021@ukzn, it is the student's responsibility to familiarise themselves with the platform
2. It is important to read the course material allocated for the session before the lecture

OUTLINE OF THE SESSIONS

WEEK	UNIT	CONTENT/ Tutorial TASKS/ ASSIGNMENTS	RESOURCE(S)
1		**Orientation to the course and overarching expectations**	
2	UNIT 1	**Introduction to the Curriculum and Assessment Policy Statement (CAPS) – Teaching Physical Sciences** • Background and Overview	CAPS Document **Examine PS CAPS** doc

		• What is Physical Science? • Specific Aims of Physical Sciences • Time allocation of Physical Sciences in the curriculum • Overview of topics (Mechanics as a context & chemical change) • Skills in sciences (Process, 21st Century and ICT Applications)	
3	**UNIT 2**	**Teaching and Learning Strategies in Science** • The 5E's Teaching approach	Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS*, *5*, 88-98.
4		**Teaching and Learning Strategies in Science** • Concept mapping	Kilic, M., & Çakmak, M. (2013). Concept maps as a tool for meaningful learning and teaching in chemistry education. Lecture Note – Concept mapping
5 14/03 – 25/03		**Teaching and Learning Strategies in Science** • Collaborative Learning	Jacobs, G. M. (2004). Cooperative Learning: Theory, Principles, and Techniques.
6&7	**UNIT 3**	**Resource-based Learning & ICT**	Hill, J. R., & Hannafin, M. J. (2001). Teaching and learning in digital environments: The resurgence of resource-based learning. *Educational Technology Research and Development*, *49*(3), 37-52.
09/04 – 18/04		**Mid-semester Break**	
8&9	**UNIT 4**	**The Pedagogy of Teaching Science and Learner Misconceptions**	Lecture notes

		• Identifying and confronting learner misconceptions/alternative ideas in science teaching	
10	**UNIT 5**	**Assessment in Physical Sciences**	CAPS Document page 143 – 151 Lecture Notes Sosniak, L. A. (1994). *Bloom's taxonomy*. L. W. Anderson (Ed.). Chicago, IL: Univ. Chicago Press.
11 -15		**TerSCK Intervention** • TerSCK Pre-test • Introduction to TerSCK – a case with organic chemistry • Historical Developments of Content in Organic Chemistry • Fundamentals of the discipline in organic chemistry • Interconnections in the concepts that make up the fundamentals • Tensions arising from the constraints associated with the focus on the fundamental • Scientific Inquiry & other modes of inquiry • TerSCK Post Test	

FORMAL ASSESSMENT

Test (25%)
Assignments/Projects/Class activities (25%)
Examination (50%)

DETAILED PROGRAM OF ASSESSMENT (PROVISIONAL*)

DATE	TASK	Content	RAW SCORE (Marks)	WEIGHT (%)
18 March 2022	Assignment 1	UNIT 2	30	10%
01 April 2022	Semester test	UNIT 1, 2&3	40	20%
22 April 2022	Assignment 2	UNIT 4	30	10%
Ongoing	Tutorials	*****	****	10%
TBC	Examination/ Equivalence	ALL UNITS	75	50%

Plagiarism

Plagiarism constitutes – Presenting ideas of another as if they are your own – Representing words or works of another as they were your own – Utilisation of ideas, words or work of another without appropriate acknowledgement – Actions involving utilization of printed text, electronic text, images, computer programs, sound, performance, etc without appropriate acknowledgement – Work utilised in the learning process or submitted for publication or assessment without appropriate acknowledgement – Any infringement of the need to reflect group effort or acknowledging previously published work.

Students are reminded plagiarism is an act of misconduct and University Rules are applicable as such.

Appendix D: Ethical clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Ndlovu

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H19/10/24**
PROJECT TITLE	The development and validation of a theoretical construct describing content knowledge for teaching science: A case study with Organic Chemistry
INVESTIGATOR(S)	Mr B Ndlovu
SCHOOL/DEPARTMENT	Education/
DATE CONSIDERED	18 October 2019
DECISION OF THE COMMITTEE	Approved Permission letters required before data collection can commence
EXPIRY DATE	16 January 2023

DATE 17 January 2020 **CHAIRPERSON** J. Knight
(Professor J Knight)

cc: Supervisor : Professor E Mavhunga

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature

07 / 04 / 2020
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix E: Permission to conduct research

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

14 March 2022

Mr Bongani Prince Ndlovu
Department of Education
Faculty of Humanities
University of Witwatersrand
Email: NdlovuB7@ukzn.ac.za Elizabeth.Mavhunga@wits.ac.za

Dear Mr Ndlovu

RE: PERMISSION TO CONDUCT RESEARCH

Gatekeeper's permission is hereby granted for you to conduct research at the University of KwaZulu-Natal (UKZN), towards your postgraduate degree, provided Ethical clearance has been obtained. We note the title of your research project is:

"The development and validation of a theoretical construct describing content knowledge for teaching science: a case study with organic chemistry."

It is noted that you will be constituting your sample by conducting interviews with the 3rd Year Science Education students doing module EDPS 334 (Taking in account the regulations imposed during lockdown ie restrictions on gatherings, travel, social distancing etc. Zoom, Skype or telephone interviews recommended) on the Edgewood campus.

Please ensure that the following appears on your notice/questionnaire, and that you have liaised with the module co-ordinator before commencement:

- Ethical clearance number;
- Research title and details of the research, the researcher and the supervisor;
- Consent form is attached to the notice/questionnaire and to be signed by user before he/she fills in questionnaire;
- Gatekeepers approval by the Registrar.

You are not authorized to contact staff and students using the 'Microsoft Outlook' address book. Identity numbers and email addresses of individuals are not a matter of public record and are protected according to Section 14 of the South African Constitution, as well as the Protection of Public Information Act. For the release of such information over to yourself for research purposes, the University of KwaZulu-Natal will need express consent from the relevant data subjects. Data collected must be treated with due confidentiality and anonymity.

Yours sincerely

Dr KE CLELAND: REGISTRAR

Office of the Registrar
Postal Address: Private Bag X54001, Durban, 4000, South Africa
Telephone: +27 (0)31 260 7971 **Email:** registrar@ukzn.ac.za **Website:** www.ukzn.ac.za

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

INSPIRING GREATNESS

Appendix F: Participants information sheet

University of the Witwatersrand Private Bag 3 Wits 2050 Johannesburg, RSA

t+27 11 7173414 f+27 11 7173259

PhD Student: Mr B. P Ndlovu
Student No.: 584432
Phone: 076 027 4587; e-mail: ndlovu@thepub.co.za

INFORMATION SHEET FOR CHEMISTRY PRE-SERVICE TEACHERS

DATE:

Dear Sir / Madam

My name is Bongani Prince Ndlovu and I am a researcher in the School of Education at the University of the Witwatersrand.

I am researching: **The Development and Validation of a Theoretical Construct Describing Content Knowledge for Teaching Science: A Case Study with Organic Chemistry**

My research involves……

The development and the validation of a theoretical framework describing a specialized teacher content knowledge in chemistry. This will consider academic discipline content knowledge and school-related science content knowledge in a specific chemistry topic, i.e. Organic Chemistry. An instrument to measure and validate this theoretical construct will be developed and a corresponding intervention will be conducted to explore the nature of the developed content knowledge

As part of this project, I would like to invite you to take part in an intervention that will develop TerSCK in organic chemistry. This intervention will be conducted as part of the methodology course located in the B. Ed program. This will involve focus group discussions on TerSCK. In addition to the discussion pre-and post, the intervention tools (developed separately) on TerSCK will be administered to measure the development of TerSCK in organic chemistry. This activity will take around 6 hours spread over 4 weeks. With your permission, I would also like to record group discussions and the interview using a digital device to audio-tape the discussion.

The purpose of this project is the requirement for a Doctor of Philosophy degree in the above-mentioned university

Your name and identity will always be kept confidential in all academic writing about the study. Your privacy will be maintained in all published and written data resulting from the study. All research data will be destroyed between 3-5 years after the completion of the project.

You will not be advantaged or disadvantaged in any way. Your participation is voluntary, so you have the right to withdraw your permission at any time during this project without any penalty. There are no foreseeable risks in participating and you will not be paid for this study.

If you have any questions during or afterwards about this research, feel free to contact me at the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to receive a summary of this report, I will be happy to send it to you (optional). If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone at +27(0) 11 717 1408, email Shaun.Schoeman@wits.ac.za

Yours sincerely,

SIGNATURE: ________________________

NAME: Bongani Prince Ndlovu

EMAIL: ndlovub7@ukzn.ac.za

TELEPHONE NUMBERS: 0760274587

SUPERVISOR: Prof E.M Mavhunga

TELEPHONE NUMBERS +27 11 717 3734

EMAIL Elizabeth.Mavhunga@wits.ac.za

Appendix G: Participants' consent forms

University of Witwatersrand, Johannesburg – RSA
Faculty of Humanities, Wits School of Education
Science Education Division

PhD Student: Mr B. P Ndlovu
Student No.: 584432
Phone: 076 027 4587; e-mail: ndloveb7@ukzn.ac.za

PRE-SERVICE TEACHERS' CONSENT FORM

Please fill in and return the reply slip below indicating your willingness to be a participant in my voluntary research project called:

The Development and Validation of a Theoretical Construct Describing Content Knowledge for Teaching Science: A Case Study with Organic Chemistry

I, _________________________ give my consent for the following:

Permission to be audiotaped

I agree to be audiotaped during the interview or observation lesson YES/NO

I know that the audiotapes will be used for this project only YES/NO

Permission to be interviewed

I would like to be interviewed for this study. YES/NO

I know that I can stop the interview at any time and don't have to answer all the questions asked. YES/NO

Permission to complete the TerSCK tool

I agree to complete the TerSCK tool. YES/NO

I know that the Tool will be used for this project only. YES/NO

Informed consent

I understand that:

- My name and information will be kept confidential and safe and my name and the name of my school will not be revealed.
- Direct quotes may be included in the final research report
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audiotaped, photographed and/or videotaped
- All the data collected during this study will be destroyed within 3-5 years after the completion of my project.

Sign______________________________ Date____________________________

Appendix H: Focused group interview protocol

- What do you understand about TerSCK
- Which aspects of TerSCK have you found most difficult? Why?
- Which aspects of TeRsck have you found easier? Why?
- Do you think TerSCK is different from the main content course you have done, if so, HOW?
- Do you think TerSCK is different from the school content course you have done, if so, HOW?
- Do you feel enlightened to teach science after the TerSCK intervention?
- What can be done better in future interventions?

Appendix I: Adapted content knowledge instrument

ORGANIC CHEMISTRY RESEARCH PROJECT

This info is for research purposes only: your responses will be treated confidentially. Pseudonyms will be used if a need to refer arises. This page will be detached and stored separately.

SECTION A: BACKGROUND INFORMATION

SURNAME: ________________________________

NAME ____________________________________ Gender (tick✓): | Femal | Male |

HOME province and town: ____

Please fill in details about all post-school qualifications. (since you left school.)

Qualification and length of course (e.g. STD - 3yrs)	From (year)	To (year)	Main Subjects

Please provide the highest level reached in your science content subjects studied - i.e. science and maths courses (not education or methodology/didactics courses) and the highest level at which you have taught (e.g. grade 11).

Subject	Highest level reached (e.g. 2nd yr univ)	Highest level taught (e.g. G 11)
Chemistry		
Physics		
Physical Science		
(Others)		

Please provide the following information about your teaching.

Number of years	School and province	Subjects taught	Classes taught

Personal Code: ……………………………….

Personal code:

ORGANIC CHEMISTRY BACKGROUND

1. Draw the structural formulae for each of the following compounds:

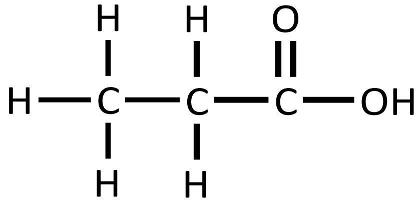
2-methylhex-3-ene	ethyl propanoate

2. Molecules with the same molecular formula can have different structures, this is known as isomerism. There are several kinds of isomerism such as structural and geometric. Answer the following questions about isomers.

a) Draw the following isomers for 2-butene, name the compounds that you draw.

A structural isomer of 2-butene	A Geometric isomer of 2-butene

b) Structural isomers can belong to different homologous series in other words they could have different functional groups. Draw two structural isomers with different functional groups for the compound below and include the IUPAC name for each.



Structural isomer of propanoic acid	Structural isomer of propanoic acid

3. The table below contains several organic compounds having different functional groups. Study the compounds and answer the questions that follow.

1 $CH_3\text{-}OH$	**2** $CH_3-\overset{\overset{O}{\parallel}}{C}-OH$	**3** $CH_3-\overset{\overset{O}{\parallel}}{C}-H$	**4** $CH_3\text{-}CH_2\text{-}OH$
5 $CH_3-\overset{\overset{O}{\parallel}}{C}-CH_3$	**6** $H-\overset{\overset{O}{\parallel}}{C}-O-CH_3$	**7** $CH_3\text{-}O\text{-}CH_3$	**8** $CH_3-\overset{\overset{O}{\parallel}}{C}-O-CH_3$

a)	Select which of the compounds are alcohols	
b)	Select which of the compounds are aldehydes	
c)	Select which of the compounds are ketones	
d)	Select which of the compounds are esters	
e)	Which two boxes contain the substances that are used to make the compound in box 8?	

f)	Which compound is the structural isomer of the compound in box 7?	

4. Study the following table and answer the questions below:

No. of carbons	**Alkanes**		**Alcohols**		**Carboxylic acids**	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

a) Why is the boiling point for hexane so much lower than that of hexan-1-ol?

b) Why is the boiling point for methanol so much lower than that of hexan-1-ol?

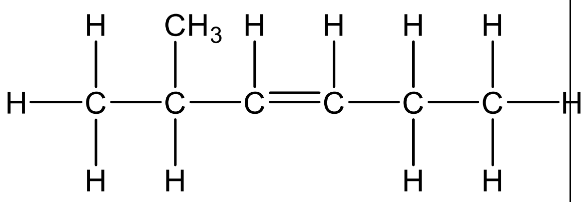
c) The boiling points for the carboxylic acids are not included. Do you expect their boiling points to be higher or lower than the boiling points of the alcohols with the same number of carbon atoms? Explain your answer.

Appendix J: Adapted content knowledge memorandum

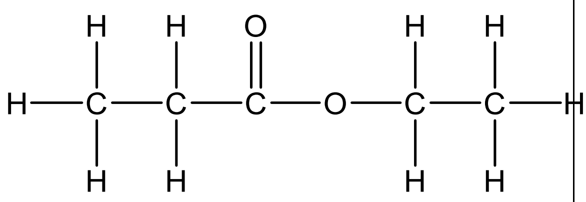
MARKING MEMORANDUM FOR CK ON ORGANIC CHEMISTRY

1 Draw the structural formulae for each of the following compounds:

2-methylhex-3-ene



ethyl propanoate



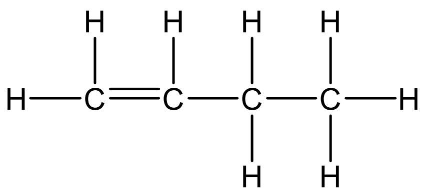
Q1a) 1 mark for correct structure

Q1b) 1 mark for correct structure

2 Molecules with the same molecular formula can have different structures, this is known as isomerism. There are several kinds of isomerism such as structural and geometric. Answer the following questions about isomers.

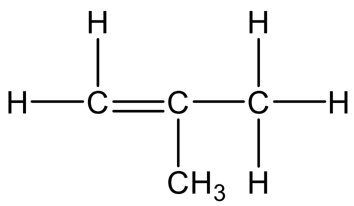
c) Draw the following isomers for 2-butene. (IUPAC names given for interest only.)

Structural isomer of 2-butene



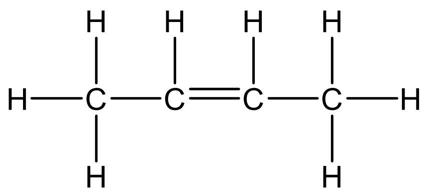
1-butene

OR



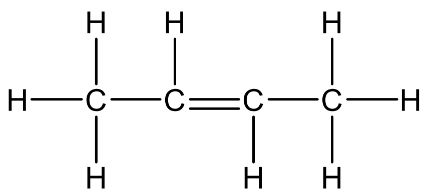
2-methyl-1propene

Geometric isomer of 2-butene

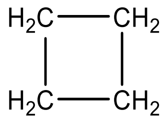


cis-2-butene

OR



trans-2-butene

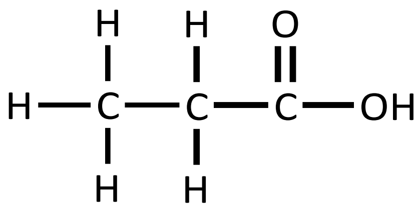


cyclobutane

Q2a) 1 mark for each correct structure, <u>2 marks</u>

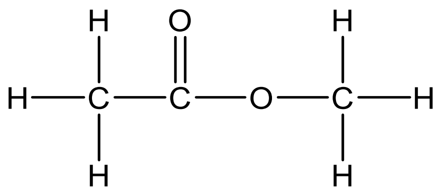
Question 2 continued

d) Structural isomers can belong to different homologous series in other words they could have different functional groups. Draw two structural isomers with different functional groups for the compound below.



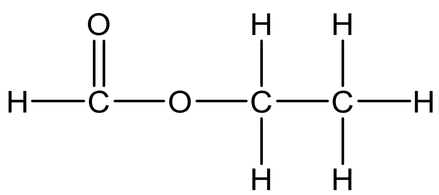
Names are shown below structures

Structural isomer of propanoic acid



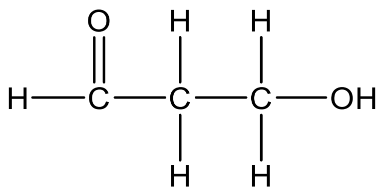
methyl ethanoate

OR



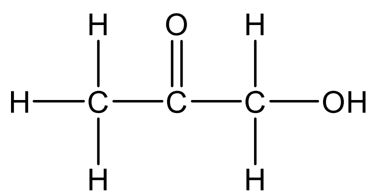
ethyl methanoate

Structural isomer of propanoic acid



3-hydroxypropanal

OR



1-hydroxypropanone

e) IUPAC name of isomer above

IUPAC name of isomer above

Q2b) Award 1 mark for each correct structure, 2 marks

Q2c) **Award 1 mark for each correct name,** **2 marks**

Award marks for the correct name in Q2c even if the structure is not correct as this question probes understanding of IUPAC nomenclature

Q4 The table below contains a number of organic compounds having different functional groups. Study the compounds and answer the questions that follow.

1	**2**	**3**	**4**
$CH_3\text{-}OH$	$CH_3-\overset{\overset{\large O}{||}}{C}-OH$	$CH_3-\overset{\overset{\large O}{||}}{C}-H$	$CH_3\text{-}CH_2\text{-}OH$
5	**6**	**7**	**8**
$CH_3-\overset{\overset{\large O}{||}}{C}-CH_3$	$H-\overset{\overset{\large O}{||}}{C}-O-CH_3$	$CH_3\text{-}O\text{-}CH_3$	$CH_3-\overset{\overset{\large O}{||}}{C}-O-CH_3$

a)	Select which of the compounds are alcohols	1 **&** 4	**1 mark**
b)	Select which of the compounds are aldehydes	3	**1 mark**
c)	Select which of the compounds are ketones	5	**1 mark**
di)	Select which of the compounds are esters	6 **or** 8	**1 mark**
dii)	Select which of the compounds are esters	6 **or** 8	**1 mark**
e)	Which two boxes contain the substances that are used to make the compound in box 8?	1 **&** 2	**1 mark***

Total of 7 marks

f)	Which compound is the structural isomer of the compound in box 7?	4	**1 mark**

4 Study the following table and answer the questions below:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (^oC)	IUPAC name	Boiling point (^oC)	IUPAC name	Boiling point (^oC)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

d) Why is the boiling point for hexane so much lower than that of hexan-1-ol?

The boiling points of compounds depend on the intermolecular forces present. Hexane has only weak van der Waals forces **[1 mark]** as the intermolecular force which needs a lower amount of energy to break, resulting in a low boiling point **[1 mark]** whereas hexan-1-ol has strong hydrogen bonding between the molecules **[1 mark]** which requires more energy to be broken hence a higher boiling point. **[1 mark]**

<u>4 marks</u>

e) Why is the boiling point for methanol so much lower than that of hexan-1-ol?

While both have a strong hydrogen bonding, methanol has a shorter chain therefore a smaller surface area for the van der Waals forces to act **[1 mark]** than hexan-1-ol which has a longer chain (larger surface area). **[1 mark]** The van der Waals forces in methanol are much weaker than in hexan-1-ol , **[1 mark]** and as such less energy is needed to break the intermolecular forces and hence a low boiling point. **[1 mark]**

<u>4 marks</u>

f) The boiling points for the carboxylic acids are not included. Do you expect their boiling points to be higher or lower than the boiling points of the alcohols with the same number of carbon atoms? Explain your answer.

Carboxylic acids have higher boiling points than corresponding alcohols. This is because of the C=O, which gives a region of high electron density (a dipole) and therefore stronger attraction which needs more energy to be broken, **[1 mark]** causing the boiling point to be higher. **[1 mark]** **<u>2 marks</u>**

OR

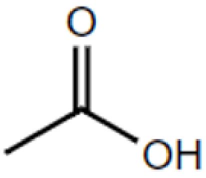
Carboxylic acids are capable of forming dimers **[1 mark]** thus increasing the extent of hydrogen bonding possible in these molecules. **[1 mark]**

<u>2 marks</u>

Appendix K: First version of the TerSCK instrument

Teacher-related Science Content Knowledge Instrument

1. Consider the following structures



(A)

(B)

(C)

1.1. Identify as many concepts/aspects linked to the knowledge of each of the three structures above.

1.2. Draw a concept map to show how you make sense of the **connections** of the concepts you have identified in (a) above

1.3. Write a paragraph to describe how you make sense of the connections outlined in your concept map.

2. *Alcohols are organic compounds that contain a hydroxyl group (-OH) and are described by a general formula $C_nH_{2n+2+}O$.*

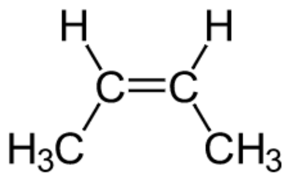
2.1. Draw the structures of:

propan-2-ol	1,2propan-diol

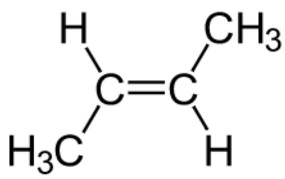
2.2. With your knowledge of school science, what difficulty do you anticipate in dealing with the two structures when teaching about the knowledge of general formulas?

3. Consider the following two structures:

3.1. Give t



compound



(A)

(B)

3.2. Given the scope of the South African curriculum and your knowledge of isomerism above, what difficulty do you anticipate in teaching and making the difference between the two structures clear to learners

4. *The scientific inquiry aims to generate knowledge in the form of testable explanations that can be used to predict the outcomes of future experiments. This, in turn, allows the scientists to gain a better understanding of the topic under study, and later use that understanding to intervene in its causal mechanism.*

A group of university students investigated the boiling and of liquid alkanes. Answer the following question based on your knowledge of the scientific process:

4.1. What would be the possible hypothesis for this investigation?
4.2. What investigative question can be asked by the student?
4.3. Identify the possible variables for this investigation

The students carried out the investigation and generated the following set of results:

Alkanes	**Boiling point (^{0}C)**
pentane	36
hexane	69
heptane	98
octane	125

4.4. What pattern can be observed from the set of results above

4.5. Fully explain the pattern observed you made in 4.4.

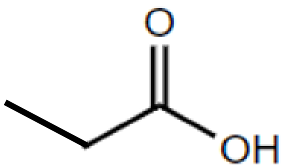
4.6. From the explanation you generated in question 4.5, draw a concept map to show your understanding of **connections** between the concepts used in the explanations.

5. *Given the rise in natural disasters experienced in our country and the rest of the world, global warming has been at the centre of it all. Global warming is caused by the burning of fuels such as octane that produce carbon dioxide (CO_2) gas. CO_2 is one of the greenhouse effect gases that trap heat in the atmosphere and thus increase the average temperatures of the earth.*

With your knowledge of science, what practical **solutions** and **interventions** you can implement in your immediate community to mitigate the effects of global warming?

Appendix L: Final version of the TerSCK instrument

1. Consider the following organic line structures and their corresponding condensed formulae



CH_3CH_2COOH

CH_3CCCH_3

$CH_3CH_3CH_2OH$

What can you say about these organic structures?

1.1. For **each** of the above, identify all the concepts/understandings that you think are conceptually connected to **each** organic structure.

1.2. Draw a concept map to show how the identified concepts connect to each organic structure and across the other structures.

1.3. Write a paragraph to describe how you would make sense of the connections outlined in your concept map. Use examples of the links from your constructed concept map to elaborate on your answer.

2. Alcohols are organic compounds that contain a hydroxyl group (-OH) and are described by a general empirical formula $C_nH_{2n+2}O$. Consider TWO alcohols each described by the following IUPAC names and condensed structural formulae propan-1-ol $CH_3CH_2CH_2OH$ and propan-1,2-diol. $CH_2(OH)CH(OH)CH_3$

2.1. Write down the molecular formula for **each** structure respectively

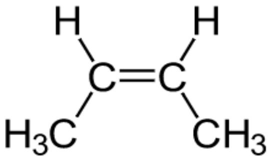
2.2. Using your answers in 2.1, what can you say about the application of the general empirical formula ($C_nH_{2n+2}O$) across these two organic alcohols?

2.3. The school science curriculum states that "*organic compounds are restricted… to a maximum of two functional groups of the same type per compound* (DBE, 2011 p 105)"

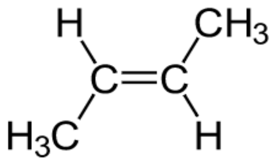
What difficulty in terms of the teachability and the perpetuation of misconceptions do you anticipate in dealing with the two structures when teaching about the knowledge of general empirical formulas?

2.4. What is the benefit in knowing about this knowledge described above in (2.3)

3. Consider the following two structural formulae:



(A)



(B)

3.1. Would you regard these molecules as isomers? If YES, what kind of isomerism is displayed by the two structures

3.2. The school science curriculum states that: "*isomers are restricted to structural isomers: (1) chain isomers (different chain); (2) positional isomers (different position of the same functional group) and (3) functional isomers (different functional group).* (DBE, 2011 p 105)"

What difficulty in terms of the <u>teachability</u> and the <u>perpetuation of misconceptions</u> do you anticipate in making the difference between the two structures clear to learners?

3.3. What is the benefit in knowing about this knowledge described above in (3.2)

4. A group of science students came across the following data:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
3	Propane	-42	Propan-1-ol	97	Propanoic acid	141
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

In addition to this data, they also learned that:

The strength of the intermolecular forces is connected to the amount of energy required to overcome the intermolecular forces. The amount of energy required thus affects the physical properties of organic compounds.

4.1. Use the case of **compounds with 3 carbons** (propane, propan-1-ol & propanoic acid) and describe how you could use the scientific inquiry (scientific method) to highlight key steps to generate the set of the observed data pattern.

4.3. Considering the knowledge of the connections in the concepts learnt, how do you explain the observed trend in the boiling points of alkanes shown in the table above.

5. *Given the rise in natural disasters experienced in our country and the rest of the world, global warming has been proposed as the root cause. Global warming is caused by the combustion of processed fossil fuels such as octane that produce carbon dioxide (CO_2) gas. CO_2 is a greenhouse gas that traps heat in the atmosphere and thus increases the average temperature of the earth.*

With your knowledge of science, what practical **solutions** and **interventions** you can implement in your immediate community to mitigate the effects of global warming?

Appendix M: TerSCK memorandum

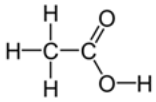
Teacher-related Science Content Knowledge Memorandum

The three molecules belong to different homologous series, OR

The three molecules each contain different functional group

A

1. Carboxyl functional group
2. Structural formula

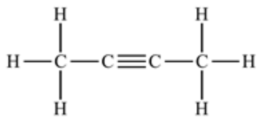
1.1. 

3. Ethanoic acid
4. Polar molecule
5. 2-stites hydrogen bonds
6. Boiling point
7. $C_3H_7O_2/C_nH_{2n+1}O$
8. Functional isomerism

1.2.

B

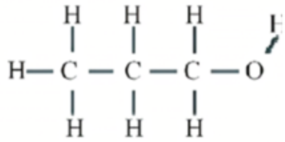
1. Triple bond
2. Alkyne



3. Non-polar molecule
4. Sp-hybridization
5. Linear geometry
6. Positional/chain isomers

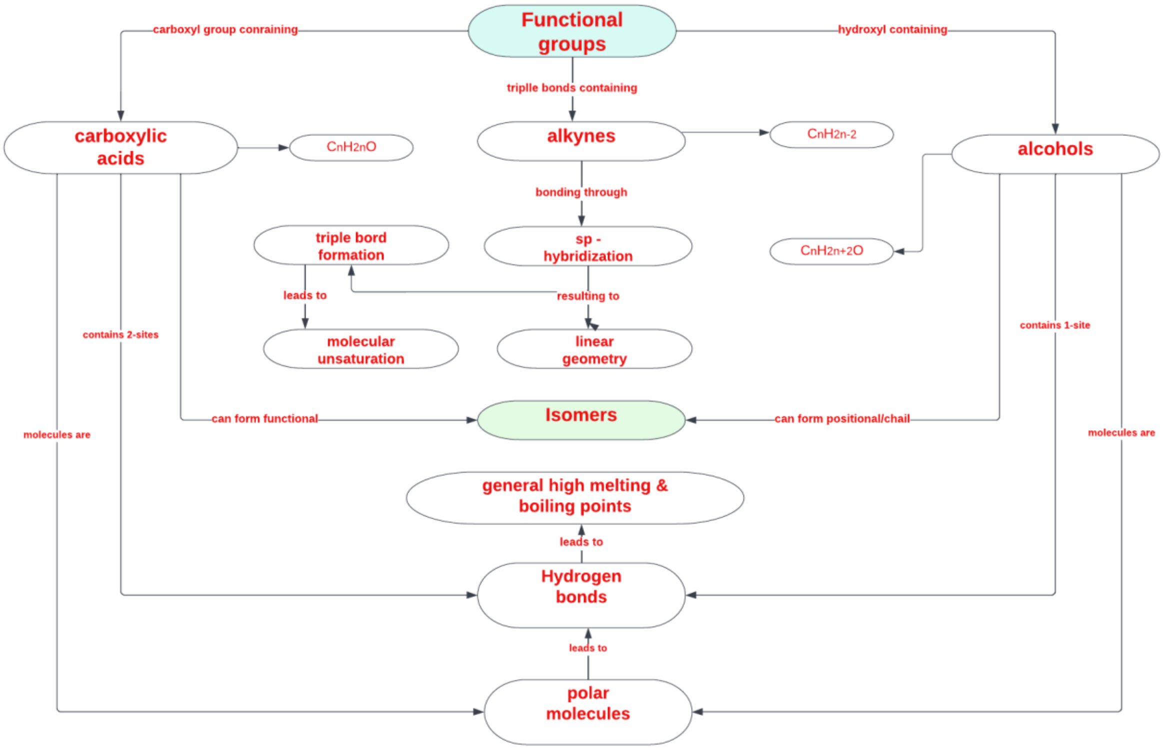
C

1. Hydroxyl group
2. Primary alcohol
3. Lewis structure



1.3.

4. Polar molecule
5. 1-site hydrogen bonds
6. Positional isomers
7. $C_3H_8O/C_nH_{2n+2}O$



The tress structures show three molecules that belong to three **homologous series** they are each described a distinct **empirical general formula**. This categorization is determined by the **functional group** (atoms, group of atoms or types of bonds) present in each molecule.

Both alcohols and carboxylic acids contains highly electromotive atoms which increases their **molecular polarity**. This in turns leads to the presence of strong **hydrogen bonds** (intermolecular forces). The present of these intermolecular forces thus increases the **energy** required to overcome them. Thus, they generally have higher **boiling/melting points**. The alkynes are **non-polar molecules** and thus contain weaker induced dipole forces (London forces).

The triple bonds in alkynes are as a result of **sp-hybridization** that forms one sigma bond & two pi-bonds between carbon atoms. This leads to the molecules of

1.

Propan-1-ol – C_3H_8O

Propan-1,2-diol – $C_3H_8O_2$

The general formula is not applicable for propan-1,2-diol. The general formula seems to be applicable when there is ONLY one functional group in a molecule. Once the molecule is a "diol" the general empirical formula does not work

The school curriculum allows for the discussion of diols as stipulated in the curriculum that "a maximum of two functional groups of the same type per compound" is permissible. In the example above, the -OH group is a limited resulting to a "diol". However, the curriculum is silent about the application of the general empirical formula across all organic compounds that contains the -OH group. It makes no explicit exception with the inclusion of the "diol" in the

2.

Yes,

Geometrical isomers

The school curriculum limits the knowledge of isomerism to ONLY structural isomers (chain, positional and functional isomers). However, in most school curriculum texts, the two structures are usually shown. A teacher who is not aware of this kind of isomerism (geometrical) in respect to the limitation of the school curriculum can easily engender misconceptions by failing to clearly distinguish these two structures as they have the same IUPAC name (but-2-ene)

Generally, when conducting a scientific research through a scientific method, there are steps that are followed, inline with the 3-C containing compounds, the following must be taken into consideration.

1. Investigative question

What is the effect the functional group on the boiling point of organic compounds with the same number of carbons?

2. Conducting background research

Functional group are atoms, group of atoms or types of bonds that determine the physical and chemical properties of organic molecules. The presence of functional groups affects such properties as melting points, boiling points, polarity, dipole moments, and solubility. Molecules with strongly polar functional groups tend to have higher melting points and boiling points than molecules with nonpolar functional groups, and prefer to dissolve in polar solvents rather than nonpolar solvents

3. Hypothesizing

Organic molecules with a strongly polar functional group generally have the higher boiling points

4. Carrying out the investigation and manipulating variables

Variables to manipulated

   a. Independent variable: type of functional group
   b. Dependent variable: boiling point
   c. Controlled variable: number of carbons

5. Data generation and Analysis

Data generation (cf. Table of results above)

Observation: Carboxylic acids have the highest boiling point, alcohols have a boiling point lesser than the carboxylic acids. Alkanes have the lowest boiling point

6. Data Analysis

Carboxylic acids contain a carboxyl ground (strongly polar) than the hydroxy group (alcohols). Alkanes are generally non-polar molecules. Carboxylic acids thus contain the strongest intermolecular forces (2-sites hydrogen bonds) that alcohols that have 1-site hydrogen bonds. Alkane only have weak London forces. Most energy is required to overcome the intermolecular forces in carboxylic acids than in alcohols and alkanes. As

3.

Considering the class of alkanes, all of the molecules have the same kind of intermolecular forces, these are induced-dipole forces (London Forces). However, an increase in the chain length increases the surface area on which these forces act. This subsequently increases the strength of the London forces over a larger surface area. So, alkanes with longer chains would require more energy to overcome the intermolecular force which subsequently increase the boiling point as we increase the carbon chain.

4.

Any practical solution AND intervention that scientifically meaningful for the betterment of immediate communities and the society at large.

This section is informed by cultivation potential of the content. The response must indicate that a candidate who has acquired TerSCK in organic chemistry can be able to draw from the historical development of content in organic chemistry discussed in class to be cultivated. A candidate is cultivated if they can be innovative, independent and can become knowledge creators.

Appendix N: First draft TerSCK rubric

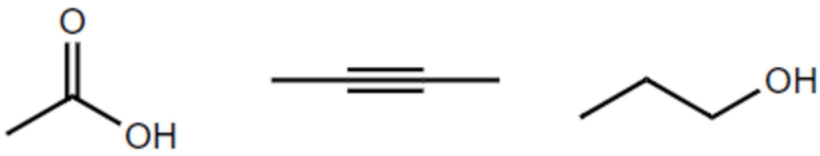
TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	1	2	3	4
Historical development of content and its cultivating potential.	There is no evidence of cultivation through the knowledge of TerSCK The response does not offer practical societal solutions and interventions to real-life problems	There is basic level of cultivation through the knowledge of TerSCK The response offers solutions and interventions that are impractical to real-life problems	There is sufficient level of cultivation through the knowledge of TerSCK. The response offers solutions and interventions that are not practical to real-life problems	There is an good level of cultivation through the knowledge of TerSCK The response shows the ability to offer practical solutions to real-life problems
Knowledge of the fundamentals in the topic	There is poor knowledge of the content. Overall content knowledge performance is at 25% and below	There is limited knowledge of the content Overall content knowledge performance is between 25% - 49%	The respondent demonstrates good knowledge of the content Overall content knowledge performance is between 50% - 74%	The respondent demonstrates outstanding knowledge of the fundamental content Overall content performance is 75% and above.
Knowledge of the interconnections between the concepts of the fundamentals	Insufficient number of concepts are identified relating to the fundamental The concept map drawn shows incorrect links between the concepts The explanation of the nature of the connections is conceptually incorrect	Acceptable number of concepts are identified relating to the fundamental Concept map is drawn but no linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to organic chemistry	Sufficient number most concepts are identified relating to the fundamental. Concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to only organic chemistry	Sufficient number most concepts are identified relating to the fundamental. Concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are not limited to only organic chemistry
Knowledge of the tensions associated with the focus of the fundamentals	– The respondent shows no awareness of the tensions created by importing academic discipline content into the school curriculum	– The respondent identifies one tension but cannot justify it by drawing from an explanation construed in the fundamentals of the discipline in the topic	– The respondent identifies one tension and explains it by drawing from an explanation construed in the fundamentals of the discipline in the topic	– The respondent identifies more than one tension and explains these by drawing from explanation construed in the fundamentals of the discipline in the topic
Knowledge of the scientific inquiry (Scientific method)	There is no evidence of the knowledge of the scientific inquiry The response lacks all aspects of the knowledge of the scientific method	There is basic knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation	There is good knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation AND draw correct observations from the presented data. The respondence draw from the scientific body of knowledge to justify observed patterns with minor conceptual errors	There is good knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation AND draw correct observations from the presented data. The respondence draw from the scientific body of knowledge to justify observed patterns with no conceptual errors

Appendix O: Revised TerSCK rubric

TerSCK Item	Poor	Limited	Good	Outstanding
Likert Scale	**1**	**2**	**3**	**4**
Knowledge of the fundamentals in the topic	There is poor knowledge of the content. Overall content knowledge performance is at 25% and below	There is limited knowledge of the content Overall content knowledge performance is between 25% - 49%	The respondent demonstrates good knowledge of the content Overall content knowledge performance is between 50% - 74%	The respondent demonstrates outstanding knowledge of the fundamental content Overall content performance is 75% and above.
Knowledge of the interconnections between the concepts of the fundamentals	At most three concepts are identified relating to the fundamental No concept map is drawn to show links between the concepts The explanation of the nature of the connections is conceptually incorrect	At most four concepts are identified relating to the fundamental The concept map is drawn but with limited linking words to show connections The explanation of the nature of the connections is partially correct The concepts identified are limited to organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are limited to only organic chemistry	More than four concepts are identified relating to the fundamentals. The concept map is drawn with linking words to show connections The explanation of the nature of the connections is conceptually correct The concepts identified are not limited to only organic chemistry
Knowledge of the tensions associated with the focus on the fundamentals	The respondent shows no awareness of the tensions created by importing academic discipline content into the school curriculum	The respondent identifies the tension/limitation but cannot justify it by drawing from an explanation construed in the fundamentals The respondent does not link the tension/limitation to explain what potential difficulty is anticipated in teaching the concept	The respondent identifies the tension/limitation and correctly justifies it by drawing from an explanation construed in the fundamentals The respondent links the tension/limitation identified to explain the anticipated difficulty in teaching the concept	The respondent identifies more than one tension/limitation and correctly justifies them by drawing from an explanation construed in the fundamentals The respondent links the tensions/limitations identified to explain the anticipated difficulty in teaching the concept
Knowledge of the scientific inquiry (Scientific method)	There is no evidence of the knowledge of the scientific inquiry The response lacks all aspects of the knowledge of the scientific method	There is basic knowledge of the scientific inquiry The respondent can hypothesize, ask investigative questions, identify all the variables involved in the investigation	There is good knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation AND draw correct observations from the presented data. The respondence draw from the scientific body of knowledge to justify observed patterns with minor conceptual errors	There is good knowledge of the scientific inquiry The response can hypothesize, ask investigative questions, identify all the variables involved in the investigation AND draw correct observations from the presented data. The respondence draw from the scientific body of knowledge to justify observed patterns with no conceptual errors
Historical development of content and its cultivating potential.	There is no evidence of cultivation through the knowledge of TerSCK The response does not offer practical societal solutions and interventions to real-life problems	There is a basic level of cultivation through the knowledge of TerSCK The response offers solutions and interventions that are impractical to real-life problems There is no link with the existing knowledge of the fundamentals	There is a sufficient level of cultivation through the knowledge of TerSCK. The response offers solutions and interventions that are impractical to real-life problems There are explicit links with the existing knowledge of the fundamentals	There is a good level of cultivation through the knowledge of TerSCK The response shows the ability to offer practical solutions to real-life problems There are explicit links with the existing knowledge of the fundamentals & there is evidence of new knowledge emerging

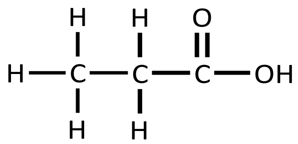
Appendix P: Pool of items produced for TerSCK

1. **Consider the following structures**



a. Identify as many concepts/aspects linked to the knowledge of each of the three structures above.
b. Draw a concept map to show how you make sense of the **connections** of the concepts you have identified in (a) above
c. Write a paragraph to describe how you make sense of the connections outlined in your concept map.

2. **Structural isomers can belong to different homologous series in other words they could have different functional group.**



a. Draw two structural isomers with different functional groups for the compound below and include the IUPAC name for each.
b. Identify a set of FIVE other chemistry concepts that are connected to the knowledge of any form of isomers. In your identification, give a brief explanation of how you see the connection.

3. **The students carried out the investigation and generated the following set of results:**

Alkanes	**Boiling point (^{0}C)**
pentane	36
hexane	69
heptane	98
octane	125

a. What pattern can be observed from the set of results above
b. Fully explain the pattern observed you made in 4.4.
c. From the explanation you generated in question 4.5, draw a concept map to show your understanding of **connections** between the concepts used in the explanations.

Tensions element

1. **Molecules with the same molecular formula can have different structures, this is known as isomerism. There are several kinds of isomerism such as structural and geometric. Answer the following questions about isomers.**

   f) Draw the following isomers for 2-butene, name the compounds that you draw.
   - Positional isomer of 2-butene
   - Structural isomer of 2-butene

   g) Using your knowledge of isomerism, what are the **tensions** associated with the teaching of isomerism at the school level as a result of sifting some aspects from the academic discipline knowledge.

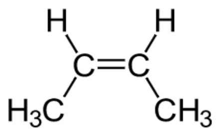
2. **Alcohols are organic compounds that contain a hydroxyl group (-OH) and are described by a general formula $C_nH_{2n+2+}O$.**

a) Draw the structures of:

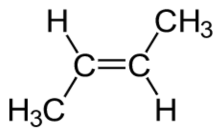
propan-2-ol	1,2propan-diol

b) With your knowledge of school science, what difficulty do you anticipate in dealing with the two structures when teaching about the knowledge of general formulas?

3. **Consider the following two structures:**



(A)



(B

a) Give the IUPAC name for each compound

(C)

(D)

b) Given the scope of the South African curriculum and your knowledge of isomerism above, what difficulty do you anticipate in teaching and making the difference between the two structures clear to learners

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Inquiry Element

1. **Study the following table and answer the questions below:**

No. of carbons	**Alkanes**		**Alcohols**		**Carboxylic acids**	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

g) Considering the first homologous series (alkanes)

(i) what is the possible investigative question that you can suggest for this investigation.

(ii) Identify the variables in this investigation
(iii) What is the general pattern observed in the boiling point of alkanes
(iv) Use the knowledge of intermolecular forces, energy required to explain the observed trend in the boiling points of alkanes

h) Why is the boiling point for hexane so much lower than that of hexan-1-ol?
i) Why is the boiling point for methanol so much lower than that of hexan-1-ol?
j) The boiling points for the carboxylic acids are not included. Do you expect their boiling points to be higher or lower than the boiling points of the alcohols with the same number of carbon atoms? Explain your answer.

2. **A group of university students investigated the boiling and of liquid alkanes. Answer the following question based on your knowledge of the scientific process:**
   a. What would be the possible hypothesis for this investigation?
   b. What investigative question can be asked by the student?
   c. Identify the possible variables for this investigation

The students carried out the investigation and generated the following set of results:

Alkanes	Boiling point (^{0}C)
pentane	36
hexane	69
heptane	98
octane	125

   d. What pattern can be observed from the set of results above
   e. Fully explain the pattern observed you made in (d)

Cultivating Social Agency

1. ***Given the rise in natural disasters experienced in our country and the rest of the world, global warming has been at the center of it all. Global warming is caused by the burning of fuels such as octane that produce carbon dioxide (CO_2) gas. CO_2 is one of the greenhouse effect gases that trap heat in the atmosphere and thus increase the average temperatures of the earth.***

   With your knowledge of science, what practical **solutions** and **interventions** you can implement in your immediate community to mitigate the effects of global warming?

2. **Cars' exhaust fumes include gases such as carbon dioxide, carbon monoxide (CO), and volatile organic compounds (VOCs). When released into the atmosphere, these gases and such pollutants have drastic environmental consequences Consider the case of carbon dioxide (CO_2) formed during the combustion of alkanes (octane) inside a car engine. CO_2 is one of the greenhouse gases that contributes to a phenomenon known as global warming**.
   Investigate this the case of CO_2 and the phenomenon of global warming and present working solutions and intervention to mitigate the global warming.

Appendix Q: PRISMA-P checklist

Section and topic	Item No	Checklist item
ADMINISTRATIVE INFORMATION		
Title:		
Identification	1a	Identify the report as a protocol of a systematic review
Update	1b	If the protocol is for an update of a previous systematic review, identify as such
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments
Support:		
Sources	5a	Indicate sources of financial or other support for the review
Sponsor	5b	Provide name for the review funder and/or sponsor
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol
INTRODUCTION		
Rationale	6	Describe the rationale for the review in the context of what is already known
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
METHODS		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators

Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2, Kendall's τ)
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)

Appendix R: Summary of all records from the exhaustive search of the four databases

Record: 1
Title: "Academic Discipline" and "School Subject": Contestable Curricular Concepts.
Author(s): Stengel, Barbara S.
Source: Journal of Curriculum Studies, v29 n5 p585-602 Sep-Oct 1997.
Peer Reviewed: Y
ISSN: 0022-0272
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: CIJAUG1998
Entry Date: 1998
Accession Number: EJ560146
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ560146&site=ehost-live&scope=site">"Academic Discipline" and "School Subject": Contestable Curricular Concepts.</A>
Database: ERIC

Record: 2
Title: Analysing the Structure of the International Business Curriculum in India
Author(s): Srivastava, Deepak K.
Source: Journal of Teaching in International Business, v23 n1 p24-30 2012. 7 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
URL: http://0-dx.doi.org.innopac.wits.ac.za/10.1080/08975930.2012.687986
Peer Reviewed: Y
ISSN:0897-5930
Number of Pages: 7
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2012
Accession Number: EJ969422
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ969422&site=ehost-live&scope=site">Analyzing the Structure of the International Business Curriculum in India</A>
Database: ERIC

Record: 3
Title: Changing a Discipline in Universities and a Subject in Schools: British Geography in the 1950s-1970s
Author(s): Johnston, Ron
Source: History of Education, v48 n5 p682-699 2019. 18 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 530 Walnut Street Suite 850, Philadelphia, PA 19106. Tel: 800-354-1420; Tel: 215-625-8900; Fax: 215-207-0050; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
URL: http://0-dx.doi.org.innopac.wits.ac.za/10.1080/0046760X.2019.1584650
Peer Reviewed: Y
ISSN: 0046-760X
Number of Pages:18
Publication Type: Journal Articles; Reports - Descriptive

Journal Code: JAN2020
Entry Date: 2019
Accession Number: EJ1223059
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1223059&site=ehost-live&scope=site">Changing a Discipline in Universities and a Subject in Schools: British Geography in the 1950s-1970s</A>
Database: ERIC

Record: 4
Title: Contesting "Powerful Knowledge": The Primary Geography Curriculum as an Articulation between Academic and Children's (Ethno-) Geographies
Author(s): Catling, Simon; Martin, Fran
Source: Curriculum Journal, v22 n3 p317-335 2011. 19 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
URL: http://0-dx.doi.org.innopac.wits.ac.za/10.1080/09585176.2011.601624
Peer Reviewed: Y
ISSN: 0958-5176
Keyword: England
Number of Pages: 19
Publication Type: Journal Articles; Opinion Papers
Journal Code: APR2018
Entry Date: 2011
Accession Number: EJ948154
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ948154&site=ehost-live&scope=site">Contesting "Powerful Knowledge": The Primary Geography Curriculum as an Articulation between Academic and Children's (Ethno-) Geographies</A>
Database: ERIC

Record: 5
Title: Curriculum Principles, Didactic Practice and Social Issues: Thinking through Teachers' Knowledge Practices in Collaborative Work
Author(s): Bladh, Gabriel; Stolore, Martin; Kristiansson, Martin
Source: London Review of Education, v16 n3 p398-413 2018. 16 pp.
Availability: Full Text from ERIC Available online: https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=EJ1197123
UCL IOE Press. UCL Institute of Education, University of London, 20 Bedford Way, London, WC1H 0AL, UK. Tel: +44-20-7911-5565; e-mail: ioe.ioepress@ucl.ac.uk; Web site: https://www.ucl-ioe-press.com/journals/london-review-of-education/
Peer Reviewed: Y
ISSN:1474-8479
Number of Pages: 16
Publication Type: Journal Articles; Reports - Evaluative
Journal Code: JAN2020
Entry Date: 2018
Accession Number: EJ1197123

<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1197123&site=ehost-live&scope=site">Curriculum Principles, Didactic Practice and Social Issues: Thinking through Teachers' Knowledge Practices in Collaborative Work</A>
Database: ERIC

Record: 6
Title: Difficulties in Developing a Curriculum for Pre-Service Science Teachers
Author(s): Booi, Kwanele (ORCID 0000-0003-0611-2305) ; Khuzwayo, Mamsi Ethel (ORCID 0000-0002-4084-8773)
Source: South African Journal of Education, v39 n3 Article 1517 Aug 2019. 13 pp.
Availability: Full Text from ERIC Available online: https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=EJ1228988
Education Association of South Africa. University of Pretoria, Centre for the Study of Resilience, Level 3, Groenkloof Student Centre, Department of Educational Psychology, Faculty of Education, George Storrar Road and Lleyds Street, Pretoria 0001, South Africa. Web site: http://www.sajournalofeducation.co.za/index.php/saje/index
Peer Reviewed: Y
ISSN:0256-0100
Number of Pages: 13
Publication Type: Journal Articles; Reports - Research
Journal Code: JAN2020
Entry Date:2019
Accession Number: EJ1228988
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1228988&site=ehost-live&scope=site">Difficulties in Developing a Curriculum for Pre-Service Science Teachers</A>
Database: ERIC

Record: 7
Title: Dilemmas of Design and Predicaments of Practice: Adapting the "Fostering a Community of Learners" Model in Secondary School English Language Arts Classrooms
Author(s): Whitcomb, Jennifer A.
Source: Journal of Curriculum Studies, v36 n2 p183-206 Mar-Apr 2004. 24 pp.
Availability: Customer Services for Taylor & Francis Group Journals, 325 Chestnut Street, Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420 (Toll Free); Fax: 215-625-8914.
Peer Reviewed: Y
ISSN: 0022-0272
Number of Pages: 24
Publication Type: Journal Articles; Reports - Evaluative
Journal Code: APR2018
Entry Date: 2005
Accession Number: EJ695075
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ695075&site=ehost-live&scope=site">Dilemmas of Design and Predicaments of Practice: Adapting the "Fostering a Community of Learners" Model in Secondary School English Language Arts Classrooms</A>
Database: ERIC

Record: 8

Title: Disciplinary History and the Situation of History Teachers
Author(s): Fordham, Michael
Source: Education Sciences, v2 p242-253 2012. 12 pp.
Availability: Full Text from ERIC Available online: https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=EJ1118212
MDPI AG. Klybeckstrasse 64, 4057 Basel, Switzerland. Tel: e-mail: indexing@mdpi.com; Web site: http://www.mdpi.com
Peer Reviewed: Y
ISSN: 2227-7102
Keyword: United Kingdom (England)
Number of Pages: 12
Publication Type: Journal Articles; Reports - Evaluative
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1118212
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1118212&site=ehost-live&scope=site">Disciplinary History and the Situation of History Teachers</A>
Database: ERIC

Record: 9
Title: Factors Strengthening School Geography's Curricular Position in the Nineteenth Century
Author(s): Moore, Zachary A.; Boehm, Richard G.
Source: Social Studies, v102 n1 p49-57 2011. 9 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
Peer Reviewed: Y
ISSN: 0037-7996
Number of Pages: 9
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2011
Accession Number: EJ909825
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ909825&site=ehost-live&scope=site">Factors Strengthening School Geography's Curricular Position in the Nineteenth Century</A>
Database: ERIC

Record: 10
Title: Home Geography and the Development of Elementary Social Education, 1890-1930
Author(s): Barton, Keith C.
Source: Theory and Research in Social Education, v37 n4 p484-514 Fall 2009. 31 pp.
Availability: College and University Faculty Assembly of NCSS. 8555 Sixteenth Street Suite 500, Silver Spring, MD 20910. Tel: 800-683-0812; Tel: 301-588-1800; Fax: 301-588-2049; Web site: http://www.socialstudies.org/cufa/trse/
URL: http://www.socialstudies.org/cufa/trse
Peer Reviewed: Y
ISSN: 0093-3104

Number of Pages: 31
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2010
Accession Number: EJ868158
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ868158&site=ehost-live&scope=site">Home Geography and the Development of Elementary Social Education, 1890-1930</A>
Database: ERIC

Record: 11
Title: Knowing the Subject Matter of a Secondary-School Science Subject
Author(s): Deng, Zongyi
Source: Journal of Curriculum Studies, v39 n5 p503-535 Oct 2007. 33 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals/default.html
Peer Reviewed: Y
ISSN: 0022-0272
Number of Pages: 33
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date:2007
Accession Number: EJ775788
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ775788&site=ehost-live&scope=site">Knowing the Subject Matter of a Secondary-School Science Subject</A>
Database: ERIC

Record: 12
Title: Listening across the Curriculum
Author(s): Ediger, Marlow
Source: Reading Improvement, v51 n4 p359-360 Win 2014. 2 pp.
Availability: Project Innovation, Inc. P.O. Box 8508 Spring Hill Station, Mobile, AL 36689-0508. Tel: 251-343-1878; Fax: 251-343-1878; Web site: http://www.projectinnovation.biz/ri.html
Peer Reviewed: Y
ISSN: 0034-0510
Number of Pages: 2
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1095733
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1095733&site=ehost-live&scope=site">Listening across the Curriculum</A>
Database: ERIC

Record: 13

Title: Persistently Disciplined Urban Students' Experiences of the Middle School Transition and "Getting in Trouble"
Author(s): Kennedy-Lewis, Brianna L.
Source: Middle Grades Research Journal, v8 n3 p99-116 2013. 18 pp.
Availability: IAP - Information Age Publishing, Inc. P.O. Box 79049, Charlotte, NC 28271-7047. Tel: 704-752-9125; Fax: 704-752-9113; e-mail: infoage@infoagepub.com; Web site: http://www.infoagepub.com/middle-grades-research-journal.html
Peer Reviewed: Y
ISSN: 1937-0814
Number of Pages: 18
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2017
Accession Number: EJ1146276
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1146276&site=ehost-live&scope=site">Persistently Disciplined Urban Students' Experiences of the Middle School Transition and "Getting in Trouble"</A>
Database: ERIC

Record: 14
Title: Philosophy of Education as an Academic Discipline in Turkey: The Past and the Present
Author(s): Under, Hasan
Source: Studies in Philosophy and Education, v27 n6 p405-431 Nov 2008. 27 pp.
Availability: Springer. 233 Spring Street, New York, NY 10013. Tel: 800-777-4643; Tel: 212-460-1500; Fax: 212-348-4505; e-mail: service-ny@springer.com; Web site: http://www.springerlink.com
Peer Reviewed: Y
ISSN: 0039-3746
Keyword: Turkey
Number of Pages: 27
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2008
Accession Number: EJ812540
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ812540&site=ehost-live&scope=site">Philosophy of Education as an Academic Discipline in Turkey: The Past and the Present</A>
Database: ERIC

Record: 15
Title: Proficiency Forms and Vocational Pedagogical Principles
Author(s): Inglar, Tron
Source: Journal of the International Society for Teacher Education, v18 n2 p30-40 2014. 11 pp.
Availability: Full Text from ERIC Available online: https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=EJ1087570
International Society for Teacher Education. Danish School of Education, Aarhus University, Niels Juelsgade 84, 8210 Aarhus N. Denmark; e-mail: isftecontact@gmail.com; Web site: http://isfte.org
Peer Reviewed: Y
ISSN: 1029-5968

Keyword: Norway
Number of Pages: 11
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1087570
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1087570&site=ehost-live&scope=site">Proficiency Forms and Vocational Pedagogical Principles</A>
Database: ERIC

Record: 16
Title: Rhetoric, "Paideia" and the Old Idea of a Liberal Education
Author(s): Miller, Alistair
Source: Journal of Philosophy of Education, v41 n2 p183-206 May 2007. 24 pp.
Availability: Blackwell Publishing. 350 Main Street, Malden, MA 02148. Tel: 800-835-6770; Tel: 781-388-8599; Fax: 781-388-8232; e-mail: customerservices@blackwellpublishing.com; Web site: http://www.blackwellpublishing.com/jnl_default.asp
Peer Reviewed: Y
ISSN: 0309-8249
Number of Pages: 24
Publication Type: Journal Articles; Opinion Papers; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2007
Accession Number: EJ774679
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ774679&site=ehost-live&scope=site">Rhetoric, "Paideia" and the Old Idea of a Liberal Education</A>
Database: ERIC

Record: 17
Title:
Skill and Physical Activity: A Central Dogma for Kinesiology
Author(s): Zelaznik, Howard N.; Harper, William A.
Source: Quest, v59 n1 p163-169 Feb 2007. 7 pp.
Availability: Human Kinetics, Inc. 1607 North Market Street, Champaign, IL 61820. Tel: 800-474-4457; Fax: 217-351-1549; e-mail: info@hkusa.com; Web site: http://www.humankinetics.com
Peer Reviewed: Y
ISSN: 0033-6297
Number of Pages: 7
Publication Type: Journal Articles; Opinion Papers; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2008
Accession Number: EJ800271
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ800271&site=ehost-live&scope=site">Skill and Physical Activity: A Central Dogma for Kinesiology</A>
Database: ERIC

Record: 18
Title: Teacher Race and School Discipline
Author(s): Lindsay, Constance A.; Hart, Cassandra M. D.
Source: Education Next, v17 n1 p72-78 Win 2017. 7 pp.
Availability: Hoover Institution. Stanford University, Stanford, CA 94305-6010. Tel: 800-935-2882; Fax: 650-723-8626; e-mail: educationnext@hoover.stanford.edu; Web site: http://educationnext.org/journal/
URL: http://educationnext.org/teacher-race-and-school-discipline-suspensions-research/
Peer Reviewed: Y
ISSN: 1539-9664
Number of Pages:7
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1122057
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1122057&site=ehost-live&scope=site">Teacher Race and School Discipline</A>
Database: ERIC

Record: 19
Title: Tension between Visions of Science Education: The Case of Energy Quality in Swedish Secondary Science Curricula
Author(s): Haglund, Jesper (ORCID 0000-0003-4997-2938) ; Hultén, Magnus
Source: Science & Education, v26 n3-4 p323-344 May 2017. 22 pp.
Availability: Springer. 233 Spring Street, New York, NY 10013. Tel: 800-777-4643; Tel: 212-460-1500; Fax: 212-348-4505; e-mail: service-ny@springer.com; Web site: http://www.springerlink.com
Peer Reviewed: Y
ISSN: 0926-7220
Number of Pages: 22
Publication Type: Journal Articles; Information Analyses; Reports - Research
Journal Code: APR2018
Entry Date: 2017
Accession Number: EJ1145874
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1145874&site=ehost-live&scope=site">Tension between Visions of Science Education: The Case of Energy Quality in Swedish Secondary Science Curricula</A>
Database: ERIC

Record: 20
Title: The Book Dog and Semiotic Resources in Envisionment Building of a Text World
Author(s): Bergh Nestlog, Ewa (ORCID 0000-0002-3863-6122) ; Ehriander, Helene
Source: Journal of Psycholinguistic Research, v48 n2 p535-550 Apr 2019. 16 pp.
Availability: Springer. Available from: Springer Nature. 233 Spring Street, New York, NY 10013. Tel: 800-777-4643; Tel: 212-460-1500; Fax: 212-348-4505; e-mail: customerservice@springernature.com; Web site: https://0-link-springer-com.innopac.wits.ac.za/
Peer Reviewed: Y
ISSN: 0090-6905
Number of Pages: 16
Publication Type: Journal Articles; Reports - Research

Journal Code: JAN2020
Entry Date: 2019
Accession Number: EJ1209555
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1209555&site=ehost-live&scope=site">The Book Dog and Semiotic Resources in Envisionment Building of a Text World</A>
Database: ERIC

Record: 21
Title: The Development of International Business as an Academic Discipline: Some Implications for Teachers and Students
Author(s): Laughton, David
Source: Journal of Teaching in International Business, v16 n3 p47-70 2005. 24 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
Peer Reviewed: Y
ISSN: 0897-5930
Number of Pages:24
Publication Type: Journal Articles; Reports - Evaluative
Journal Code: APR2018
Entry Date: 2009
Accession Number: EJ843229
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ843229&site=ehost-live&scope=site">The Development of International Business as an Academic Discipline: Some Implications for Teachers and Students</A>
Database: ERIC

Record: 22
Title: The Great Debate in Reading Instruction
Author(s): Ediger, Marlow
Source: Reading Improvement, v49 n4 p129-133 Win 2012. 5 pp.
Availability: Project Innovation, Inc. P.O. Box 8508 Spring Hill Station, Mobile, AL 36689-0508. Tel: 251-343-1878; Fax: 251-343-1878; Web site: http://www.projectinnovation.biz/ri.html
Peer Reviewed: Y
ISSN: 0034-0510
Number of Pages:5
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2013
Accession Number: EJ992998
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ992998&site=ehost-live&scope=site">The Great Debate in Reading Instruction</A>
Database: ERIC

Record: 23
Title: The Historical Process of Development of Engineering Sciences as a School Discipline in France

Author(s): Christian, Hamon; Joël, Lebeaume
Source: Universal Journal of Educational Research, v4 n6 p1266-1272 2016. 7 pp.
Availability: Full Text from ERIC Available online: https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=EJ1103158
Horizon Research Publishing. 506 North Garfield Avenue #210, Alhambra, CA 91801. e-mail: editor@hrpub.org; Web site: http://www.hrpub.org
Peer Reviewed: Y
ISSN: 2332-3205
Keyword: France
Number of Pages: 7
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1103158
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1103158&site=ehost-live&scope=site">The Historical Process of Development of Engineering Sciences as a School Discipline in France</A>
Database: ERIC

Record: 24
Title: The Ohio Transfer Articulation Guide: An Ethics Case Study for Social Foundations of Education Faculty Author(s): Abowitz, Kathleen Knight
Source: Philosophical Studies in Education, v37 p117-126 2006. 10 pp.
Availability: Full Text from ERIC Available online: https://eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=EJ1072483
Ohio Valley Philosophy of Education Society. Web site: http://ovpes.org/?page_id=51
Peer Reviewed: Y
ISSN: 0160-7561
Keyword: Ohio
Number of Pages: 10
Publication Type: Journal Articles; Reports - Descriptive; Opinion Papers
Journal Code: APR2018
Entry Date: 2015
Accession Number: EJ1072483
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1072483&site=ehost-live&scope=site">The Ohio Transfer Articulation Guide: An Ethics Case Study for Social Foundations of Education Faculty</A>
Database: ERIC

Record: 25
Title: The Pure and the Applied in Nursing Education.
Author(s): Cash, Keith
Source: Nurse Education Today, v20 n1 p73-77,78-83 Jan 2000.
Availability:
Peer Reviewed: Y
ISSN: 0260-6917
Keyword: Pure Research
Publication Type: Journal Articles

Entry Date: 2000
Accession Number: EJ602828
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ602828&site=ehost-live&scope=site">The Pure and the Applied in Nursing Education.</A>
Database: ERIC

Record: 26
Title: Tradition, Authority and Disciplinary Practice in History Education
Author(s): Fordham, Michael
Source: Educational Philosophy and Theory, v49 n6 p631-642 2017. 12 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 530 Walnut Street Suite 850, Philadelphia, PA 19106. Tel: 800-354-1420; Tel: 215-625-8900; Fax: 215-207-0050; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
Peer Reviewed: Y
ISSN: 0013-1857
Number of Pages: 12
Publication Type: Journal Articles; Reports - Evaluative
Journal Code: APR2018
Entry Date: 2017
Accession Number: EJ1135445
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1135445&site=ehost-live&scope=site">Tradition, Authority and Disciplinary Practice in History Education</A>
Database: ERIC

Record: 27
Title: Transnationalism and Women of Colour Courses: Diversity, Curricula, and New Pedagogies of "Race"
Author(s): Nair, Sridevi
Source: Feminist Teacher: A Journal of the Practices, Theories, and Scholarship of Feminist Teaching, v24 n1-2 p1-17 2014. 17 pp.
Availability: University of Illinois Press. 1325 South Oak Street, Champaign, IL 61820-6903. Tel: 217-244-0626; Fax: 217-244-8082; e-mail: journals@uillinois.edu; Web site: http://0-www.press.uillinois.edu.innopac.wits.ac.za/journals.php
Peer Reviewed: Y
ISSN: 0882-4843
Number of Pages: 17
Publication Type: Journal Articles; Reports - Evaluative
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1123244
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1123244&site=ehost-live&scope=site">Transnationalism and Women of Color Courses: Diversity, Curricula, and New Pedagogies of "Race"</A>
Database: ERIC

Record: 28
Title: What Are the Connections between Subject Developments in Academic and School Geography?

Author(s): Rawding, Charles
Source: International Research in Geographical and Environmental Education, v19 n2 p119-125 May 2010. 7 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
Peer Reviewed: Y
ISSN: 1038-2046
Keyword: England
Number of Pages: 7
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2010
Accession Number: EJ886582
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ886582&site=ehost-live&scope=site">What Are the Connections between Subject Developments in Academic and School Geography?</A>
Database: ERIC

Record: 29
Title: What Knowledge Appears as Valid in the Subject of Physical Education and Health? A Study of the Subject on Three Levels in Year 9 in Sweden
Author(s): Ekberg, Jan-Eric
Source: Physical Education and Sport Pedagogy, v21 n3 p249-267 2016. 19 pp.
Availability: Routledge. Available from: Taylor & Francis, Ltd. 325 Chestnut Street Suite 800, Philadelphia, PA 19106. Tel: 800-354-1420; Fax: 215-625-2940; Web site: http://0-www.tandf.co.uk.innopac.wits.ac.za/journals
Peer Reviewed: Y
ISSN: 1740-8989
Keyword: Sweden
Number of Pages: 19
Publication Type: Journal Articles; Reports - Research
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1094420
<A href="http://0-search.ebscohost.com.innopac.wits.ac.za/login.aspx?direct=true&db=eric&AN=EJ1094420&site=ehost-live&scope=site">What Knowledge Appears as Valid in the Subject of Physical Education and Health? A Study of the Subject on Three Levels in Year 9 in Sweden</A>
Database: ERIC

Record: 30
Title: Why Gateway-Course Improvement Should Matter to Academic Discipline Associations and What They Can Do to Address the Issues
Author(s): Brookins, Julia; Swafford, Emily
Source: New Directions for Higher Education, n180 p75-85 Win 2017. 11 pp.
Availability: Wiley Periodicals, Inc. 350 Main Street, Malden, MA 02148. Tel: 800-835-6770; Tel: 781-388-8598; Fax: 781-388-8232; e-mail: cs-journals@wiley.com; Web site: http://www.wiley.com/WileyCDA

Peer Reviewed: Y
ISSN: 0271-0560
Number of Pages: 11
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2017
Accession Number: EJ1162788
Why Gateway-Course Improvement Should Matter to Academic Discipline Associations and What They Can Do to Address the Issues
Database: ERIC

Record: 31
Title: Why STEM?
Author(s): Mitts, Charles R.
Source: Technology and Engineering Teacher, v75 n6 p30-35 Mar 2016. 6 pp.
Availability: International Technology and Engineering Educators Association. 1914 Association Drive Suite 201, Reston, VA 20191-1539. Tel: 703-860-2100; Fax: 703-860-0353; e-mail: itea@iteaconnect.org; Web site: http://www.iteaconnect.org
Peer Reviewed: Y
ISSN: 2158-0502
Number of References: 12
Language: English
Number of Pages: 6
Publication Type: Journal Articles; Reports - Descriptive
Journal Code: APR2018
Entry Date: 2016
Accession Number: EJ1096249
Why STEM?
Database: ERIC

Appendix S: Pre & post-intervention CK score converted to percentages

Name	Code	Knowledge of Pure Chemistry Content (Fundamentals)					
		Raw	percentage	**Pre**	Raw	percentage	**Post**
Nokulunga	PST1	17	68	**3**	17	68	**3**
Morgan	PST2	12	48	**2**	22	88	**4**
Thami	PST3	16	64	**3**	12	48	**2**
Thando	PST4	16	64	**3**	23	92	**4**
Maxwell	PST5	15	60	**3**	25	100	**4**
Nosipho	PST6	16	64	**3**	25	100	**4**
Lexie	PST7	21	84	**4**	18	72	**3**
Sabelo	PST8	4	16	**1**	25	100	**4**
Themba	PST9	18	72	**3**	25	100	**4**
Nelson	PST10	11	44	**2**	25	100	**4**
Lettie	PST11	5	20	**1**	25	100	**4**
Peter	PST12	22	88	**4**	25	100	**4**
Sonto	PST13	17	68	**3**	25	100	**4**
Mongezi	PST14	17	68	**3**	25	100	**4**
Cebo	PST15	18	72	**3**	25	100	**4**
Jacob	PST16	18	72	**3**	18	72	**3**
Mfanafuthi	PST17	12	48	**2**	17	68	**3**
Nomkhosi	PST18	4	16	**1**	12	48	**2**
Thokozani	PST19	22	88	**4**	25	100	**4**
Thembelani	PST20	22	88	**4**	25	100	**4**
Sfiso	PST21	11	44	**2**	25	100	**4**
Lindani	PST22	11	44	**2**	25	100	**4**
Bandile	PST23	10	40	**4**	25	100	**4**
Andile	PST24	23	92	**4**	25	100	**4**
Mpunki	PST25	4	16	**1**	24	96	**4**
Luyanda	PST26	17	68	**3**	18	72	**3**
Zodwa	PST27	20	80	**4**	25	100	**4**
Khulekani	PST28	17	68	**3**	25	100	**4**
Ziyanda	PST29	10	40	**2**	25	100	**4**
Owethu	PST30	11	44	**2**	16	64	**3**
Junior	PST31	23	92	**4**	25	100	**4**
Naledi	PST32	21	84	**4**	25	100	**4**
Mpho	PST33	10	40	**2**	25	100	**4**
Asanda	PST34	10	40	**2**	17	68	**3**
Karabo	PST35	11	44	**2**	25	100	**4**
Item Average		14,6	58,5	**3,0**	22,5	90,2	**4,0**
NOTES:							
CK test was /25 and these were converted to percentages for locating in the Likert scale of 1-4							

Appendix T: Pre-intervention person-item map

```
TABLE 1.0 Pre TerSCK Scores.xlsx                  ZOU843WS.TXT  Jan 14 2023 11:56
INPUT: 35 PERSON  5 ITEM  REPORTED: 35 PERSON  5 ITEM  4 CATS   MINISTEP 5.3.1.0
--------------------------------------------------------------------------------

MEASURE                         PERSON - MAP - ITEM
                                    <more>|<rare>
    2                          PST24 PST32  +
                                            |
                                            |
                                            |
                                           T|S Inquiry          Tensions
                                            |
    1                                       +
                                            |
                                            |
                                            |                    Item mean
                                            |
                         PST10 PST13 PST30  |
    0                                       +M
                                           S|
                         PST16 PST31 PST5   |  Interconnections
                                            |  Hist & Cultivati
                                            |
                                            |
   -1                    PST15 PST6  PST7   +
                                            |
                                            |S
             PST19 PST23 PST27 PST33 PST34  |
                                            |
                                           M|  Fundamentals
   -2 PST1  PST2  PST20 PST29 PST35 PST4    +                   Person mean
                                            |
                                            |
                                            |T
             PST11 PST14 PST26 PST28 PST9   |
                                            |
   -3                                       +
                                            |
                                           S|
             PST17 PST18 PST21 PST22 PST25  |
                                            |
                                            |
   -4                                       +
                                            |
                                            |
                         PST12 PST3  PST8   |
                                            |
                                            |
   -5                                      T+
                                    <less>|<freq>
```

Appendix U: TerSCK reflection schedule by pre-service teachers post-intervention

- What does TerSCK stand out for?
- What do you understand about TerSCK?
- What are the main components of TerSCK?
- Do you think TerSCK is different from the main content course you have done, if so, HOW?
- Do you think TerSCK is different from the school content course you have done, if so, HOW?
- Do you feel enlightened to teach science after the TerSCK intervention?
- What can be done better in future interventions?

Appendix V: Turnitin similarity index report

All Chapters.docx

ORIGINALITY REPORT

8%	6%	6%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	hdl.handle.net Internet Source	1%
2	www.researchgate.net Internet Source	1%
3	www.tandfonline.com Internet Source	<1%
4	Stephen Andrew Malcolm, Elizabeth Mavhunga, Marissa Rollnick. "The Validity and Reliability of an Instrument to Measure Physical Science Teachers' Topic Specific Pedagogical Content Knowledge in Stoichiometry", African Journal of Research in Mathematics, Science and Technology Education, 2019 Publication	<1%
5	e-space.mmu.ac.uk Internet Source	<1%
6	"Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for	<1%

Appendix W: Language and formatting certificate

Registered with the South African Translators' Institute (SATI)

Reference number 1000686

11 August 2023

THE DEVELOPMENT AND VALIDATION OF A THEORETICAL CONSTRUCT DESCRIBING CONTENT KNOWLEDGE FOR TEACHING SCIENCE: A CASE STUDY WITH ORGANIC CHEMISTRY

This certificate confirms that I edited and formatted substantively the above document, including a Reference list. The text, as edited by me, is grammatically correct. The document was returned to the author with various suggestions and tracked changes from me intended to correct errors. After completion of my language editing, the author can accept or reject suggestions/changes before re-submission to the supervisor who will check the content and instances of plagiarism, if any.

Yours faithfully

Dr. K. Zano

Ph.D. in English

kufazano@gmail.com/kufazano@yahoo.com

0631434276