Enhancing Initial Teacher Training to Teach Science in Secondary Schools

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This thesis is submitted for the degree of Doctor of Philosophy

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as specified in the text. It is not substantially the same as any work that has already been submitted before for any degree or other qualification.

Abstract

Science teaching quality, a shortage of specialists and retention of science teachers have been longstanding concerns for governments internationally. To address these issues, many countries have diversified routes into teaching to enable high quality candidates from diverse science backgrounds enter the teaching profession. In England, the government has opened the ITT market by extending school-based training routes allowing more career changers to enter teaching. However, the experiences of career changers in ITT programmes, their readiness to teach, and how they develop knowledge and skills are underexplored. Furthermore, syntheses of international research literature on the effectiveness of different approaches to preparing science teachers are lacking. The relationship between teachers' voices and approaches to their preparation is fundamental in developing coherent ITT models that better align theory with practice. This study identifies how best ITT programmes can prepare trainees to teach science in secondary schools by gathering data through two different methodologies: through a synthesis of the available international evidence on effective approaches to preparing science teachers, and through a qualitative case study that explores the views and learning experiences of trainee science teachers enrolled on a teacher training programme in England. A framework based on Pedagogical Content Knowledge (PCK) developed during the study and a thematic approach are used to analyse and synthesis data generated through the two methodologies. Findings reveal evidence of effective strategies for preparing science teachers and show how trainees develop themselves professionally by drawing on five pillars of teaching within contextual factors that influence their learning. Collectively, the findings assemble into a novel ITT model which, alongside a set of evidence-based practices identified in the study, can guide the design of learning opportunities for trainee teachers. The model supports policies aiming at narrowing the theory practice gap to increase trainees' access to quality training.

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List of Abbreviations

CCF - Core Content Framework

CoRe - Content Representation

DfE - Department for Education

EBITT - Employment-based Initial Teacher Training

GTP - Graduate Teacher Programme

HEI - Higher Education Institution

HOS - History of Science

ITT - Initial Teacher Training

LS - Lesson Study

LtTF - Learning to Teach Framework

NOS - Nature of Science

OECD - The Organisation for Economic Co-operation and Development

OTTP - Overseas Trained Teacher Programme

PCK – Pedagogical Content Knowledge

PGCE - Post-Graduate Certificate in Education

PICOSS - Population, Intervention, Comparator, Outcomes, Study design, and Setting

PISA - Programme for International Student Assessment

QTS - Qualified Teacher Status

SCITT - School Centred Initial Teacher Training

SD – School Direct

SDS – School Direct Salaried

STEBI-B - Science Teachers Efficacy Beliefs Instrument Variant B

TCK - Technological Content Knowledge

TF – Teach First

TPCK - Technological Pedagogical Content Knowledge

TPK - Technological Pedagogical Knowledge

TPK&S - Teacher Professional Knowledge and Skills

TSPCK - Topic Specific Pedagogical Content Knowledge

ZPD - Zone of Proximal development

ZPTD - Zone of Proximal Teacher Development

Chapter 1. Overview of the Study

This chapter provides an overview of the entire study. It starts with an introduction outlining the problem statement of the study followed by the rationale for the methodological approach undertaken to answer the research questions. The aims and research questions are then presented. Further, the chapter provides some information on the researcher's background and outlines the next chapters of the thesis.

1.1 Introduction

The role of science education in developing scientifically literate citizens able to make informed decisions and to contribute to the economic growth and international competitiveness has global recognition (Goldberg and Harvey, 1983; Drori, 2000; House of Commons, 2002). To develop scientifically informed citizens, many countries strive to improve teacher education programmes (Osborne and Dillon, 2008; AITSL, 2011a; Darling-Hammond, 2017; DfE, 2019). To improve education programmes, a great attention has been paid to high-quality teaching and teachers. In science education, concerns have been raised about students' low attainment in international league tables and low rates of progression in science subjects (Dillon, 2009; OECD, 2010; DeWitt and Archer, 2015; OECD, 2016). Darling-Hammond (2007; 2010) comments on a stagnant underperformance of students in the US, especially in poor areas where students are being taught by inexperienced and unqualified teachers. In their Critical Reflection paper, Osborne, and Dillon (2008) analyse common issues with teaching science in schools across nine European countries. Their analysis reveals that countries face similar challenges. A big challenge internationally it has been to make science more attractive to students to increase their participation in science and their motivation to follow a science career (Osborne and Dillon, 2008; Smith, 2010). Several reasons for low achievements in science and the decline in the number of students following a science career were identified. First, teachers across countries have been constantly blamed for their lack of ability to make science understandable to students (Osborne and Collins, 2000; Lyons, 2006; DeWitt and Osborne, 2008). Making science understandable to students is crucial in increasing their participation and motivation in science. However, science is not viewed to be an easy subject. Discourses around 'difficult science' have been problematised. Studies on students' attitudes and motivation in science found that science is perceived by students as an abstract subject, complex and difficult to grasp (Osborne and Collins, 2000; Osborne, Simon and Collins, 2003; White and Harrison, 2012; DeWitt and Archer, 2015). Thus, making science understandable to students is a challenging task.

In addition, powerful accountability measures place pressure on teachers and students to perform well in national and international tests. Ryder (2015), in a review of teachers' experiences of externally driven science curriculum reform, reveals that, in many countries, there are accountability measures that force teachers to 'teach to the test' (p.114). These pressures often determine teachers to quit teaching early in their career leaving the system with a shortage of specialists. For example, in Netherlands, 22.5% of upper secondary teachers leave the profession within their first 5 years (OECD, 2014 in Guerriero, 2017). Hobson, Giannakaki and Chambers (2009) cite evidence from the US showing that 30% of teachers quitted teaching after one year in the profession and nearly one quarter of teachers left the profession within their first three years (p. 322).

The above issues with science teaching and teachers resonate nationally. In England, the average science score has remained constant since 2006, as the Programme for International Student Assessment National Report reveals (DfE, 2016c). The report raises concerns about the attainment gap between students in science. The gap between advantaged and disadvantaged students is also highlighted in the white paper *Educational Excellence Everywhere* (DfE, 2016a). The paper highlights the progress made whilst acknowledging that the progress ‘is not felt everywhere’ (DfE, 2016a, p. 5):

> There are increasing numbers of outstanding and inspirational schools, but this excellence is not yet a reality across the whole country. There remain areas of chronic underperformance, where low standards are exacerbated by a lack of capacity to improve (DfE, 2016a, p. 6)

The Education Policy Institute (EPI) report (2020) shows concerning evidence that the disadvantage gap has significantly widened in the last decade, and it is likely to worsen due to the recent lockdown caused by COVID-19 pandemic. In science, the lack of specialists in schools, especially in disadvantaged areas, further deepens the inequalities among students. In England, science education has always suffered from a shortage of specialists (Smith, 2010; Woolhouse and Cochrane, 2015). With a successive emphasis on accountability measures and pressures to raise students’ achievements in international and national league tables (MacBeath, 2011; Ryder, 2015), science teachers, compared with teachers in other subjects, are more likely to quit teaching ‘exacerbating the ongoing national shortage’ of specialists (Menter, 2016; Allen and Sims, 2017, p. 5). Menter (2016) cites evidence according to three in five teachers have thought about quitting with science teachers being the most likely to want to leave. Likewise, based on data from the Department for Education’s School Workforce Census (SWC), Allen and Sims (2017) found that the percentage of science teachers leaving their school within five years is 26% higher than non-science teachers.

Through its vision of ‘excellence everywhere’, the government has aimed to place a specialist in every classroom (DfE, 2016a) and has diversified routes into teaching while increasing the entry requirements and accountability measures (Furlong, 2008; McIntyre, Youens and Stevenson, 2019). Routes into teaching such as School Centred Initial Teacher Training, (SCITT), School Direct (SD) or Teach First hope to attract highly academic candidates in the programme from different fields and with different level of experiences. Yet, the process is not straightforward. The Department for Education in England recognises the difficulty with the recruitment and retention of 'great teachers' (DfE, 2016a, p.12):

> … teacher recruitment is becoming more difficult as the economy grows stronger, competition for the best graduates and career changers increases…. At the same time, the number of teachers we need is steadily increasing as pupil numbers grow and as schools invest more teaching hours in core subjects, the demand for teachers in some subjects is rising even faster (DfE, 2016a, p. 12).

Problems with recruitment and retention of good teachers have been more acutely felt in science than in other subject areas. Currently, in England, the candidates for science training have a range of options for entering the teaching profession, yet they must possess a science degree. Although the candidates have a science degree, their scientific background does not always align with the science subjects taught in schools (biology, chemistry, and physics). This misalignment may have consequences on the quality of teaching and learning and ultimately on the retention of science teachers. For example, Kind (2014), in a quantitative study involving graduates with good science degrees enrolled in one year university-based teacher education programme in England, found that initial teachers' content knowledge in the subject outside their specialism was insufficient for teaching despite their possession of good science degrees.

Commonly, the call for 'great teachers' able to make science understandable to students, much highlighted in policy documents (DfE, 2010; DfE, 2016a), encourages candidates to teach outside their specialism. The effect is that many career changers enter the profession with prior beliefs about teaching and learning science, limited knowledge, and skills for teaching, and low confidence (Kind and Kind, 2011; Kind, 2014; Woolhouse and Cochrane, 2015). In the context of accountability and performativity which characterise the education system in England, trainees need adequate and consistent support for developing good conceptual understanding, skills, and confidence for teaching.

Efforts to improve ITT have been ongoing for the last two decades. The government has funded subject knowledge enhancement programme to allow ITT candidates to increase their subject knowledge before meeting the Teaching Standards (DfE, 2014b; DfE, 2021a). Carter (2015) conducts a review of ITT to identify key elements of the programmes that equip trainees with the required skills and knowledge to become effective practitioners. The review finds a great diversity in the provision and many challenges based on which several recommendations were made. A lot of experts disagree with much of the content of the review. Mutton, Burn and Menter (2017) argue that the review does not explicitly address the real issues in ITT, rather it calls for government intervention. Indeed, the government (DfE, 2019), in response to the Carter review, initiate a Core Content Framework that defines in detail the minimum entitlement of all trainee teachers. The framework serves as a guide for individual providers to design appropriate curricula for their trainees. A new ITT market review (DfE, 2021b) takes into consideration the challenges brought about by the COVID -19 pandemic and complements the Core Content Framework with several recommendations to ensure high-quality training for all trainees.

Although significant attention has been paid to the quality of ITT (DfE, 2014b; Carter, 2015; DfE, 2019; DfE, 2021b), the progress in closing the gap between theoretical and practical parts of programmes has been slow. In the current context of rapidly changing standards, curriculum, and new ways of teaching and learning, trainee science teachers may find their training overwhelming and confusing. For example, the rapid turn to remote teaching and learning, due to the impact of Covid-19 pandemic on education, forced trainee teachers to adapt rapidly to remote learning. This way of learning may negatively impact trainee teachers who choose a school-centred initial training to gain experience in the classroom. Trainee teachers may not get the support they expect, and the quality of their preparation is likely to suffer. The quality of preparation of teachers has often been questioned (Hulme and Quirk-Marku, 2017; Whitty, 2017). Under the new Ofsted inspection framework (DfE, 2021c), a significant number of ITT providers have been found to fail in ensuring high quality training for their trainees (Ofsted, 2021).

Zeichner and Liston (2013) suggest that supporting teachers' practice throughout their programme would be the most effective way for solving problems with the quality of teaching, recruitment, and retention. Discussions about what is effective in supporting teachers' practice have not led yet to a comprehensive model for teacher training. The discussions tend to focus more on structural issues and less on the activities and experiences of teachers within the programmes (Furlong, 2008; 2013; Menter, 2016; Burn, Mutton and Hagger, 2017; Whiting et al., 2018). Burn, Mutton and Hagger (2017) observe that discussions tend to focus on partnership arrangements, the specific content of initial teacher training programmes and meeting the Teaching Standards, and less on how teachers learn during their education programmes. Trainee teachers' particular experiences in ITT programmes, their readiness to teach, and how they develop knowledge and skills have been insufficiently explored in the literature.

1.1.1 Problem Statement

The efforts to improve ITT have not yet brought much coherence between theoretical and practical parts of programmes. The gradual move in England towards more school-led and school-based training has received much criticism because trainee teachers have less access to educational theory which is crucial in developing critical understandings about practice (Mc Donough, 2012; Childs and Menter, 2013; Marshal, 2014; Whitty, 2017). In closing the gap between theory and practice, a more comprehensive model for teacher training is required. A more cohesive model for teacher training would better help in aligning theory with practice and more consistently support and monitor trainee teachers' progress. As a result, the quality of ITT can be enhanced.

To develop a cohesive model for ITT there is a need for research evidence on what works best in preparing science teachers. Syntheses of research literature on the effectiveness of different approaches to preparing science teachers are lacking. In addition, a cohesive model for ITT must be based on teachers' learning needs which can be revealed through an exploration of trainees' own experiences on programmes. George and Maguire (2019) remark that little attention is given to the perceptions and experiences of the candidates who enrol on teacher education programmes. McIntyre, Youens and Stevenson (2019), in an analysis of teacher education policy enactment in England, point to a 'deliberate marginalisation' of voices, such as universities and teachers, from discussions on teacher training (p.164). Similarly, Burn, Mutton and Hagger (2017) call for more focus on 'how novice teachers accumulate knowledge and teaching skills from their educators as a main source of learning' (p.105). In the current climate of significant changes, including the recent shift to remote learning, it is imperative that trainee teachers' voices are heard and considered in the design of the activities that support their own preparation.

This thesis addresses the above two gaps in the literature through two complementary studies. First, a systematic review addresses the gap in research synthesis of the existing international literature on enhancing science teachers' development during their education programmes, and second, a primary qualitative case study explores trainee science teachers' learning experiences on an ITT programme in England. The findings from both studies allowed a formulation of a more comprehensive framework for initial teacher training. The dual approach to this study and its significance are detailed in the next section.

1.2 Methodological approach. A Rationale

Given that teaching skills are developed during formal training (Grossman, 1990), how teachers are prepared during education programmes has become a global preoccupation (DfE, 2010; Carter, 2015; DfE, 2016a; Darling-Hammond, 2017). In the light of issues of accountability, globalisation, and international competitiveness, many countries have made efforts to identify what works best in preparing teachers (Darling-Hammond et al., 2017). In England and many parts of the world, apart from calls to increase the quality of teaching, there are calls for teachers to demonstrate that their practices are based on the best available research evidence (Furlong, 2013; Carter, 2015; Menter, 2016). This poses a greater challenge for initial science teachers, as research shows that they enter education programmes with different science backgrounds and limited knowledge, skills, and confidence (Abel, 2007; Kind and Kind, 2011; Kind, 2014).

Many attempts have been made to accelerate teachers' knowledge and skills in the short time frame of their training programmes (see the studies included in the systematic review in Chapter 4). The attempts have been in the form of educational interventions as it is in healthcare. In healthcare, an intervention involves a treatment with a control group. The evidence of the effectiveness of healthcare interventions was mainly synthesised through systematic reviews of quantitative evidence (Major and Savin-Baden, 2010; Boland, Cherry and Dickson, 2017). However, in healthcare, Major and Savin-Baden (2010) observe a tendency of focus towards more qualitative evidence. Qualitative evidence has been seen to be valuable in providing in depth information about a particular phenomenon. Given its value, scholars have started to combine the two types of evidence in a qualitative synthesis to advance evidence-based policies and practices (Major and Savin-Baden, 2010). Major and Savin-Baden (2010) also observe that, in education, the interest in qualitative research synthesis has grown. Yet, in science education, there is a scarcity of syntheses of evidence on supporting science teachers' preparation.

In science education, experimental studies are rare. Though, qualitative approaches to conducting interventions studies with the aim to enhance science teachers' development have been widely used in the last two decades (see the studies included in the systematic review in Chapter 4). As science teaching is complex and context dependent, different interventions studies use different approaches with different emphases to prepare science teachers. An effective way to gather a set of effective strategies is to synthesise the findings from multiple intervention studies through a systematic review. Therefore, I carried out a systematic review to synthesise the available evidence on enhancing science teachers' development during their education programmes. Through a systematic review, I identified what works best internationally in preparing science teachers for secondary schools. A promising well-articulated approach to preparing science teachers is the concept of Pedagogical Content Knowledge (PCK) first developed by Shulman (1986). PCK (described in detail in Chapter 3) is a blend of content with pedagogy, a departure from an emphasis on either content or pedagogy. Given the significance of the concept in preparing science teachers over time, a synthesis of multiple studies (which utilised the PCK framework to guide their intervention activities) was performed to identify effective PCK approaches to preparing science teachers.

On the other hand, when considering ways to facilitate trainee teachers' development, their views and experiences of their particular programme is a good starting point. To be able to learn and identify effective strategies from other contexts, an insight and understanding of what trainee teachers' needs are and what strategies help most in meeting their needs, is equally important. Therefore, I explored trainee teachers' views of their learning experiences in the context of Initial Teacher Training in England to identify useful information for the design of an effective teacher training model.

Collectively, the findings contribute to the body of knowledge by offering a comprehensive model for preparing science teachers alongside a set of evidence-based practices that help in advancing practice in teacher training programmes. The findings help providers and educators to make more informed decisions about how to design and deliver activities aligned to trainees' learning needs. The study's findings also advance a new perspective on PCK conceptualisation. Research may use the findings of this study to further clarify difficult concepts that create confusion in practice (for example, the PCK concept). The findings are also hoped to inform policy on more effectively closing the gap between theory and practice. Lastly, the findings of this study may benefit trainee teachers by providing them with evidence-based teaching strategies in different topics, especially in those outside their specialism. Although the sample of participants in the case study is small and from a single centre, the findings are hoped to be readily transferred to other centres and routes into teaching. The good degree of transferability is based on the argument that trainee teachers enrolled on teacher training programmes across England are assessed against common Teacher Standards (Carter, 2015). The findings can also be transferred to other teacher education programmes outside England based on context similarity.

1.2.1 Aims and Research Questions

The overarching aim of the study - **to identify effective ways through which ITT programmes can enhance the preparation of science teachers** - was achieved through two complementary studies: A Systematic Review and An Exploratory Case-Study.

Systematic Review

A Systematic Review is secondary research that 'locates, appraises and synthesises the best available evidence related to a specific research question' (Boland, Cherry and Dickson, 2017, p. 2). Systematic reviews, also known as research synthesis, started to become common in educational area since with the development of Campbell Collaboration (2000) - a social research organisation that disseminates high quality systematic reviews (Littell and White, 2018). The role of systematic reviews has been in informing practice and decision-making by offering a synthesis of research findings on a specific topic (Boland, Cherry and Dickson, 2017).

The aim of the present Systematic Review was to systematically select, appraise, analyse, and synthesise the available evidence on effective PCK approaches to enhance secondary science teachers' development during their education programmes.
The main research question addressed through the review was:

- What PCK approaches are effective in preparing science teachers?

To answer this question, two sub-questions were addressed:

- o What is the evidence for teachers' development of PCK during their education programmes in different contexts?

- What learning opportunities contribute to teachers' PCK development?

The questions were answered following a rigorous protocol for systematic reviews (Petticrew and Roberts, 2005; Boland, Cherry and Dickson, 2017). The theoretical framework of the study (detailed in Chapter 3) and a thematic approach were used to analyse data from each study included in the review. From the analysis of data that answered the first research sub-question a new PCK based framework was developed. The first research sub-question sought to identify the evidence for teachers' development. The types of evidence for teachers' development, resulting from the analysis, contributed to the development of the new framework. The newly developed framework guided the subsequent data synthesis in the review study, and the second study of this thesis.

Exploratory Qualitative Case-Study

A qualitative Case-Study explored trainees' views and learning experiences in one School Centred Initial Teacher Training (SCITT) programme in England to identify what was effective in their preparation and what challenges they faced from their own perspectives. A school-centred route into teaching was of interest because it attracts many career changers due to the classroom experience that the programme provides. An exploration of trainees' views and their perceived effective learning opportunities is helpful in identifying learning strategies that respond to their own needs.

The study was guided by the following questions:

- What learning opportunities develop trainee teachers' knowledge, skills, and self-efficacy during their training programme?
- What challenges and barriers trainee teachers encounter during their training programme?

To answer the questions, data was collected through questionnaires, interviews, and field notes. The mostly qualitative data (a few quantitative data generated through questionnaires), generated from the three sources, was analysed using Braun and Clarke's (2006) steps for thematic analysis and the new PCK based framework developed in the first study.

Cross-Study Synthesis

The findings from the two studies were integrated and compared in a cross-study synthesis using a thematic framework. The findings and the implications resulting from the Systematic Review were compared to the implications resulting from the Case-Study to identify matches, mismatches, and gaps that can inform and advance practice in teacher training programmes. The purpose was to identify to what extent the practical implications resulting from the Case-Study were addressed in the review study and what was their effectiveness in practice, and in which ways the review study may inform a more cohesive model for preparing trainee science teachers.

In short, the study attempted to address two gaps in the literature through two complementary studies. In addressing the first gap regarding the lack of research syntheses on the effectiveness of approaches to preparing science teachers, I performed a systematic review to synthesise the existing literature on enhancing science teachers' development during their education programmes. In addressing the second gap regarding teachers' missing voices on their preparation, I conducted a primary research study to gain a better understanding of trainee science teachers' experiences on the programme. Collectively, the findings enabled the development of a more comprehensive framework for initial teacher training.

1.3 Researcher's Background

The interest in the topic of this research came from my own science education and experience of teaching science. I entered the teaching profession with a master's degree and speciality in Biology. I was educated in Romania where I taught biology to secondary school students for sixteen years. During the time, other roles outside the classroom (e.g., coordinator of extracurricular activities and/or mentor) further shaped my thinking about teaching and learning science. Therefore, I embarked on postgraduate education studies at a University in England with personal knowledge, beliefs, and understandings about what it meant to be a science teacher and what good science teaching was.

From a teacher practitioner abroad to a postgraduate student in England

When I moved to the UK, the new-socio-cultural context offered me new challenges as well as opportunities. The challenges imposed by a new language and a new and unfamiliar context of teaching impacted on my teaching ability. I came to realise, when I enrolled on postgraduate studies at a local University, that my views about teaching and learning were limited and mostly traditionally oriented. I was educated in a traditional educational system where teaching and learning were largely based on transmission and memorisation of information with little focus on understandings. Thus, I found Lortie's (1975) concept of apprenticeship of observation relevant to the way in which I used to teach.

My experience accumulated overtime, and the recognition of my academic and professional work during my career in Romania gave me confidence in my knowledge and skills and made me feel that I was an effective teacher. During my postgraduate studies, I had many opportunities to learn about what makes a teacher truly effective and what makes teaching effective. Progressing through postgraduate studies, my views and perspectives on education were greatly challenged. I realised that I had not been aware of the complexities of teaching nor of the theoretical foundations that underpin teaching. I came to develop deep understandings, knowledge, and skills for student-centred approaches to teaching and learning. I became aware that many teachers like me lack access to 'powerful knowledge' that would allow them to develop themselves as practitioners (Young, 2009; 2013). Having developed a good understanding of the requirements and expectations of teachers in my new context, I felt prepared to join the community of teachers as a secondary science teacher, when I was offered the opportunity to join a research programme.

From a postgraduate student to a researcher

Joining the community of researchers in a familiar context was a dream came true. My engagement with research further fostered my interest in science education. I extended my readings in the areas of science and educational policy. I became aware of the debates on education, particularly on science education. I also became aware of the demands on science education from a political, social, and economic perspective as well as of the requirements for teachers to be knowledgeable in their own subject, to have deep learning and transferable skills (Guerriero, 2017). I became aware of the issues surrounding initial teacher training programmes and the reasons why there is a lack of science teacher specialists in schools. Coming from a context where the entry into the teaching profession is very competitive, I was struck by the contrasting situation in the English context. I understood the reasons for shortage of specialists in schools and why so many teachers quit teaching in their first years of teaching, partly because of accountability measures and pressure to 'teach to the test' (Ryder, 2015). All these acknowledgements were decisive for the topic of this study. I felt that I could use my knowledge and understandings to contribute to the support for career changers, for whom teaching career is at least as new as it was for me when I changed the context of teaching. The decision to study about trainee teachers' development was partly based on the need to improve my own practice. I felt that the best way to improve my own practice was to conduct an action research project. Because I decided to study full time, I could not undertake an action research project. Thus, I chose to study international science education with the confidence that I would find useful approaches that I can apply in my future teaching. I explored the initial teacher training programmes to gain insight into the current context of preparation of teachers for teaching science in secondary schools.

During my research, I had opportunities to gain valuable experience in teaching in higher education by leading some sessions to masters' students at the University as well as to act as an occasional lecturer and leading a couple of modules on a childhood studies course. These useful experiences consolidated my view that the way in which future practitioners are prepared influences their motivation which shapes the foundations of their career. The belief that teachers need relevant knowledge, meta-awareness, and high self-efficacy was important and decisive in conducting my study. I describe next, how I came to develop a conceptual framework to guide my study.

Working towards a conceptual framework for the study

Constantly, reading through the literature, I remarked the emphasis on the requirement for teachers to have knowledge and skills for teaching. Yet, the concept of knowledge is complex and mostly addressed in general terms rather than explicitly. I found Shulman's Pedagogical Content Knowledge (PCK) concept very useful in understanding that there is a 'unique' knowledge for teaching (Shulman, 1986; 1987, p. 8). I started to map the literature on PCK and became aware of the complexity of the concept. Despite its complexity, the framework offers a good way to organise the knowledge for teaching, an important feature for developing expertise in teaching (Berliner, 2001). I started, with advice from my research supervisory team, to conduct a scoping review, a literature mapping which proved useful in developing research skills. I navigated extensively through existing research for models of systematic reviews in science education. Because it was difficult to find comprehensive reviews in my area of interest, I was inspired by systematic reviews in healthcare from which I borrowed methods and adapted to my own study. As I chose to conduct both a secondary and primary research, I struggled to find methods to combine the findings. Thomas's et al. (2003) and Thomas and Harden's (2007; 2008) approach to systematic review offered useful insights into how to combine the findings from different types of studies. It was necessary, though, to adapt the methodology and data collection to fit with the purpose of my study. I used PCK framework to decide on the studies to be included in the review, on the research questions, data collection, and analysis.

I also found Lave and Wenger's (1991) theory of 'legitimate peripheral participation' useful to understand how trainee teachers from my case study tried to navigate their own way from 'marginal participation to full participation' (Lave and Wenger, 1991, p. 29). The theory helped me to acknowledge and understand the feeling of marginal participant that all new teachers experience in their schools. For new teachers, as newcomers, the access to information, school activities, and resources is limited and 'less transparent' (Lave and Wenger, 1991, p. 102). Teachers' social interactions in schools open possibilities for learning by gradually 'absorbing and being absorbed' in the culture of their school (Lave and Wenger 1991, p. 95). Hence, the support teachers receive as marginal participants or newcomers is decisive in their path towards full participation (becoming part of the school communities). Lave and Wenger (1991) explain that legitimate marginal participation may be 'an empowering' or 'disempowering position', depending on the opportunities given to new teachers to participate more fully (p. 36). In my experience, an intense participation in school life with full responsibilities for teaching and learning creates opportunities for developing knowledge and skills in a more accelerated way. The theory seemed useful to explore how trainee teachers in my study viewed their own experiences in their school placements working alongside more experienced teachers. I was interested to know what opportunities they were given to make decisions, to be innovative and creative whilst learning from veteran teachers. In short, I was interested to know what learning opportunities trainees perceived to be effective in accelerating their participation as full members of the teaching communities in their schools and in developing their expertise.

Initially, my view about expertise was based on a wrong perception. I used to associate expertise with experience. Reading on Berliner's (2001) theory of teachers' development, I found that expertise is not the same as experience, and to be an expert, a teacher must rather be efficient and innovative. It is clearer now that not every experienced teacher is an expert. Expertise is a departure from routine to a course of action drawing on a rich repertoire. Expertise is topic and context dependent. These understandings helped me to change my perspective on expertise and I feel that even a beginner teacher can be expert if she or he develops good knowledge and confidence for teaching a given topic and is familiar with a particular context.

I realised why confidence is much emphasised in the literature on teachers' knowledge. Teachers may know well a given topic, yet they may find it challenging to teach the topic through an innovative approach if they lack confidence in their teaching capabilities. This relationship between teaching and perceived capability motivated me to explore Bandura's (1993) self-efficacy theory. Bandura's theory of self-efficacy helped me to understand people's behaviour, why they act as they do, particularly why teachers teach the way they teach. As a teacher myself, I had not been aware of how my self-efficacy predicted and guided my teaching in the classroom. Reflecting on my past teaching experiences, I consider myself a person with strong sense of efficacy. According to Bandura, teachers with strong sense of efficacy do not give up easily when teaching becomes challenging. Teachers with high efficacy are more willing to try innovative ideas and new methods of teaching in the classroom. In addition, teachers with strong efficacy have more commitment and persevere in effort. When teaching is unsuccessful, highly efficacious teachers tend to blame the methods chosen for teaching rather than the students for their lack of interest and participation in science lessons.

Bandura's observational learning theory and sources of self-efficacy development were also of interest as I realised that people learn much from doing and observing others. This way of learning is opposite to learning in isolation, the way I was familiar with. In my study, trainee teachers learned from their own teaching and observed experienced teachers' teaching in their school placements.

However, it is easy to observe, yet more difficult to understand. As observations are limited due to tacit knowledge and lack of experience in reflection, trainee teachers need 'windows into thinking' or practice (Smith and Banilower, 2015, p. 93; Guerriero, 2017). They need support to go beyond of what they can observe; to go beyond of their existing level of knowledge and understandings. Vygotsky's (1978) zone of proximal development was also useful in understanding why trainee teachers need support from more knowledgeable others during their training programmes. New learning is possible only when teachers add new knowledge, understandings, and skills to their actual development, and this is dependent on the quality of support, on opportunities for discussions and reflections.

To conclude, I decided to integrate all the above theoretical underpinnings into a conceptual framework to guide the whole study and to help in answering the research questions. The conceptual framework is described in Chapter 3. This thesis is structured into nine chapters. This first chapter presented an overview of the entire study. The following section outlines an overview of the next eight chapters.

1.4 Overview of the following chapters

Chapter 2 places the study in a broader context of science education programmes. The chapter includes a discussion on the aims of science education within the past and present political context and why it is important for initial teachers to acknowledge the aims. The expectations imposed by standards are then explored. This chapter also makes an international comparison between science education programmes across countries with an emphasis on ITT in England to identify similar issues.

Chapter 3 describes the theoretical framework that informs the study. The theoretical framework includes Pedagogical Content Knowledge (PCK) and a range of learning theories. The chapter is structured into four sections. The first section elaborates on PCK conceptualisations and components. The second section addresses issues with PCK measurements. The third section details factors (personal, cognitive, social, contextual) that shape teachers' PCK development. In this section, a range of learning theories are discussed. The chapter ends with an elaboration on the application of the theoretical framework to the study.

Chapter 4 covers the methodology of the first study of this thesis – A Systematic Review. The chapter starts with an introduction into the systematic review methodology, explains the rationale for carrying out a systematic review, and describes the protocol (the step-by-step methodology). This study was initially informed by the PCK framework described in Chapter 3. Through the thematic analysis of data comprising the evidence for teachers' enhancement, a new framework, named *Learning to Teach Framework* (LtTF), was developed. The newly developed framework guided the subsequent synthesis of data in the review study and the second study of this thesis.

Chapter 5 presents and discusses the findings of the Systematic Review in five sections. The first section describes the studies included in the review. The second section reports on the methodological quality of the selected studies. The third section reports the review findings according to the research questions. The chapter ends with a discussion and conclusion of the first study. From the review findings, a second framework was developed as a lens for understanding why PCK approaches were effective in enhancing teachers' development and how teachers developed PCK during their education programmes. The second newly developed framework, namely the *Triadic Framework for Learning to Teach,* was applied as an interpretive lens in the second study.

Chapter 6 covers the second study of the thesis – An Exploratory Case Study. The Case-Study explored trainee teachers' learning experiences in a School Centred Initial Teacher Training (SCITT) programme in England. This second study was informed by the two frameworks developed in the first study (described in Chapter 5). The chapter describes the research design and rationale of the Case Study. Selection of the participants, procedures, context, data collection, and analysis are described. Ethical and credibility issues were identified and addressed.

Chapter 7 discusses the findings of the Case Study. The findings are presented and discussed in relation with the literature according to four main themes that resulted from data analysis. The chapter ends with conclusions of the findings.

Chapter 8 presents the Cross-Study Synthesis – the integration of the findings from the two studies: Systematic Review and Case-Study. In this chapter, first, a summary of the findings generated by the Systematic Review and Case-Study are outlined. The findings from the two studies are integrated through a thematic approach, then, compared and discussed. The findings resulting from the cross-study synthesis revealed a set of evidence-based practices that are presented and discussed in this chapter.

Chapter 9 provides a general discussion and conclusion of the entire thesis drawing on the findings and discussions of the two studies and of the cross study-synthesis. The chapter summarises the main findings of the whole study highlighting the implications of the study's findings for practice, research, and policy as well as the contribution of the study to the body of knowledge. In this chapter, the strengths and limitations of the study are critically reflected upon. The chapter ends with final conclusions and recommendations for future research.

Chapter 2. The Landscape of Science Education Programmes

To enable an adequate preparation for trainee science teachers during their training programmes, it is important to consider the wider context in which this study is located. First, the aims of science education within the past and current policy in the international context are considered. Next, what is required from science teachers to respond to social and political demands are addressed. In the end, some issues and debates surrounding science education programmes across countries with an emphasis on ITT in England are discussed.

2.2 Aims of Science Education

The recognition that quality teaching depends on how teachers are prepared during their education programmes is widespread (Darling-Hammond, 2006; Osborne and Dillon, 2008; AITSL, 2014; DfE, 2016a; Darling-Hammond et al., 2017). Yet, questions surrounding what good teaching comprises and how future science teachers can be better prepared, continue to exist (Barber and Mourshed, 2007; Hattie, 2009; Furlong, 2013; Sickel et al., 2015; Menter, Peters and Cowie, 2017; Guerriero, 2017). In the context of rapid changes, a starting point would be to make the aims of science education more explicit. Osborne and Dillon (2008; 2010) comment that, in implementing change in science education, well-articulated aims are important. New teachers need to know why it is important to teach science and why students should learn about science (Osborne and Dillon, 2010). According to Osborne and Dillon (2010), by acknowledging the aims of science education, teachers can justify their own discipline which in turn may instil motivation in students' engagement with science. To engage students with science is not easy in the context of multiple and contrasting aims which characterise science education today (Osborne and Dillon, 2010). In the book '*Good Practice in Science Teaching*', Osborne (2010) gathers from the literature and outlines four aims of science education: utilitarian (related to individual’s ability to cope with everyday life) economic (related to future supply of scientists and engineers) cultural (related to science as shared heritage) and democratic (related to socio-scientific issues of a society).

Earlier international literature reveals that school curriculum has been dominated by the economic aim concerned with supplying society with scientists (Osborne and Dillon, 2010, p. 11). Osborne and Dillon (2008) called for changing science curricula to consider the needs of the majority of students. Their recommendations were reflected in a ‘science for all’ reform implemented in many countries (Osborne and Dillon, 2008; Darling-Hammond, 2010). However, science for all requires multiple aims, some of them being more emphasised than others (Osborne and Dillon, 2010). Different emphases on different aims have shaped science curricula over time leading to confusion about the content to be taught. In a systematic review, Ryder (2015) examines empirical studies focused on teachers’ experiences of externally driven science curriculum reform across countries. The review identifies a range of curriculum emphases with a tendency towards the goals of scientific literacy. The studies in the review include shifts towards context-based science teaching, teaching about ethical issues in the context of socio-scientific issues, and teaching about the history and philosophy of science or nature of science.

It is apparent from the findings of the above review that it is difficult to address all the aims and one aim may take priority over another. As explained by Osborne and Dillon (2008), multiple and contrasting aims makes difficult to know what aim to prioritise and what content to teach. Similarly, Schulz (2009), in a paper concerned with how science education reforms can be made more effective, also notices the competing aims promoted by different stakeholders with different interests. The author talks about three objectives for teaching science that undermine each other: teaching science for intellectual development (knowledge), for individual character, or for socio-economic benefit.

In England, the focus on the economic aim resonated in the government's promise to 'make Britain the best country in the world in which to be a scientist' (Brown, 2009 in Smith, 2010, p.199). However, scholars notice different emphases on different aims suggesting that the contrasting aims for school science may create tensions between the stakeholders involved (Ryder and Banner, 2011). Ryder and Banner (2011), in an analysis of science education reform curriculum for 14 – 16 - year-olds in England, suggest that for science education reforms to be successful, the multiple aims and the potential tensions must be acknowledged.

The aims of science education have relevance in the context of initial teacher training programmes. If teachers acknowledge the multiple aims for science education, they can avoid confusion and learn how to make science more relevant to students. However, in making science more relevant to students, simply acknowledging the aims of science education may not be enough. Based on a review of the literature, Stuckey et al. (2013) comment that multiple aims and goals for teaching and learning science may lead to different understandings of what it means to make science more relevant to students. The authors propose a model of relevance in terms of present and future consequences for students on three dimensions: individual, societal, and vocational. The individual dimension connects science with students' personal lives. The societal dimension prepares students for their roles as responsible citizens by developing scientific literacy skills and preparing for societal participation and decision making. Lastly, the vocational dimension offers orientation for future professions and careers.

The model of relevance suggested by Stuckey et al. (2013) may be useful for initial teachers as it helps them to focus on students' learning by taking into consideration the three dimensions of relevance when planning for teaching. Studies showed that the model of relevance promotes scientific literacy and increases students' motivation in science as they become more aware of their own interests (Bennett et al., 2005; Jong, 2006; Marks and Eilks, 2009; Eilks and Marks, 2010; Eilks, Jesper and Hofstein, 2017). In short, the proposed model suggests understanding relevance in science in a balanced way around students' interests. However, keeping a balance between aims may be a challenging task. Schulz (2009) notices that 'the attempts to achieve a balance are illusory and must undermine the strengths of any one at the cost of the others' (p. 233). The difficulty of keeping a balance between aims becomes noticeable in a comparison of teacher education programmes and teaching science in many countries. For example, although school reform documents (e.g., school curriculum) place an emphasis on the Nature of Science as a separate strand for teaching (NZ Science Curriculum, 2007; NGSS, 2013; DfE, 2014a), in many countries, teaching about the nature of science is absent from teacher education programmes (Olson et al., 2015; Cofre et al., 2015) or from science teaching in schools (Osborne and Dillon, 2008).

2.3 Expectations of Initial Teachers

Having outlined, in the above section, some of the main aims of science education and their importance in shaping the content to be taught, the expectations of new science teachers are worth considering. As noted by the authors above (Osborne and Dillon, 2008; Schulz, 2009; Ryder, 2015), multiple and contrasting aims create difficulty in prioritising the aim and content for teaching. This difficulty makes teachers confused about what is expected of them in terms of practice. The expectations of initial teachers are not different to what is expected of their more experienced colleagues. A considerable number of studies highlight what teachers are expected to know and do. Shulman (1986) places an emphasis on the balance between content and pedagogy asking teachers to transform the content in forms understandable to students. A great emphasis internationally has been on developing students' 21st century skills (Merriam and Bierema, 2013). Yet, as Meriam and Bierema (2013) stress, initial teachers need to develop 21st century skills for themselves if they are to demonstrate them effectively to students. Furthermore, with an increasing emphasis on research evidence, there are calls for teachers to be research informed (Furlong, 2013; Menter, 2016). To be research informed, teachers need time and practice to develop research skills. Therefore, the skills may not be yet part of initial teachers' repertoire (Osborne and Dillon, 2008).

A solution in helping teachers to develop their knowledge and skills is to make clear what is expected of them and how these expectations will be achieved. The expectations of teachers are more systematically described in the science standards of each country (NBPTS, 1992; Ingvarson and Kleinhenz, 2003; AITSL, 2011b; DfE, 2011; Guerriero, 2017). Standards comprise a list of statements that define what effective teachers need to know, understand, and be able to do (Page, 2015). Also, standards are national measures of teachers' preparedness to teach (Harrison, 2007).

Given that in many countries the standards are criteria of performance, they have been largely analysed and often criticised (Hextall and Mahony, 2000; Harrison, 2007; Smith, 2013). Several reasons for the controversial nature of standards were identified. First, there are issues with clarity of standards. Harrison (2007), focusing on assessment measures for trainee teachers in England, notices that trainees' expectations about their practice are not always clear and trainees find it difficult to know what to prioritise in their school contexts. It might be that trainees' confusion about their expectations of them is due to differing interpretations of the standards and how they might be implemented or demonstrated in a variety of contexts (Hextall and Mahony, 2000; Harrison, 2007). Hextall and Mahony (2000) suggest that standards 'do not resolve issues of consistency and fairness when used for assessment purposes and rely heavily on interpretation for translation into practice' (p.60). Ingvarson and Kleinhenz (2003), in a critical review and comparison of several sets of standards across countries including England, conclude that teaching standards must be governed by three rules: a clear definition of what a good teaching is, clarity in the kind of evidence needed for meeting the standard, and how the evidence will be interpreted.

Then, there are issues with applicability of standards. Hextall and Mahony (2000), in an analysis of education policy in England, observe that the Qualified Teacher Status (QTS) standards published in 1997 were 'outdated and ill-suited to the purpose of equipping teachers to meet the challenge of change' (p. 53). The authors cite studies that found similar issues in Australia, Denmark, and Scotland. The Australian report *Action Now: Classroom Ready Teachers* (2014) reveals that standards are not being effectively applied and implementation timeframes are too slow. Moreover, there are issues with the alignment of standards with school curriculum.

Criticisms of standards are not limited to those above. However, Lucas, Nasta and Rogers (2012) claim that, in England, successive standards have not brought more about coherence. Their claim is supported by Smith (2013) who, in a critical analysis of Teachers' Standards, notices that standards 'operate to maintain the status quo' (p. 443). Currently, in England, the standards for teachers are divided into two parts: *Teaching,* and *Professional conduct*. The first part requires teachers to: - Set high expectations which inspire, motivate and challenge pupils; - Promote good progress and outcomes by pupils; - Demonstrate good subject and curriculum knowledge; - Plan and teach well-structured lessons; - Adapt teaching to respond to the strengths and needs of all pupils; - Make accurate and productive use of assessment; Manage behaviour effectively to ensure a good and safe learning environment; - Fulfil wider professional responsibilities. The second part, *Professional conduct*, asks teachers to demonstrate consistently high standards of personal and professional conduct. The new Teachers' Standards outlined above were launched in 2011 by Michael Gove, the Secretary of State for Education in England:

> The Teachers' Standards set a clear baseline of expectations for the professional practice and conduct of teachers and define the minimum level of practice expected of teachers in England (DfE, 2011).

Undoubtedly, issues with clarity of standards have consequences on the quality of support teachers receive during their education programmes. Davis, Petish and Smithey (2006), in a review of challenges initial teachers face, argue that they are not appropriately supported in meeting the expectations imposed by standards. In their view, the expectations of new science teachers, set by the standards, are 'extremely high', and it is difficult for initial teachers to achieve them all (p. 637).

Davis, Petish and Smithey (2006) conclude that not all the challenges imposed by standards can be addressed by teacher education programmes, and some challenges need to be addressed at institutional or policy level. The suggestions are reflected in initiatives across countries that aimed to further clarify and support the applicability of standards. For example, The Australian Institute for Teaching and School Leadership (AITSL, 2013 in Guerriero, 2017), developed videos and broad explanations of how standards apply to the classroom. In England, the government initiated in 2019 a new framework for ITT developed around the Teachers' Standards to support trainees' development on five core areas: behaviour management, pedagogy, curriculum, assessment, and professional behaviours. Within each standard area, there are key statements based on research evidence that define what makes effective teaching. Other statements define an ‘entitlement to practise key skills as well as opportunities to work with and learn from expert colleagues as they apply their knowledge and understanding of the evidence in the classroom’ (DfE, 2011; 2019). However, the framework is not used for assessment purposes, rather it gives insight into how trainee teachers must be assessed against each standard. Teachers’ Standards remain the only measurements against which trainee teachers are assessed (DfE, 2019). Therefore, the content of standards is worthy of closer examination.

On closer examination of the content of standards, it becomes apparent that the expectations of teachers are high. Guerriero (2017) makes an analysis of the standards in four countries (England, Ontario, Scotland, and Australia). The four countries were of interest for the author because all the countries use the standards widely within their system and often serve as examples for other countries. The analysis reveals similarities in some emphases, especially on differentiated instruction and teachers’ capacity to adapt to different students and the environment, in all the four countries. As 21st century schools are characterised by multiculturalism, the emphasis on adaptability to different students becomes central in the context of equitable education (Darling-Hammond, 2013; Furlong, 2013; Darling-Hammond et al., 2017). The challenge to find strategies to meet the needs of diverse students is even greater for beginner teachers who have a limited repertoire of knowledge and skills.

Given the high expectations imposed by standards (Davis, Petish and Smithey, 2006; DfE, 2011) and the difficult task for teachers to achieve them (Stuckey et al., 2013), efforts have been made internationally to support teachers’ preparation (Guerriero, 2017). Many comparative studies showed that some countries perform better than others (Barber and

Mourshed 2007; Darling Hammond, 2010; 2017). Some of the issues surrounding science teacher education programmes in diverse countries are explored in the next section.

2.4 Science Education Programmes. An International Context

Comparison between countries is not straightforward. Science education programmes across countries are influenced by different socio-historical and cultural factors (Evagorou et al., 2015). Yet, as comparative studies demonstrate, many countries share some commonalities (Evagorou et al., 2015; Darling-Hammond et al., 2017). One commonality is that many countries aim to equip the students with 21st century skills as measured by international assessments (e.g., Program for International Student Assessment - PISA and Trends in International Mathematics and Science - TIMSS). PISA reveals every five years the top performing states that have become models for the others (Barber and Mourshed, 2007; Sahlberg, 2011). Their successful approaches to preparing teachers have been much scrutinised (Barber and Mourshed, 2007).

Barber and Mourshed (2007) (McKinsey report) take a holistic approach and carry out an international study exploring twenty-four school systems in Asia, Europa, North America, and the Middle East. In their study, they include the world's top ten best performing school systems rated by OECD and PISA and those school systems with a rapidly rate of improvement. The report identifies three effective tools for improvement applicable to any culture and location. These tools are recruiting highly quality graduates, developing them into effective teachers and ensuring the best teaching for every child.

The quality of teaching is highlighted in another comparative study conducted by Darling-Hammond et al. (2017). Darling-Hammond et al. (2017) compare studies located in different social, cultural, and political contexts. The authors find and group the common challenges on eight policy levels. Among them, enhancing teacher and teaching quality has been seen as key for educational improvement. Darling-Hammond et al. (2017) suggest that teacher education programmes would be more effective if countries can learn from each other's successes:

> The teaching challenges posed by higher expectations for learning and greater diversity of learners around the globe will likely be better met if nations can learn from each other about what matters and what works in different contexts (Darling-Hammond et al., 2017, p. 307).

In science education, comparative studies focus on different aspects of teacher education programmes. Park et al. (2017) compare undergraduate secondary science teacher education programmes from two universities in Korea with two in Oregon (USA) to examine the programmes' structural curricular coherence, conceptual curricular coherence, and curricular balance. The study finds structural coherence in all the programmes. Korean programmes stress the subject knowledge and pedagogical content knowledge more than the Oregon programmes, and Oregon programmes place a more emphasis on content knowledge of the discipline than the Korean programmes. The differences are attributed to the type of licensing and employment. The emphasis on subject matter knowledge in Korea is due to TEE (Teacher Employment Examination) that certifies science teacher candidates in each subject area.

Other studies look at the impact of policy on education programmes for science teachers. For example, Olson et al. (2015) examine critical issues in science teacher education policy in North American context (Canada and the USA). The study has a focus on qualifications, certification, requirements for entry the programme, and general trends in science teacher education. Given that countries in America are composed of many states and districts with unique characteristics and have a decentralised education, it is not surprising that the study finds a great variability in the landscape of science teacher education and certification. Despite the variability which makes the access to accurate information difficult, creating, thus, difficulties in assessing the quality of science teacher preparation, the study finds a 'striking similarity' (p. 22). In both reviewed countries, preparation of teachers for teaching science is found deficient. The policies promote minimal science content requirements and hence minimum requirements for gaining a qualification to teach. The polices are criticised for perpetuating status quo and the lack of efforts in preparing highly qualified science teachers. Additionally, more frequently in rural parts of Canada, because of shortage, teachers teach outside their specialism. As a result, there are concerns about teaching practices that promote superficial understanding of science content especially under pressure to teach for the test.

The impact of education policy on science education programmes is also examined in South America context. Cofre et al. (2015) focus on the main characteristics of science teacher education in Argentina, Colombia, and Chile. As in the previous study, concerns relate to low effectiveness of teaching, pointing to underdeveloped science education programmes for science teachers. The programmes do not prepare teachers in line with the clear objectives of science teaching identified at the government and training institutions level. A lack of emphasis on the nature of science and scientific inquiry in teacher education programmes leads to teachers adopting traditional teaching practices (e.g., cookbook-like demonstrations). In the authors' view, the quality of teachers and teaching can be increased through more scientific research and disciplinary coverage during the education programme.

Science education programmes in African countries are surrounded by similar long-standing issues (Ogunniyi and Rollnick, 2015). In an analysis of science teacher education in twelve African countries, Ogunniyi and Rollnick (2015) find ongoing challenges with recruitment and retention of qualified science teachers. The shortage of science teachers are partly resolved by imigrants with no teaching qualifications. The measure causes concerns about those teachers' level of content knowledge and hence about the quality of teaching. In addition, science education, centrally controlled, is impacted by conflicting educational polices due to ever changing administrations.

Initiatives to improve the quality of science teacher education has also been the focus of continuous political debate in Australia. (Treagust et al., 2015). Treagust et al. (2015) investigate the issues and implications of government initiatives on science education programmes. The initiatives such as Teach for Australia, an alternative way to recruit candidates to teach science subjects, have been driven by concerns over the shortage of qualified science teachers. As in the countries previously mentioned, the shortage of qualified science teachers leads to science being taught by out of field specialists or unqualified teachers. On the other hand, the quality of education programmes has been questioned, with critics pointing to theory-practice divide reflected in an emphasis on practical knowledge or 'craft of teaching' (p. 94). The authors observe that the issues surrounding teacher education in Australia have a strong political voice that emphasises international competition, test performance, and teacher accountability.

In European countries, it becomes noticeable that some of the challenges in science education follow similar trends to those identified elsewhere. Evagorou et al. (2015) compare teacher education programmes in England, Finland, France, and Cyprus. The study identifies that in Finland there is greater emphasis on research and the balance between theory and practice. Sahlberg (2011), in an examination of the education system in Finland, contends that Finland 'remained immune to the winds of marked-driven educational policy changes' that influenced many other countries (p.10). Successful features that make Finland and Singapore model nations are highlighted in many international studies (OECD, 2012; Darling-Hammond et al., 2017). Some of the successful features are worth mentioning: - an increased attention given to subject specific pedagogy; - good training in diagnosing diverse students and in adapting teaching to the diverse learning needs and styles of students; - collaborative planning; - and action and reflection. In contrast, in other countries, initial teacher training is characterised by standards, skills, and competences as revealed by Page (2015) in a study of common pressures in England, France, and Germany. The findings of the study indicate that in England, 'teaching as a research-based profession… has yet to be resolved' (Page, 2015, p.197).

Having explored some of the issues in science education around the world, the attention is turned to the Initial Teacher Training in England, the national context in which the present study is situated.

2.4.1 Initial Teacher Training (ITT) in England

Routes into teaching

Teacher education in the UK has gone through major and ongoing changes over the last two decades. In England, the diversification of the routes into teaching has made the landscape of teacher education more complex. Currently, graduates, entering teaching profession, have to choose from two main training models: university - led model, and school - led model. During the 1990s, university - led model has been the main pathway to teaching, offering undergraduate routes into teaching leading to a degree with QTS, and postgraduate routes into teaching leading to Post Graduate Certificate of Education (PGCE) (Whiting, 2019). The education courses have been provided in partnership between universities and schools, with universities deciding the content for teacher training, and schools serving as resources for trainees' learning opportunities (Sorenson, 2019). The traditional route, the PGCE, offers a one-year full time training with most of the time spent in university and a minimum twenty-four weeks spent in two different school placements (DfE 2016a). Post Graduate Certificate of Education (PGCE), led by universities, keeps remaining 'the most popular and prestigious route into teaching' (Whitty, 2019, p. XVII).

Concerns about the quality of teacher training provision led to a growing focus on pedagogy and pedagogical content knowledge. Trainees were required to spend more time in schools to learn from more experienced teachers (Whitty, 2019). The government accredited a group of schools to run their own training independently. This group of schools was called School-Centred Initial Teacher Training (SCITT). The SCITT has given power and responsibility in terms of selection of candidates and course content (Sorenson, 2019). SCITT places an emphasis on practical approach to training, an approach that is close to an apprenticeship model (Whiting, 2019). A school which is part of a SCITT may work in partnership with a university to provide PGCE content (Whiting, 2019).

Up to 2010, under the Labour government, SCITT has been further developed and other routes into teaching were introduced: Employment-based Initial Teacher Training (EBITT), Graduate Teacher Programme (GTP), the Overseas Trained Teacher Programme (OTTP), and Teach First (TF) (Menter and Reynolds, 2019). The participants on the Teach First programme take intensive five-week periods of theory and practice of teaching course before continuing their training in schools for another two years. On the completion of their training, the participants are awarded Post Graduate Diploma in Education (PGDE) which has double the credits of a PGCE (Whiting et al., 2018). Other distinct targeted programmes (such as Researchers in Schools, Troops for Teachers) have been also developed.

The shift towards school-led initial teacher training in England has been accelerated under the coalition government. The White paper '*The importance of Teaching*' (2010) places even further emphasis on the school-led model of training by introducing School Direct scheme. School Direct (SD) involves the allocation of training places, both salaried and fee-paying, directly to schools rather than to provider. Whiting et al. (2018), in a topography of ITT, provide a full account of the routes into teaching. The authors highlight the complexity of provision caused by the proliferation of routes into teaching. Whiting (2019) identifies twelve routes that lead to QTS and explains that all the routes to QTS had to identify an accredited ITT provider (HEI or SCITT) to make formal agreements on recruitment, training, and funding. Later, the routes to QTS, were summarised to three: Teach First, School Direct, and SCITT as provider school-led (Whiting, 2019).

Regardless the route into teaching, trainees, who intend to teach in secondary schools, need to have an undergraduate degree in their chosen specialist subject. They need to have GCSEs (or their equivalent) in English and Mathematics at grade C or above. In addition, before beginning their training course, they need to pass professional skills tests in literacy and numeracy. From April 2020, this criterion was replaced with a new approach to assessing numeracy and literacy. The new approach requires ITT providers to assure that trainees have a set of fundamental English and maths skills by the end of their ITT (Foster, 2019). By the end of their ITT training, trainees also need to demonstrate that they meet the ITT standards (Foster, 2019). The ITT standards are set out in the new ITT Core Content Framework (CCF) (2019) designed to support trainees' development in five core areas: behaviour management, pedagogy, curriculum, assessment, and professional behaviours. The CCF ensures that all trainees across the routes receive minimum entitlement for meeting the Teachers' standards, the only measures against they will be assessed. The five areas of development are addressed in congruence with the eight Teachers' Standards. Thus, behaviour management is addressed in ‘*High Expectations and Managing Behaviour*’ (Standards 1 and 7). Pedagogy is addressed in ‘*How Pupils Learn, Classroom Practice and Adaptive Teaching’* (Standards 2, 4, and 5). Curriculum, Assessment and Professional behaviours are addressed in ‘*Demonstrate good subject and curriculum knowledge’, ‘Make accurate and productive use of assessment ‘and ‘Fulfil wider professional responsibilities’* (Standards 3, 6, and 8) (DfE, 2019).

Trainees’ perceptions of teacher training

The impact of diversification of provision on trainee teachers is worth mentioning. No matter the route, most of trainee teachers were found to be happy with their own preparation. Giannakaki, Hobson and Malderez (2011) re-analysed data from the ‘Becoming a Teacher’ (BaT) study (a large-scale longitudinal study 2003 – 2009 of the experiences of trainee and early career phase teachers) to compare trainees’ experiences or perceptions of the effectiveness of their training across the range of available pathways in England. The findings reveal that trainee teachers, in England, reported positive expectations of their training before starting the programme and positive experiences at the end of the programme. Most trainees on each programme reported great confidence in their preparation.

More recently, in a re-analysis of the Department for Education survey (2015) of 7,770 newly qualified teachers (NQTs), Gorard (2017) finds that a high proportion of newly qualified teachers were very satisfied with their preparation across all the routes. The author suggests that one route should not be considered superior over another. The suggestion is pertinent given that ’teachers and the students they teach are too diverse for a single prescription’ (Shuls and Ritter, 2013, p. 30). Shuls and Ritter (2013) comment that ‘elementary and secondary teachers need different sorts of training since they have different needs’ (p. 30). In the authors’ view, alternative routes are key for increasing the number of high-quality teachers by reducing the barriers to entry into teaching profession. Indeed, in a small-scale exploratory qualitative study with twelve trainee teachers from three dominant routes into secondary school teaching in England (a university-based course - PGCE, School Direct Salaried - SDS, and School Direct Unsalaried - SDU), George and Maguire (2019) show that the diversity of routes into teaching benefited some individuals who initially have not been able to access training.

Some issues and debates on ITT in England

The proliferation a school-led ITT, in England, has led to a fragmented provision (Sorenson, 2019). This fragmented provision has generated much political debate. Initial Teacher Training (ITT) in England is surrounded by similar issues and debates as in other countries, as revealed by comparative studies (Evagorou et al., 2015; Page, 2015). Predominant issues surrounding the ITT in England relate to shortage of science teachers, recruitment issues, teaching quality, and theory-practice gap. One of the common discourses surrounding ITT in England is characterised by issues of 'marketisation' and 'fragmentation' (Merriam and Bierema, 2013; Hulme and Quirk-Marku, 2017, p. 349; Whitty, 2017). Diversification of routes into teaching raises issues about the status of teaching as a profession. Some would argue that attracting highly quality candidates from diverse fields may lead to an increase of teaching professional status like that found in medicine and law (Guerriero, 2017). Though, studies show that 'a degree is not enough' to ensure high quality teaching (Kind, 2014, p.1313). Kind (2014) notices that many candidates for teacher training have science backgrounds with little resemblance with school science. Therefore, these candidates possess limited knowledge and skills in the science subjects which are not their specialism. Moreover, Guerriero (2017) argues that ITT in England is not enough competitive, and diversification of routes has resulted in the lowering even further of entry requirements which may lead to teaching profession to be perceived as being easily accessible.

Another point of criticism is that the proliferation of routes into teaching takes place with an increasing move towards school-led and school-based training. In other words, trainee teachers have less access to educational theory at university. The movement towards more practical knowledge than theory has been based on the argument that the best way to learn to teach is in the classroom as an apprentice observing a master (DfE, 2010; Childs and Menter, 2013). This movement has inevitably created a gap between theory and practice that has generated much criticism. In an analysis of educational polices in England, Childs and Menter (2013) argue that the apprenticeship model limits the creativity and autonomy of teachers and educators. Others (Whitty, 2017) suggest that this view of teaching moved teacher education many years back to when the prescribed curriculum had been seen ‘a good dose of proper subject knowledge’ (p. 378).

It is clearly suggested in Mc Donough’s (2012) account of the relationship between theory and practice, that the model currently adopted in teacher training limits teachers’ intellectual development. In the author’s view, the model of apprenticeship works like ‘a recipe’, meaning that teachers learn the ‘craft’ without providing rationales for their actions (p.16). Within the current context of teacher training, it is argued that trainees no longer have access to the kind of knowledge of ‘know-why’ that can only be achieved by learning about educational theory (Durkheim, 1977, cited in Beach and Bagley, 2013, p. 390). The long-term effect is that ‘narrow views’ of theory underlying practice place a barrier and limit trainee teachers’ ability to adequately respond to students’ needs (Mc Donough, 2012, p. 8). Because habits of good practice develop early in career, it seems crucial that educators must make the relationship between theory and practice clear and relevant to trainee teachers during their training programmes (Mc Donough, 2012).

In the same note, Marshal (2014) stresses that trainee teachers need access to powerful educational knowledge if they are to develop more autonomy in practice, deep understanding, and creativity, avoiding thus, adoption of learned routines. When talking about preparation of teachers, Marshall (2014) differentiates between training and education of teachers. For example, the author feels that the emphasis on ‘key teaching skills’ aims to train teachers rather than to educate them (p. 275). Education of teachers, compared to training, reflects a broad research informed knowledge bases for teaching (Beauchamp et al., 2013). Instead, the current approach to ITT, ‘narrowly practical and overly managerial’, is unlikely to raise teaching standards, as Marshall suggests (2014, p. 275).

From another perspective, Hulme and Quirk-Marku (2017) contend that teacher training is negatively impacted by the proliferation of providers and competition for training places. Perhaps, the competition between providers makes them focus more on recruitment and less on the quality of the candidates (Hulme and Quirk-Marku, 2017). Lucas, Nasta and Rogers (2012) suggest that providers ‘are being forced to play a game’ in responding quickly to changing standards and regulations (p. 693). As a result, the attention from more important aspects such as mentoring support and coherence between theory and practice has been diverted. On the other hand, a positive aspect of marketisation is that it gives providers (training schools) more autonomy in teacher training (Whitty, 2014). However, some would say that this autonomy is misleading, given that teachers’ practice is constrained by accountability measures and conformity with prescribed national policies (Furlong, 2008; Ryder, 2015).

Another essential point is that, through marketization, the ITT in England has become very complex due to the rapid proliferation of routes into teaching over the last two decades (Whiting et al., 2018; Lofthouse, 2018). The problem is that this complexity creates confusion and difficulties in evaluating the quality of the programmes (Mutton, Burn and Menter, 2017; Hulme and Quirk-Marku, 2017; Whiting et al., 2018). Such concerns are raised recently by Whiting et al. (2018) whose topography questions the evaluation of the quality of teacher training in a diverse system and points to the fragmentation of a national system:

> With a prevailing emphasis on choice and diversity in ITT within the gathering momentum of a system in which the balance of control is moving from HEIs to schools, questions about quality are becoming difficult to answer (Whiting et al., 2018, p. 89).

However, the view of teaching as a craft is not shared everywhere in the UK. In Scotland, for example, the report ‘Teaching Scotland’s Future’ by Donaldson (2011) agrees with the craft components of teaching if they are based on research-informed practice. The report recognises that teaching is a complex and highly intellectual demanding profession and advocates for a strong partnership between schools and universities. Such partnership is founded on a clinical practice model that emerged in the last decade in the world (Donaldson, 2011). Donaldson declares:

> The capacity of the teacher should be built not just through extensive ‘teaching practice’ but through reflecting on and learning from the experience of supporting children’s learning with all the complexities which characterise twenty-first century childhood…Simply advocating more time in the classroom as a means of

> preparing teachers for their role is therefore not the answer to creating better teachers (Donaldson, 2011, p. 5).

The clinical model of teaching within ITT, as summarised by Burn and Mutton (2013; 2015) and Menter, Peters and Cowie (2017), is research-informed practice based on principles of collaboration between schools and universities. Within a strong partnership, the theoretical and practical components are better integrated; a genuine integration which give teachers opportunities to develop ‘clinical reasoning’ (Kriewaldt and Turnidge, 2013, p. 2). Clinical reasoning means that trainee teachers can access their educators’ thinking. Through clinical reasoning, educators articulate their pedagogical decisions, making their tacit craft knowledge explicit to trainees (Burn and Mutton, 2013; Kriewaldt and Turnidge, 2013). Kriewaldt and Turnidge (2013) define clinical reasoning as a ‘type of logical thinking and discourse in which specific evidence is evaluated and different types of knowledge are integrated and applied’ (p.107). Ultimately, the model of research informed practice moves the focus from imitation or trial and error in the classroom to understanding students’ learning (Burn and Mutton, 2015).

In England, an integrative programme of this kind is the Oxford Internship Scheme described by Burn and Mutton (2015, p. 217) in a review on programmes designed on principles of ‘research-informed clinical practice’. The Glasgow West Teacher Education Initiative is another integrative programme in the UK grounded in clinical practice, described by Conroy, Hulme and Menter (2013). The common features of these programmes are that they claim to be based on principles of social justice and high-quality teaching (Menter, Peters and Cowie, 2017). As mentioned by Menter, Peters and Cowie (2017), in England, there is an increasing move towards evidence-based teaching. However, Burn and Mutton

(2013) express doubts that single programme or initiative could have a significant impact across the variety of training programmes:

> Neither a simple increase in classroom 'field experiences' nor even claims to be operating 'partnership' models are sufficient in themselves to warrant inclusion (Burn and Mutton, 2013, p. 219).

On the other hand, the benefits of diversification of routes into teaching have been acknowledged. In an independent review on the quality of ITT, Carter (2015), although recognising the complexity of the routes into teaching and the uncertainty of the nature of partnerships, considers the diversity of provision as 'a strength of the system' and the partnership, 'the key' (p. 3). The report ordered by the House of Commons (2012) – *Great Teachers: attracting, training, and retaining the best*, recognises that the increased diversity of routes is an effective way to enable high quality graduates from different backgrounds to enter the profession. With the proliferation of routes into teaching, the quality of teachers who entered the profession has been considered by some 'the best ever' (Whitty, 2017, p. 375). `

Although, diversification of routes solves to some extent the problem with recruitment, the high rate of attrition, especially in science, has drawn attention to the quality of training programmes. The government's concern has been that the progress made in ITT is unevenly spread (Carter, 2015; DfE, 2016a). To ensure that the quality of teaching reaches every classroom, in the White paper, *Educational Excellence Everywhere* (DfE, 2016a), the government recognises the need for further measures. Thus, the recommendations made by Carter's (2015) review led to the elaboration of ITT Core Content Framework that defines the essential elements of course content that helps in supporting trainees to meet the Teachers' Standards (DfE, 2016b). To ensure that teachers can have access to high quality evidence-based practice, the same paper announces a new independent College of Teaching to help in spreading good practice, as it is in medicine (DfE, 2016b).

To conclude, there is much support for an active partnership between schools and universities. Such partnership enables trainees to learn from the expertise of both parts. Learning from the expertise of both partners is the best way for trainee teachers to accumulate the ‘social capital’ needed for developing reflective thinking about practice (Wilson, 2012, p. 18). A strong collaboration between schools and universities as well as a good integration of coursework and school placements have been identified as one of the characteristics of powerful teacher education programmes by Darling-Hammond in 2006. On the other hand, Darling-Hammond (2006) observes that reform initiatives generate much discussion about the structure of teacher education programmes and certifications. Such discussions, the author comments, have led to a range of models of programmes. Yet, less discussion has been on learning experiences inside the programmes and how experiences develop teachers’ knowledge, skills, and confidence for teaching (Darling-Hammond, 2006). Whilst these issues appear to have been in the USA, recently in England, Burn, Mutton and Hagger (2017) urge for more attention to the nature of teaching itself and to the ways in which trainee teachers engage in the process of learning to teach. This study attempted to fill this gap by exploring trainees’ experiences and looking inside various science education programmes to identify effective ways of learning to teach.

In summary, this chapter described the international and national context in which the present study is located. The chapter highlighted the significance for trainee science teachers to acknowledge the competing aims of science education. The aims of science education were found to be multiple and conflicting with each other. Therefore, to make science relevant to students, trainee teachers need to be aware of how each aim influences the content for teaching. Then, the chapter outlined the expectations of trainee science teachers. The expectations are defined in Teachers' Standards, measures against trainee teachers are assessed. Scholars found that the expectations imposed by standards are high. Thus, this study highlighted the need for trainee teachers to be made aware of the demands and to be effectively supported in achieving them.

An international and national perspective on science education programmes revealed that most of the countries face similar challenges. The most cited challenges were shortage of science specialists, accountability measures, performativity, low entry requirements and theory practice gap. All these issues were highlighted because they are constraints which impact on preparation of teachers. Trainee teachers need to acknowledge the constraints so that they can learn how to teach effectively within them (Hammerness et al., 2005).

The next chapter covers the theoretical framework of the study.

Chapter 3. Theoretical Framework

This chapter elaborates on the theoretical framework that guided the study. The aim of this study was to identify how ITT programmes can be enhanced to teach science in secondary schools. The study draws on Pedagogical Content Knowledge (PCK) and a range of learning theories. The first section of this chapter addresses PCK conceptualisations and components. The second section addresses issues with PCK measurements. The third section details factors (personal, cognitive, social, contextual) that shape teachers' PCK development. In this section a range of learning theories are discussed. The last section elaborates on the application of the theoretical framework to the study.

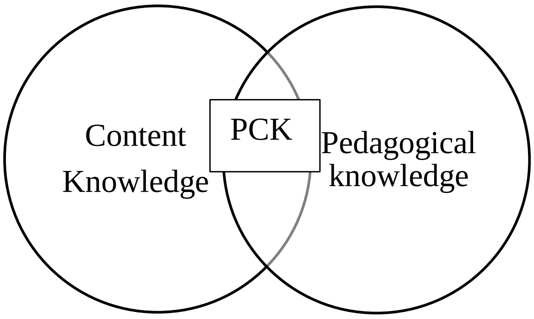
3.1 PCK framework: conceptualisation and components

3.1.1 PCK Conceptualisation

Pedagogical Content Knowledge (PCK) framework was developed by Shulman (1986) at a time when the educational debate on evaluation and certification of teachers was mainly focused on the pedagogy of teaching. The pedagogy of teaching places more emphasis on class management, organisation of activities for teaching, structure of assignments and lesson plans. In *Knowledge Growth in Teaching* (1986), Shulman raises a series of questions to address the lack of focus on the content for teaching, calling it the 'missing paradigm problem' (p.7).

The concerns raised by Shulman have been especially relevant to teachers who are required to teach out of their specialism. He asks: 'How does the teacher prepare to teach something never previously learned?' (p. 8). His concerns relate to sources of teacher knowledge and transformation of content into forms understandable for students. Rather than denying the importance of pedagogy, Shulman emphasises the need for the two aspects of teaching to be blended into one as Pedagogical Content Knowledge (PCK) (Figure 1).

Figure 1. Shulman' s (1986) conceptualisation of PCK



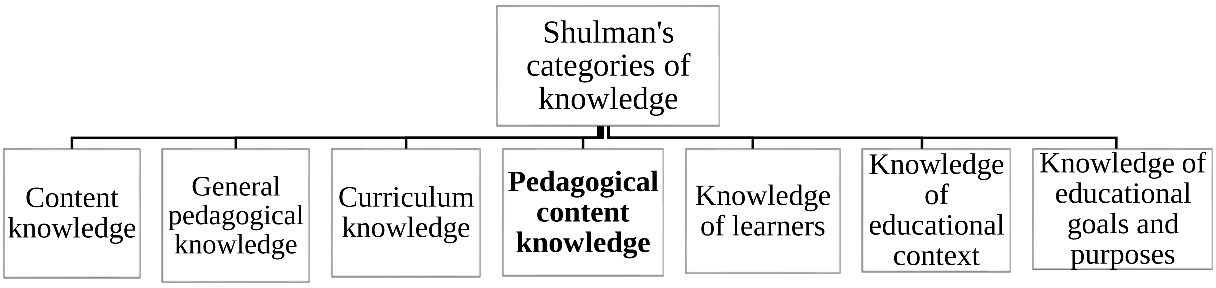
Shulman initially distinguishes among three categories of content knowledge for teaching: subject matter content knowledge, pedagogical content knowledge, and curricular knowledge. Content knowledge requires an understanding of the substantive (ways to organise the concepts) and syntactic (ways of explaining why a given topic is worth knowing) structure. In Shulman's words, a teacher must understand both 'what' and 'why it is so' (Shulman, 1987, p. 9). Pedagogical Content Knowledge is defined by Shulman as:

> … a particular form of content knowledge …including the most powerful analogies, illustrations, examples, explanations, and demonstrations-in a word, the ways of representing and formulating the subject that make it comprehensible to others. Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult… (Shulman, 1986, p. 9).

Curricular knowledge includes the 'programs designed for the teaching of subjects and topics at a given level, the variety of instructional materials available in relation to those programs' (Shulman, 1986, p.10).

Later, in 1987, Shulman provides a framework for a knowledge base of teaching including seven categories of knowledge that a teacher needs to know to help students understand the content: content subject knowledge, general pedagogical knowledge, PCK, curricular knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of the philosophical and historical aims of education (Figure 2).

Figure 2. Shulman's seven categories of knowledge



These categories of knowledge form teachers' professional knowledge base on which science teachers base their decisions about what and how to teach. Among these categories, Shulman (1987) gives a special attention to PCK as the knowledge unique for teachers. In Shulman's conceptualisation of PCK, all the categories of knowledge are transformed in the process of teaching into a new category which is PCK. Thus, PCK makes the distinction between 'a content specialist and that of a pedagogue' (Shulman 1987, p. 8) or between a science teacher and non-science teacher. For example, a non-science teacher may know and understand well the knowledge bases for teaching. Yet, comprehension does not distinguish a non-science teacher from a science teacher. What makes the difference is:

'…the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students' (p. 15).

Shulman (1987) stresses that comprehension must be linked to judgement and action. He supports Fenstermacher (1978) in declaring that teachers should not be trained to behave in prescribed ways but to be educated to reason soundly about their teaching (Shulman, 1987). Thus, Shulman develops a model of pedagogical reasoning and action to emphasise teaching 'as comprehension and reasoning, as transformation and reflection' (p. 13). Shulman's model of pedagogical reasoning and action gives useful insight into how the content is transformed for teaching (Table 1).

Table 1. Shulman's Model of Pedagogical Reasoning and Action (1987, p.15)

Reasoning	Action
Comprehension	Understanding the content, purposes, both within and outside the discipline
Transformation	Preparation – analysis of text, clarification of purposes Representations – repertoire of strategies available: metaphors, explanations, demonstrations Selection – choices of strategies Adaptation – tailoring to students' needs -background, gender, interests, grade
Instruction	Active teaching
Evaluation	Checking for students' understandings Evaluating own teaching
Reflection	Reviewing, re-enacting, critically analysing own's performance
New comprehensions	Consolidation of new understandings, and learnings from experience

The idea of PCK, generated by Shulman, has been widely explored in research. Its attribute of the knowledge base ‘uniquely to the province of teachers, their own special form of professional understanding’ was useful for exploring the complexities of teaching, especially in science (Shulman, 1987, p. 8). Many other scholars elaborate further on Shulman’s PCK concept as the knowledge base for teaching.

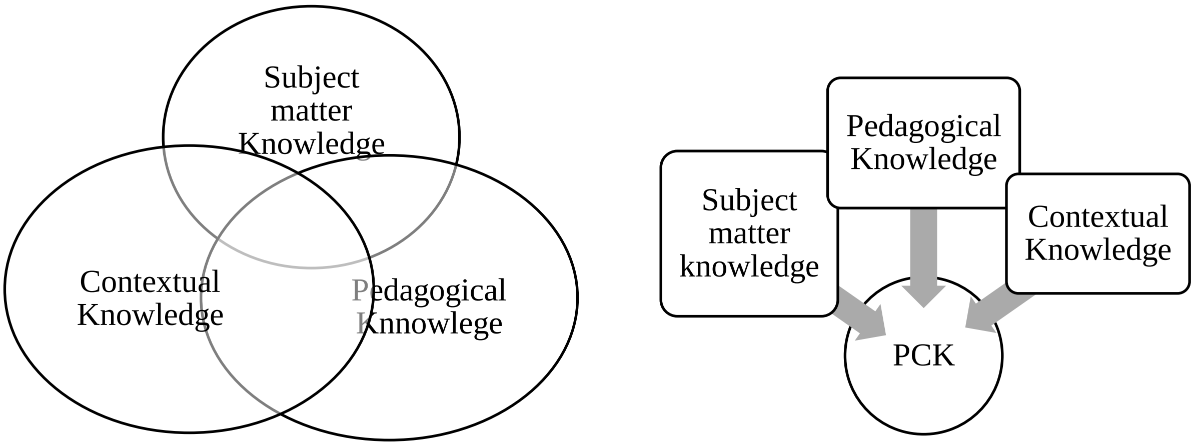
Tamir (1988) includes *Knowledge of Curriculum, Knowledge of Learners, Instruction,* and a new distinct category of knowledge namely *Evaluation* and makes a distinction between knowledge and skill for each category of knowledge or component comprising PCK (e.g., for the component *Knowledge of Learners,* Tamir adds both the knowledge about students’ misconceptions and diagnostic skills needed to assess students’ learning conceptual difficulties of the topic taught).

Grossman (1990) adds *Conceptions of Purposes for Teaching Subject Matter* and provides four sources for PCK components development: education courses for subject matter knowledge, conceptions of teaching the discipline, observation of classes, and classroom teaching experiences.

Cochran, DeRuiter and King (1993) replace the concept of PCK with Pedagogical Content Knowing (PCKg) to place more emphasis on knowing and understanding as active /dynamic processes. Their model includes four categories of knowledge: content knowledge, pedagogical knowledge, knowledge of students and knowledge of the environmental context. The four categories are viewed integrated rather than separated and develop simultaneously and not necessarily in a uniform matter.

Gess-Newsome (1999), reviewing the literature on PCK conceptualisation, identifies two extreme models of PCK: integrative and transformative (Figure 3). The integrative models view the subject matter as a component of PCK. The models integrate knowledge across three domains: subject matter, pedagogy, and context.

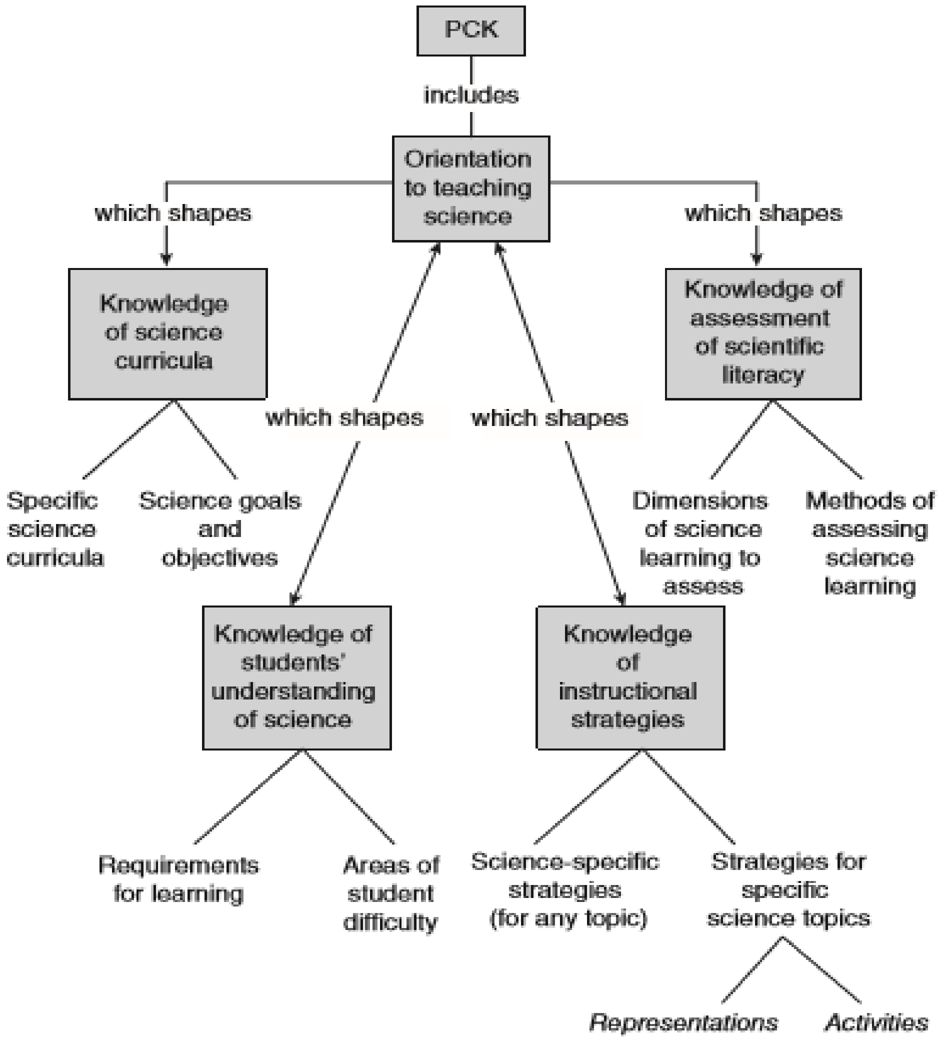
Figure 3. Integrative (a) and transformative (b) models of PCK (Gess-Newsome 1999, p.12)



Teachers select and integrate knowledge from these three separate domains in the process of teaching in the classroom. In transformative models, as per Shulman's, the subject matter is viewed as a separate component. The three domains, subject matter, pedagogy, and context are combined into a new form of knowledge - the only form of knowledge that impacts teaching practice.

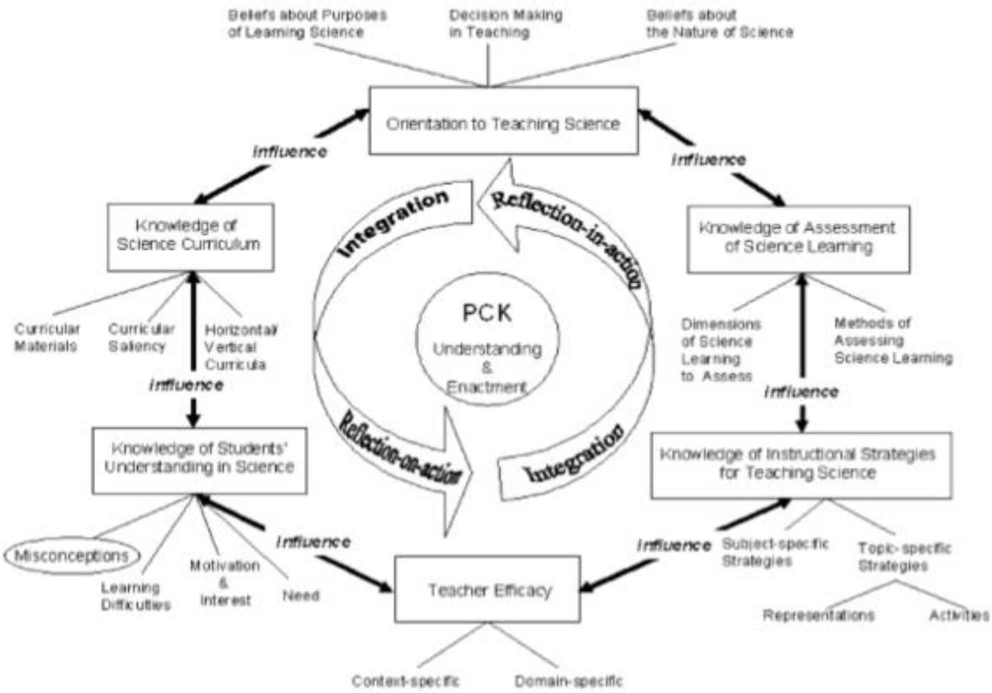
The most widely used transformative model of PCK is developed by Magnusson, Krajcik and Borko (1999) (Figure 4). The model draws on Grossman's (1990) and Tamir's (1988) work and includes five components of pedagogical content knowledge for teaching science: orientations toward science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge, and beliefs about assessment in science, and knowledge and beliefs about instructional strategies for teaching science. Magnusson, Krajcik and Borko (1999), by assigning specific subcomponents to each component, gives more clarity to the model, making it easier to apply in practice.

Figure 4. Magnusson, Krajcik and Borko's model for PCK (1999, p. 99)



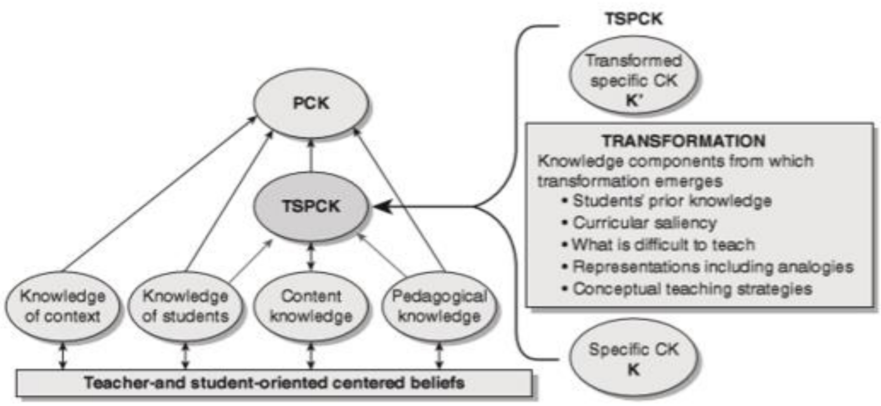
Park and Oliver (2008) draw on Grossman's (1990), Tamir's (1988) and Magnusson, Krajcik and Borko's **(**1999) work to design a pentagon transformative PCK model (Figure 5). The model acknowledges the importance of both teachers' understanding and enactment within a given context of practice. The model contains subcomponents as potential sources within an instructional setting. Later, the authors extend the model to a hexagonal to include teacher efficacy.

Figure 5. Park and Oliver's hexagon model of PCK (2008, p. 279)



Influenced by mathematical content knowledge for teaching model elaborated by Ball, Thames, and Phelps (2008), Mavhunga (2012 in Rollnik and Mavhunga, 2015) elaborate more on Topic-Specific Pedagogical Content Knowledge (TSPCK) placing it between PCK and Content Knowledge (Figure 6).

Figure 6. Mavhunga's model of Topic Specific PCK (2012, in Rollnick and Mavhunga 2015, p. 140)

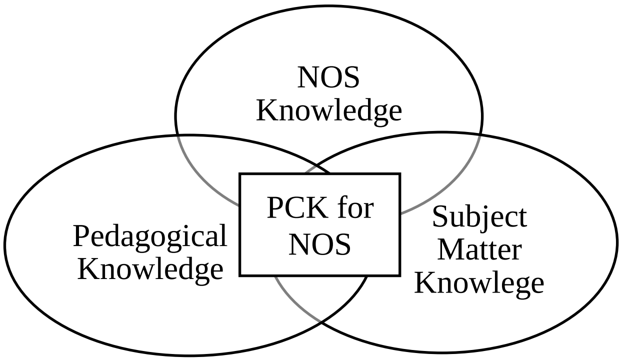


According to the model, the content knowledge is transformed through five components: - learners' prior knowledge, including misconceptions; - curricular saliency; -what makes the topic easy or difficult to understand; - representations, including powerful examples and analogies; - and conceptual teaching strategies (Rollnick and Mavhunga, 2015).

Apart from the PCK models presented above, there are many other models both in science and other disciplines. Other models and clarifications on PCK are addressed in a review on PCK models carried out by Kind (2009). Based on the PCK models, other scholars developed models of PCK for Nature of Science (NOS) (Schwartz and Lederman, 2002; Abd-El-Khalick, 2012) or modified existing PCK models (Hanuscin, Lee and Akerson, 2011). Nature of Science (NOS) refers to the epistemology and sociology of science - science as a way of knowing or the values and beliefs inherent to scientific knowledge (Abd-El-Khalick and Lederman, 2000). In simpler terms, nature of science is about what science is and how it works, or as Matthews (1998) points out, it is 'the ability to distinguish good science from parodies and pseudoscience' (p. 163). Nature of Science is seen as a science topic, with many advocating the introduction of NOS as a goal of science teaching (McComas, 2017). The arguments reside in the potential of NOS to enhance students' learning. First, by learning about NOS, it is argued that students can develop dynamic rather than static views of science. Second, understanding of how science works enables students to evaluate the strengths and limitations of science (McComas, 2017).

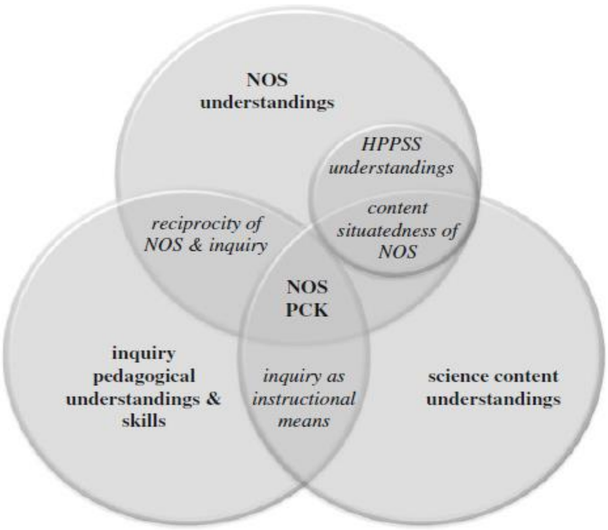
Schwartz and Lederman (2002) propose a model of PCK for NOS representing a blending between Subject Matter Knowledge (SMK), NOS knowledge, and Pedagogical Knowledge (PK) (Figure 7). The authors complement the model with other components such as teachers' beliefs and intentions. Beliefs are defined as teachers' beliefs in their abilities to teach about the nature of science (NOS teaching self-efficacy) and students' ability to learn about the nature of science (outcome expectancy). Intentions refer to teachers purposefully planning to teach about nature of science as an instructional learning goal.

Figure 7. Schwartz and Lederman's model of PCK for NOS (2002)



Abd-El-Khalick (2012) proposes and describes a model of PCK for Nature of Science or NOS PCK with three domains and sub-domains that intersect with each other (Figure 8). The three domains are considered necessary and enough to enable teaching with and about NOS. Teachers' science content understandings represents the first domain: deep and integrated understandings of science content enable teachers to better implement effective NOS instruction.

Figure 8. PCK NOS model (Abd-El-Khalick, 2012, p. 2101)



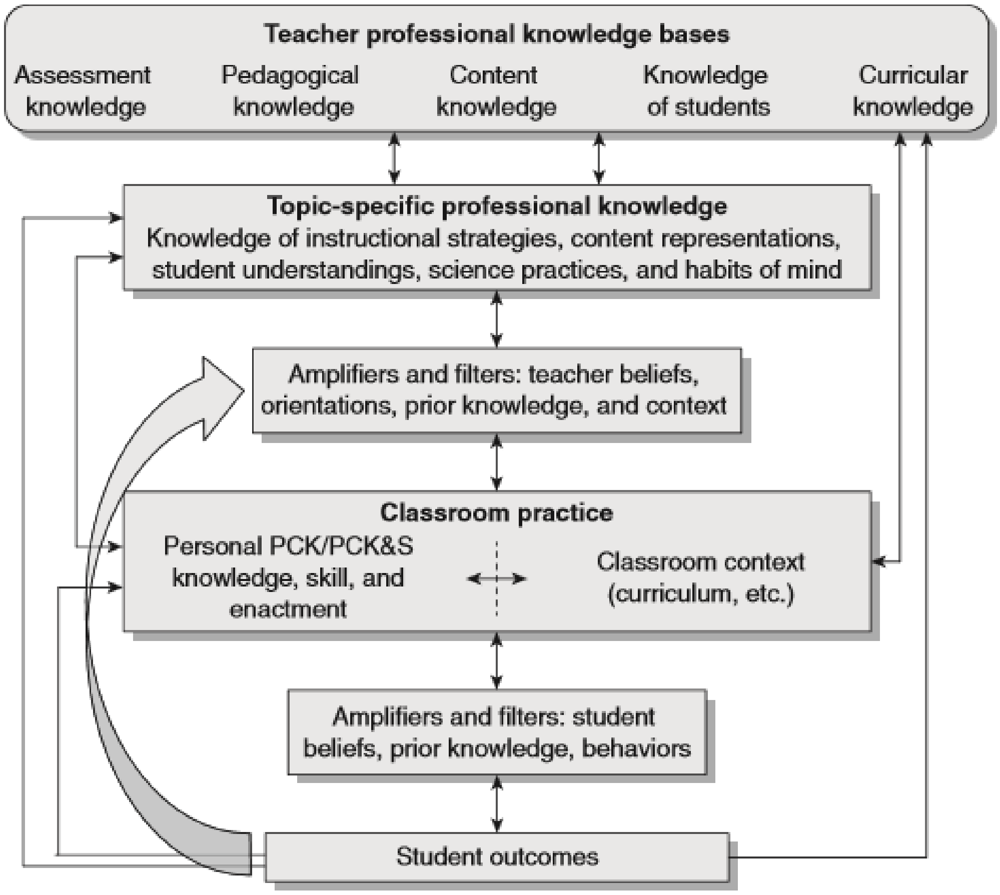
The second domain is a set of pedagogical understandings and skills related to enacting student centred and inquiry teaching, and appreciating, assessing, and monitoring changes in students' conceptions of NOS. The third dimension is related to teachers' NOS understandings for teaching about NOS (Abd-El-Khalick, 2012).

In a digital world, it is difficult to imagine teaching and learning without technology. Mishra and Koehler (2006) notice that, in the last two decades, technology has become more transparent in educational settings. Inspired by Shulman's PCK, the authors developed a technology-based model namely, Technological Pedagogical Content Knowledge (TPCK). The TPCK model shows an interplay between and among three categories of knowledge: Technological Knowledge (TK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK). TPCK goes beyond the above three categories of knowledge, being central to teachers' work with technology. Following Shulman's thought on PCK, Mishra and Koehler (2006) explain that TPCK lays at the heart of good teaching with technology. It requires

'an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones' (Mishra and Koehler, 2006, p. 1029).

Efforts to advance and clarify PCK conceptualisation generate a new model - *Teacher Professional Knowledge and Skill* (TPK&S) (2015) - Figure 9. The new model resembles a complex version of all the models combined (Gess-Newsome, 2015; Kind, 2015). The model includes a new category of knowledge - *Topic-Specific Professional Knowledge* (TSPK) - implying that the content for teaching occurs at topic level.

Figure 9. Consensus Model for PCK -Teacher Professional Knowledge and Skill (Gess-Newsome 2015, p. 31)



Orientations for teaching together with other components, such as beliefs and efficacy, are placed into a separate category - *Amplifiers and Filters*, as mediators of teachers' actions and choices in the classroom. According to the authors, the uniqueness of the model lays in that it comprises both the knowledge base (the public or canonical knowledge) and the skill (the act of teaching or personal PCK) (Gess-Newsome, 2015). Gess-Newsome (2015) contends that the model makes more sense for classroom context as it differentiates between what teachers know and what they can do. For example, because of the amplifiers and filters, a teacher may know the knowledge but he or she may not apply it in practice. Likewise, teachers may not have mastered the skill of teaching to apply the knowledge in practice.

Because of its integrative nature and distinction between knowledge and skills, the Consensus Model for PCK seemed more appropriate for the present study. The model is more aligned with the aim of the present study that seeks to enhance initial teachers' development rather than to be used for assessment purposes (Gess-Newsome, 2015). It defines more explicitly both public (Teacher Professional Knowledge Bases - TPKB and Topic Specific Professional Knowledge-TSPK) and personal knowledge (PCK), allowing for targeting learning opportunities for teachers to develop the types of knowledge they need to apply in practice. The application of the model to this study is explained later in this chapter.

Having outlined some of the PCK models, a description of the PCK components would give more understanding of why PCK still 'remains a useful idea' (Abell, 2008, p.1413). I describe next, the most used categories of knowledge and three amplifiers from the Teacher Professional Knowledge and Skill (TPK&S) model chosen for this study.

3.1.2 PCK Components

Knowledge of Students' Understandings of Science

Knowledge about students' understanding of science is prerequisite to developing students' scientific knowledge (Magnusson, Krajcik and Borko, 1999). Science teachers need to know about students' abilities and skills for learning a particular topic, about learning difficulties and misconceptions students might have with respect to a particular topic, and about their motivation, prior knowledge, interests, and needs (Park and Oliver, 2008; Smith and Banilower, 2015). Research finds that not always teachers are aware of students' misconceptions and how these affect their learning. For example, Larkin (2012) found that students' ideas were perceived by initial teachers as evidence of content coverage, as obstacles to understanding, as tool for eliciting students' thinking, interest and activity or as raw material for learning, rather than as resources for learning. Yet, it is not enough for teachers to be aware of students' misconceptions. They need strategies to overcome them. The preconceptions or misconceptions students bring into the classroom are strongly influenced by their previous experiences outside the school (family influences), their background and culture in which they live (Archer et al., 2015; King et al., 2015). Archer et al. (2015) develop the notion of 'science capital' to include the influential factors on students' motivation, interest, and participation in science (p. 922). The authors find that science related resources (cultural and social) such as students' parents' scientific qualifications, participation in science-related activities outside of school, and students' science aspirations, contribute to students' science capital (DeWitt, Archer and Osborne; 2014; Archer et al., 2015).

Students come to school with different level of science capital that influence their learning. In a survey conducted with secondary school children in England, Archer et al. (2015) found that only a low percent of students possessed high science capital. The authors suggest that many students' preconceptions may have deep roots and be resistant to change. To be able to use students' misconceptions as resources for learning, teachers must challenge and anticipate students' initial understandings. They need to identify their science capital they bring in the classroom (Archer et al., 2015). In other words, teachers need to identify the source of students' misconceptions and beliefs that may hinder their motivation and/or participation in science. Therefore, a reflection on multiculturality and diversity of students' social class is important.

Knowledge of Science Curriculum

Curriculum knowledge includes teachers' knowledge about goals and objectives, curricular programmes, and curricular materials (Magnusson, Krajcik and Borko, 1999). Teachers need to know the goals and objectives for the students they teach in science, as well as to have knowledge of vertical (links within the topics) and horizontal (links with other topics and disciplines) curricula (Shulman, 1986). Knowledge about horizontal and vertical science curriculum (often referred to as curricular saliency) gives teachers insights into what students have learned in previous years and what they are expected to learn in later years (Grossman, 1990). Curricular saliency enables teachers to identify student' previous knowledge, select, modify, and adapt curricular materials, concepts, and teaching to meet the needs of their students (Magnusson, Krajcik and Borko, 1999; Park and Oliver, 2008; Rollnick and Mavhunga, 2015). Curriculum knowledge also includes knowledge of curricular materials for teaching a certain topic at a given level (e.g., National Science Curricula). Curricular materials guide teachers' practice in the sense that teachers plan the lessons, evaluate, adapt, and assess students according to the curricular materials available (Davis et al., 2011). Knowing what curricular programmes and materials are available and how to incorporate them into teaching it is recognised as an important aspect of PCK (Zembal, Starr and Krajcik, 1999).

Knowledge of Instructional Strategies

Knowledge of instructional strategies includes knowledge about science instructional strategies in a broader term and science topic instructional strategies (Magnusson, Krajcik and Borko, 1999). Magnusson, Krajcik and Borko (1999) acknowledge some science instructional strategies that teachers can use to approach science teaching such as learning cycle or problem-based learning. Topic specific instructional strategies are strategies that facilitate students' learning. Such strategies are representations, demonstrations, explanations, analogies, and models. Teacher's ability to use appropriate instructional strategies depends upon their knowledge of subject matter, pedagogy, and context as well as understandings of learners. Research shows that teachers possess a richer repertoire of instructional strategies as they develop more sophisticated PCK.

Knowledge of Assessment

First proposed by Tamir (1988), knowledge of assessment of science learning is teachers' knowledge about what is important to assess and about methods of assessment. It also includes knowledge about advantages and disadvantages of a particular method of assessment (Magnusson, Krajcik and Borko, 1999). Zembal-Saul, Starr and Krajcik (1999) state that teachers must have the ability to check students' understandings through probing questions during instruction. Magnusson, Krajcik and Borko (1999) also suggest a variety of assessment methods that can be implemented in teaching science such as tests created by teachers or products created by students (e.g., journal entries, written laboratory reports and artefacts such as drawings, working models, or multi-media documents).

Knowledge of Content

Content knowledge is not a component in PCK recent conceptualisations/models. Yet, it is hugely recognised as a prerequisite for PCK development (Shulman, 1986). Content knowledge is the knowledge from the area of science. It is subject and topic specific. Since the content knowledge has been brought into public debate by Shulman, it has been constantly outlined in science reform policies (DfE, 2011; 2016a). Teachers are required to have deep content knowledge and ability to make the content understandable to students. The emphasis on content supports a strong conceptual knowledge and understanding of the topic.

This in turn leads to teachers' ability to make connections to other topics and easily draw upon this knowledge in teaching.

Orientations to Teaching Science

Orientations refers to teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level (Grossman, 1990; Magnusson, Krajcik and Borko, 1999). Teachers' orientations act as filters and guide decisions in the classroom regarding the use of curriculum materials, instructional strategies, and assessment (Magnusson, Krajcik and Borko, 1999; Park and Oliver, 2008; Gess-Newsome, 2015). Teachers were found to hold multiple and different orientations for practice (Magnusson, Krajcik and Borko, 1999; Friedrichsen and Dana, 2005). For this reason, it has been argued that teachers' orientations are difficult to study (Friedrichsen and Dana, 2005). Magnusson, Krajcik and Borko (1999) identify and describe nine orientations to teaching science: 'process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry' (p.100). In their review, Friedrichsen, Driel and Abell (2011) notice unclarity in conceptualisation of orientations and propose defining science teaching orientations as a set of beliefs on three domains: beliefs about the goals and purposes of science teaching, beliefs about the nature of science and beliefs about science teaching and learning.

Knowledge of Context

It is widely agreed that PCK is context dependent (Loughran, Mulhall and Berry, 2004; Abel, 2007; Friedrichsen and Berry, 2015; Gess-Newsome, 2015). Therefore, knowledge of context is critical to teaching success (Zembal-Saul, Starr and Krajcik, 1999). Although omitted in Shulman's model of PCK, the context is highlighted in the recent

Consensus Model of PCK - TPK&S. The most recent model of PCK makes the distinction between public (canonical) and personal PCK. Canonical knowledge is represented as context free, relatively static, visible, and clearly identified as a knowledge base. Personal knowledge is embodied in the classroom context, is more dynamic and mostly tacit and thus, more difficult to describe and assess (Gess-Newsome, 2015).

Gess-Newsome (2015) acknowledges some contextual features that influence teachers' instructional decisions in the classroom: curriculum materials, resources, support available, the amount of planning time available, responsibilities outside the classroom, class size, students' background, political and cultural influences. Given the importance of the context for teaching, Hofstein, Eilks and Bybee (2011) recommend that teachers need to experience context-based approach to teaching during their initial teacher training programme. Such approach will help them to anticipate the contextual complexities of real-life classroom and to adapt and link teaching with real life situations or problems (Guskey and Yoon 2009). It is assumed that exposing initial teachers to such approaches, their existing beliefs and practices will be challenged. As a result, they will feel more prepared and more confident to teach.

Teacher Efficacy

Self-efficacy or teacher efficacy is teachers' confidence in their capabilities to teach. Teacher efficacy emerged as an affective component from Park and Oliver's (2008) conceptualisation of PCK. Park and Oliver (2008) show that self-efficacy directly influence teachers' enactment of their understandings. In their study, the authors noticed that when the enactment was successfully performed, teacher efficacy was in turn increased. In the consensus model of PCK (Teacher Professional Knowledge and Skill - TPK&S) self-efficacy is included in the Amplifiers and Filters category (Gess-Newsome, 2015). Self- efficacy acts as a filter or amplifier between knowledge and practice. It influences what teachers learn, what strategies they choose and what decisions they make (Gess-Newsome, 2015). In other words, self-efficacy is teachers' motivation which guides their teaching activities they wish to perform or avoid (Bandura, 1977; Guerriero, 2017). As a concept, self-efficacy derives from Bandura's (1999) socio-cognitive theory detailed more in the following sections of this chapter.

Magnusson, Krajcik and Borko (1999) highlight two aspects regarding PCK components that are worth mentioning. First, within each component, teachers develop specific knowledge which may be different across topics. For instance, teachers need to develop knowledge in all the components of PCK for each topic to be taught. Second, the components function as parts of a whole and they interact in highly complex ways. Therefore, increased knowledge of a single component may not be sufficient to change practice. These aspects have relevance in the context of measuring teachers' PCK. For a long time, educators and researchers have looked for effective ways to measure teachers' PCK components. Due to the variation and confusion in PCK components, capturing and measuring teachers' PCK has proved to be difficult. Some issues with PCK measurement and available measuring tools are communicated in the following section.

3.2 Capturing and Assessing Teachers' PCK

The attempts to capture and assess teachers' PCK revealed the complexity in conceptualisation and interpretation of the concept (Kind, 2009; Park et al., 2011). Scholars (e.g., Kagan, 1990; Baxter and Lederman, 2002) view PCK as an internal construct which cannot be directly observed as it is often held unconsciously, and teachers do not always possess the language to express their thoughts and beliefs. For this reason, PCK has a tacit nature (Kind, 2015; Henze and Driel, 2015). A further criticism of PCK has been that it is not sufficiently clear about its components (Neumann, Kind and Harms, 2018). All these issues on PCK conceptualisation have consequences on teachers' awareness of and ability to recognise and articulate PCK knowledge (Loughran, Mulhall and Berry, 2004). Teachers' ability to enact their knowledge and understandings in practice is important in the light of Teachers' Standards that measure their level of performance. Sickel et al. (2015) indicate that teachers find it difficult working towards high levels of performance without pedagogical tools. Attempts to develop pedagogical tools are made by Loughran, Mulhall and Berry (2004). The authors develop Content Representation (CoRe) and Professional and Pedagogical experience Repertoire (PaP-eR), instruments which contain components aligned with Teachers' Standards (Sickel et al., 2015).

Content Representations (CoRe) and Professional and Pedagogical Experience Repertoire (PaP-eR)

Content Representation (CoRe) and Professional and Pedagogical experience Repertoire (PaP-eR) are pedagogical tools for capturing and articulating teachers' PCK (Table 2). The tools help teachers to gain insight into the complex nature of learning about teaching. Loughran, Mulhall and Berry (2008) notice that, because of PCK's tacit nature, teachers find it difficult to access its knowledge when observing teaching in their school placements. CoRe and PaP-eR tools provide teachers with a common language and give them the opportunity to access the experienced science teachers' thinking and reasoning on teaching (Loughran, Berry and Mulhall, 2012). What makes CoRe effective is that it is based on 'big ideas' of a given topic for a particular grade level (Loughran, Mulhall and Berry, 2004, p. 376). Big Ideas are learning outcomes that teachers consider important for students' understandings of the topic. CoRe template has different questions and prompts that 'unpack' the big ideas with the purpose to make the content explicit (Loughran, Mulhall and Berry, 2004, p. 376).

Table 2. CoRe (Content Representation) and associated PaP-eRs (Pedagogical and Professional Experience Repertoires) (Loughran, Mulhall and Berry, 2004, p. 376)

Prompts	Big Idea 1	Big Idea 2	Big Idea 3
What do you intend students to learn about this idea?			
Why is it important for students to know this?			
What else might you know about this idea that you don't intend students to know yet?			
Difficulties or limitations connected with teaching this idea?			
What do you know about student thinking about this idea?			
What other factors influence your teaching of this idea?			
What instructional strategies will you use and why?			
How will you monitor student understanding or confusion around this idea?			

PaP-eR

PaP-eR

On the other hand, PaP-eR is a narrative account of a teacher's PCK associated to CoRe. Loughran, Berry and Mulhall (2012) define it 'accounts of practice that are intended to offer windows into aspects of the CoRe'(p.28). PaPeR provides more details upon a particular aspect of science content to be taught. It unpacks a teacher's thinking and reasoning about a particular aspect of PCK (Loughran, Berry and Mulhall, 2012).

CoRe and PaPeR focus attention from simple delivery to conceptual understanding of the content for teaching. Moreover, the authors declare that its design challenges teachers' thinking about what is important in teaching a particular topic and why, acting as a trigger to improvement and development. The authors further suggest that the tools help teachers to develop a constructivist view of teaching. This is important since a constructivist way of teaching was found to be incompatible with many teachers' existing knowledge and beliefs about teaching and learning science (Magnusson, Krajcik and Borko, 1999). Teachers' knowledge and beliefs are important resources and constraints on change because they act as filters or amplifiers through which they come to understand the components of PCK (Magnusson, Krajcik and Borko, 1999; Gess-Newsome, 2015). Therefore, tools like CoRe may help teachers to challenge their prior knowledge and beliefs (Loughran, Berry and Mulhall, 2012).

More recently, other PCK instruments to measure teachers' knowledge are developed. For example, some authors develop PCK rubrics (Park and Oliver, 2008; Kind and Chan, 2019). Kind and Chan (2019) develop PCK rubrics potentially applicable to a range of science topics and levels of teacher experience, especially as support for out-of-field teachers. Gess-Newsome et al. (2019) develop an instrument to capture and measure teachers' gains in knowledge and skills, applicable to written reflections, interview reflections and videorecorded classroom observations. However, because of issues with clarity on PCK conceptualisation, the measurements pose some limitations (Park and Oliver, 2008). For example, the rubrics developed by Park and Oliver (2008) focus only on two PCK components, and although the authors recognised that PCK is topic and context specific, the rubrics are used across the topics. Therefore, further research is needed to check for its relevance to practice.

From another perspective, teacher educators and researchers have been interested to know how teachers develop PCK (Hammerness et al., 2005). Commonly, PCK is seen as a 'life-long learning' and cannot be developed over a short time education programme (Osborne, 2014, p. 192). Instead, it is important that teachers are supported in developing their foundation for teaching rather than a whole 'edifice' that requires continuous learning (Osborne, 2014, p.192) which sustains adaptive expertise (Hammerness et al., 2005). Hammerness et al. (2005) stress the emphasis on procedural knowledge (knowing why and how) rather than on how a beginner teacher is different from a teacher expert. Adaptive expertise is explored through the lens of Berliner's (2001) theory of teacher's development in the following section.

3.3 Factors that Shape Science Teachers' PCK

PCK is often associated with expertise in teaching. Many times, experienced teachers are thought of as experts or having sophisticated PCK. Yet, scholars acknowledge that expertise in teaching is not the same with accumulating knowledge or experience (Berliner, 2001; Kind, 2009). Berliner (2001) identifies thirteen features of a teacher expert that reassemble the components of PCK. Among these features, the author mentions a deep representation of subject matter knowledge, better adaptation and modification of goals for diverse learners, better ability to read the cues from students, greater sensitivity to context and more autonomy in choosing the content and pedagogy in their domain of expertise.

Gess-Newsome (1999) posits that an expert teacher has well-organized individual knowledge bases that are easily accessed and flexibly drawn upon during teaching. Expert teachers were found to move smoothly from one knowledge base to another, giving the appearance of a single knowledge base for teaching. When things are going smoothly, expert teachers rarely appear to be reflective about their own teaching (Berliner, 1994; Guerriero, 2017).

In a review on deeper learning and transfer of knowledge, Pellegrino and Hilton (2012) comment that deep learning means not only the development of well-organized knowledge in a domain, but also the knowledge can be readily retrieved to apply (transfer) to a new context. Though, from Berliner's (1994) perspective, expertise is context and domain dependent. In his study, Berliner (1994) found that experienced teachers failed to teach successfully when taken out of their classroom context. The study shows that teachers' knowledge expertise is situated and not automatically transferable across contexts. The author finds that experts rarely enter their classrooms without having sufficient time to understand the content to be taught and plan one or more activities for teaching that content. However, whilst transferring knowledge across contexts links more to teachers who already possess well-developed PCK, good mental organization of knowledge helps teachers to develop their planning and teaching skills during their training programmes.

How does a science teacher can develop expertise in teaching? The variety of models of PCK do not explain how teachers can develop the knowledge base for teaching. The model of teacher development described by Berliner (1988) provides a useful insight in this matter. The theory gives insight into how teachers move through stages of development starting from the initial stage, that of a novice. In a comparative study of teachers' stages of development, Berliner (1988) finds that, at the beginning, teachers think more pragmatically, are more inflexible, and tend to conform to rules and procedures. This is the stage for gaining experience when they need to be taught context-free knowledge and skills. The models of

PCK are very useful in providing teachers with this kind of ’knowing what’ rather than ’knowing how’ knowledge (Guerriero, 2017, p. 103).

In the Consensus Model of PCK, the context free knowledge is the canonical or public knowledge: the knowledge elaborated by experts and used by teachers. Once teachers have the basics, they move to the next stage of advanced beginner when context begins to guide behaviour - knowing when and how to use a particular instructional strategy. This is followed by the competent **s**tage when teachers make conscious choices about what they are going to do. It is the stage at which teachers can determine what is and what is not important, they have more control of the events around them and are more autonomous. The next is the proficient stage at which intuition or ‘know-how’ becomes prominent. The last stage is the expert one. Berliner states that not all teachers reach this stage. Some will stay in the proficient stage where they become routinised, bored or tired. To reach the expert stage they need further challenges. The expert stage, described earlier, is the stage in which teachers act automatically without thinking. Because of this automatism, they are found to have difficulties in unpacking and describing their own performance or PCK (Kagan, 1992a). For this reason, Kagan (1992) argues, expert teachers are better models that mentors.

Berliner’s theory of teacher development finds support in more recent developments on theories of learning, such as cognitive neuroscience theory. Cognitive neuroscience involves the knowledge of the brain. The brain possesses a plasticity which is its capacity to change its structure and function because of experience (Schunk, 2013). In his book, Schunk (2013) explains how learning takes place through forming and strengthening neural connections in stages. The first stage, namely consolidation, is like the advanced beginner stage in Berliner’s model when the connections between neurons are not made automatically. With repetition (experience), these connections increase in number and become strengthened.

As a result, they occur more automatically and make teachers to quicker retrieve and apply the relevant knowledge to new situations (Schunk, 2013). It is thus apparent that practice and experience are critical for learning. Yet, a lot of other factors influence teachers' development of PCK.

Research suggests that a sophisticated PCK only develops over time through motivation, practice, and experience (Bishop and Denley, 2007). Besides, there is not a short and one single linear path towards developing a sophisticated PCK (Berliner 1988; 2001; 2004; Magnusson, Krajcik and Borko, 1999). It is widely agreed that this process is ongoing and challenging (Osborne, 2014; Gess-Newsome et al., 2019). Numerous factors influence teachers' PCK development throughout their journey towards expertise. These factors are explored next.

3.3.1 Prior Beliefs and Experiences

According to Bandura (1999), individuals possess a self-system that mediates between their behaviour and the environment. This self-system includes beliefs, expectations, self-perceptions, goals, and intentions that guide behaviour. Bandura (1999) highlights the belief system as foundation of human functioning stating that:

> 'Unless that people believe that they can produce desired effects by their actions they have little incentive to act or to persevere in face of difficulty' (Bandura, 1999, p.28)

Teachers' prior beliefs, practices and attitudes are often a concern for teacher educators because they were found to be resistant to change. Constantly, many scholars report on the stable nature of beliefs (Kagan, 1992b; Pajares, 1992; Wilson, 2012) and inconsistencies between teachers' beliefs and their practice (see the review by Davis, Petish and Smithey, 2006; Mansour, 2009; 2013). The inconsistences between beliefs and practice are attributed to conceptual and measurement issues, contextual factors, lack of relevant knowledge, resistance to certain innovative practices, and teacher education programmes that, according to the above authors, perpetuates the traditional view of teaching and learning leaving teachers' beliefs and knowledge unaffected.

From a sociological perspective, this set of predetermined beliefs is called habitus, a concept developed by Bourdieu (1977, in Reay, 2004). Habitus is a set of internal, durable dispositions which predispose people to behave in ways that reflect previous experiences or practices (Swartz, 2002; Reay, 2004). With the shift towards constructivist approaches to teaching and learning, researchers found that many new teachers only experienced teaching within a traditional approach framed by behavioural principles (Smith, 2005). Therefore, they have been noticed to have the tendency 'to teach as they were taught' (Lortie, 1975; Smith, 2005). This is explained, in the literature, by Lortie's model of apprenticeship of observation. During their schooling, teachers develop well established perceptions about what teaching involves and what is a good teaching from a pupil perspective, not from the perspective of a teacher. Students only observe teachers' actions and their influence on them as students; they do not have access to teachers' reasons for and reflections upon their actions (Mewborn and Tyminski, 2006). According to Lortie's (1975) model, teachers only imitate the types of instruction they observed as students. For instance, they contribute to a 'cycle of the authoritarian approaches to classroom instruction' (Smagorinsky and Barnes, 2014, p.31). Some authors notice that teaching and learning have not changed too much in the last decades (Russell and Bullock, 2010; Melville, Hardy and Bartley, 2011). Because of this, it is not surprising that new teachers will find in school the same routines and practices they are familiar with from their own schooling. In this familiar context, 'teachers teach how they were taught', perpetuating the status quo in the classrooms (Dillon and O'Connor, 2010; Oleson and Hora, 2014, p. 30).

From another perspective, Hutner and Markman (2016; 2017) explain the lack of congruence between beliefs and practice through a goal-driven approach. In their view, beliefs, knowledge, and goals are distinctive, and behaviour is driven by goals rather than by beliefs and knowledge. The authors view beliefs and knowledge as truth that teachers hold, and goals as desired actions or future outcomes teachers hope to achieve or avoid. From beliefs and knowledge perspective, teachers apply in practice only those strategies which they know and believe in. From a goal driven perspective, teachers may know about and believe in a particular strategy (e.g., inquiry) but may not have the goal to use it in practice (Hutner and Markman, 2016; 2017; Hutner, Petrosino and Salinas, 2019). The authors introduce the idea of activation of goals meaning that only active goals influence teachers' action. From this perspective, science teachers' instructional practice is an attempt to achieve one or more of their goals. For example, science teachers who use traditional teaching may feel that this approach is more appropriate for students to learn the content. At the same time, they want to meet other goals such as improving tests scores (Hutner and Markman, 2016). In their study, Hutner, Petrosino and Salinas (2019) found that the lack of alignment between teachers' classroom practice and teaching practices, emphasised in education programmes, was due to a lack of goal adoption and/or goal conflict. Goal conflict appears when teachers must prioritize one goal over another. For example, a teacher may have the goals to maintain students' safety in a lab and to have students conduct a practical involving toxic substances. These two goals may be in conflict because one goal cancels the other (Hutner and Markman, 2016). The commonality between beliefs and goals lays in that both are mental motivational constructs that guide teachers' actions.

Fives and Buehl (2012), reviewing studies on teachers' beliefs, uncover three functions of the beliefs: beliefs as guide for action, as filters for interpretation and as frameworks for decision-making. The beliefs as guide for action are motivational beliefs considered by Bandura (1977; 1999; 2005) the most influential of all, as they are predictors of individual behaviour, of the choices and decisions they make throughout their lives. These beliefs are called self-efficacy beliefs. Tschannen-Moran, Hoy and Hoy (1998) conceptualise efficacy beliefs for teachers as:

> …teachers' judgments of their capability to organize and execute courses of action required to successfully accomplish a specific teaching task in a particular context Tschannen-Moran, Hoy and Hoy, 1998, p. 233).

Research finds that teachers' confidence in their ability to perform a teaching task is a predictor of their practice and students' outcomes (Woolfolk and Hoy, 1990; Ross, 1994; Pajares, 1996; Tschannen-Moran and Hoy, 2001). Evidence from research shows that teachers' self-efficacy is associated with their effectiveness (see for example the metanalysis carried out by Klassen and Tze, 2014). Garvis and Pendergast (2016), in their book, report on studies that found teachers with strong self-efficacy beliefs to be more committed to teaching, more enthusiastic, more perseverant, more willing to try innovative ideas, and happier with their job. Bandura identifies four sources for self-efficacy development: mastery experiences, vicarious experiences, social persuasion, and psychological arousal.

3.3.2 Mastery Experiences

Successful experiences or mastery experiences are the most powerful source for enhancing teachers' efficacy beliefs (Bandura, 1977; 1999). Based on Bandura's view, when teachers perceive that a teaching task has been successful, their efficacy beliefs increase which in turn raises their expectation of successful teaching in the future. On the other hand, the perception that teaching has been a failure, lowers efficacy beliefs, which contributes to the expectation that future teaching will also be unsuccessful. Therefore, it is important for teachers to have opportunities to experience successful teaching. Though, Bandura warns that easy experiences only raise easy successes. Teachers may expect quick results and are easily discouraged by failure. For instance, teachers need to develop resilient efficacy. Resilient efficacy requires experience in overcoming obstacles through perseverant effort (Bandura, 1977).

3.3.3 Vicarious Experiences

Hammerness et al. (2005) declare that an important aspect of adaptive expertise is to learn from others. Others means more experienced teachers, experts, or even more knowledgeable peers (Vigotsky, 1978). To develop constructivist views of teaching and accumulate valuable science capital (Archer et al., 2015), it is important for teachers to have models of effective practices. As Lortie (1975, in Kagan, 1992a) states, initial teachers need models of good teaching if it is for them to be good models for their students. A concern related to observation of models has been that teachers do not have access to the models' reasoning; thus, they only adopt the practices observed (Mewborn and Tyminski, 2006; Loughran, 2013). As previously mentioned, Lortie (1975) notices that teachers' learning via observation is imitative rather than analytical. By imitation teachers contribute to the 'cultural transmission' of teaching practice (Lortie, 1975 in Mewborn and Tyminski, 2006, p.30).

Others (Ross, 1987 in Mewborn and Tyminski, 2006) show that teachers can select features of instruction from different models, blending them into new practices. The same perspective is found in Bandura' observational learning theory (Bandura, 1971; 1999). Through observational learning, teachers learn new behaviours, knowledge, and skills modelled by others. In Bandura's view, modelling is more than simple imitation. In observational learning, the models make visible the reasoning behind teaching so that teachers to develop a cognitive understanding about teaching. This is called by Bandura

(1989), ‘higher-level learning’, a powerful way to enhance teachers’ self-efficacy (p. 25). In cognitive modelling, teachers first observe the models explaining and demonstrating the instructional strategies (teaching). Next, they practice the skills receiving feedback from educators. By engaging in discussions and reflections about effective teaching, teachers may develop a better understanding of and align their teaching with student-centred approaches (Schunk, 2013).

Learning through observation or vicariously is also supported by neuroscience. Neuroscience studies discovered that the cortical circuits involved in performing an action respond when observing someone else performing that action (Schunk, 2013). Scholars (Evans et al., 2014) suggest that teachers must have opportunities to observe effective practices in multiple settings where the models demonstrate success using diverse strategies. This suggestion supports Bandura’s view according to, through exposure to different models of teaching, teachers may develop original and creative ways of teaching (different from what they observed). In observational learning, teachers deliberately choose what behaviours (skills, knowledge) to borrow from models, according to their own beliefs, prior knowledge, and outcome expectations (Bandura, 1971; 1977). They anticipate whether a modelled activity is relevant or not to their practice, based on their perceived capabilities to achieve the expected outcome (Bandura, 1977; Salkind, 2004). For instance, they only attend to models from who they can learn valuable skills in terms of knowledge, style of teaching, or way of thinking. Given the power of models in influencing science teachers’ development, teacher educators should make their pedagogical reasoning visible to give teachers access to the ‘what, how and why’ of teaching (Hammerness et al., 2005; Loughran, 2013, p.130).

3.3.4 Support (social, cognitive, affective)

A powerful source of support for developing self-efficacy is social persuasion. Social persuasion involves verbal input from others, such as peers and educators. The verbal input (feedback) serves to strengthen a person's belief that he or she possesses, the capability to achieve a desired level of performance (Bandura, 1977, 1993; Tschannen-Moran and McMaster, 2009). Social persuasion can provide information about the nature of teaching, gives encouragement and strategies to overcome challenges. Research finds that constructive feedback, focused on aspects requiring improvement, is more effective in developing the skills for teaching (Hattie and Timperley, 2007). Bandura (1971; 1977) suggests that self-efficacy is malleable early in learning and the support early in career could be critical to the development of teacher efficacy.

Vygotsky (1978) also points to some form of social and cognitive support through collaboration or social interactions. Vygotsky emphasises the guided and/or collaborative learning that helps in moving individuals beyond their zone of proximal development (ZPD). The concept of ZPD was developed by Vigotsky to address issues related to intelligence quotient (IQ) and IQ testing arguing that testing only measured the actual level of development or achievement rather than learners' potential for further development (Warford, 2011). Applied to teachers, the concept of ZPD means the difference between what teachers achieved and what they can achieve further with support from educators and more knowledgeable peers (Warford, 2011).

Warford (2011) coins the term of Zone of Proximal Teacher Development (ZPTD), which unlike ZPD that starts with mediation from others, ZPTD starts with teachers 'self-assistance', a reflection on their prior knowledge and beliefs (p. 253). At this stage, the author argues, teachers are supported with prompts from educators, to facilitate their reflection. At later and more advanced stages, internalisation, and repeated application of what has been learned leads to automatization of skills. Teachers can learn with mediated assistance through joint activities with a common goal such as analysis of teaching practices, role playing, microteaching, collaborative planning, discussions, and reflections (Warford, 2011).

3.3.5 Reflection

Reflection is commonly acknowledged as key in teacher learning, being emphasised in the PCK models (Shulman, 1986; Gess-Newsome, 2015). In teacher education, reflection is based on the work of Dewey (1933) and Schon (1983; 1987). Dewey emphasises reflective thinking whilst Schon reflection on and in action. For Dewey, reflective thinking involves a rigorous way of thinking that follows a circular process that begins with a problem to be solved or a particular uncertainty (Rodgers, 2002; Zeichner and Liston, 2013; Reale, 2016). Reflective thinking involves teachers in a process of searching, inquiring, and reasoning about why they are doing what they are doing (Zwozdiak-Myers, 2012). From another perspective, reflection is a set of attitudes (Rodgers, 2002; Zeichner and Liston, 2013). Dewey (1933) believes that attitudes guide reflection, open mindedness, responsibility, whole-heartedness, and directness, alongside skills of inquiry. These set of attitudes help teachers to continually reason on practice, to be open to new ways of seeing and understanding, reflect about unexpected outcomes of teaching, acknowledge the consequences of their actions, and adopt them, examine their own assumptions and beliefs, be curious and have desire for growth (Zeichner and Liston, 2013; Rodgers, 2020). For Dewey reflection is deliberate and intentional; it is a process of questioning the 'status quo' (Reale, 2016. p.7). Dewey argues for a balance between reflection and routine, between thought and action rather than continuing questioning of practice (Zeichner and Liston, 2013).

Schon (1983), on the other hand, views reflection as a way of knowing, an ability of teachers to respond effectively and intuitively in particular situation. From this perspective, teachers' behaviour is intuitive, spontaneous, and tacit, called knowing in action or reflection in action. This reflection in action occurs when, faced with a new situation, teachers can analyse what is taking place and change the course of action instantly. Reflection and action take place simultaneously. Also, reflection can occur before and after an action - and this is what Schon calls reflection-on-action. In teaching, reflection-on-action occurs before a lesson, during planning and thinking about the lesson, and after teaching when teachers think about what worked well or not. This kind of reflection in and on action is often found at experienced teachers who possess a richer repertoire of knowledge and skills (Zwozdiak-Myers, 2012). As initial teachers do not have yet a rich repertoire of knowledge and skills, Dewey's view of reflection is more relevant for teacher education programmes. Reale (2016) declares that reflection is a skill and like any other skill takes time to develop through practice until it can be mastered. With experience, reflection becomes automatic and unconscious like in experts (Berliner, 1988).

Starting from Dewey's assumption that teachers do not learn from experience, but from reflecting on experience, teachers need opportunities to practice reflection as a skill by learning from their experiences during their education programmes (Dewey, in Reale, 2016). In Reale's (2016) view, teachers try out teaching by doing, and by repeated teaching they learn how to teach. According to this view, experience is shaped by both action and reflection on action (Reale, 2016). Reale (2016) comments that, through reflection, teachers develop new ways of thinking which can improve practice because teachers engage in reflection deliberatively.

3.3.6 Social Participation

Lave and Wenger (1991), through their socio-cultural theory, explain the power of full social participation in the process of learning to teach. Teachers become who they are as they are learning through social interactions in practice as full participants (Lave and Wenger, 1991). Lave and Wenger (1991) describe learning as ‘an evolving form of membership’, meaning that practice and learning are underpinned by membership and social relations (p.53). Thus, the activities of learning can only be understood through social relations (Hodkinson and Hodkinson, 2004). When teachers enter a new context, they become ‘legitimate peripheral’ participants (Lave and Wenger, 1991, p. 29). This is relevant for this study in which the participants are newcomers to the teaching profession. As ‘peripheral’, they are not initially full participants in the school practice.

The theory offers insight into how teachers move from periphery towards full participation as they get more involved within the school culture. This understanding is important because, through participation in their school culture, the new teachers gain more access to information, resources, and other opportunities (Lave and Wenger, 1991). Though, Lave and Wenger (1991) argue that to become full participants teachers acquire certain beliefs and behaviours. Beginner teachers need to learn the discourse of practice, ‘how to think, act and speak (and be silent) in the manner of full participants’ (p. 105). Through full participation and social engagement, learning becomes, ‘a joint enterprise’ (Fullan and Hargreaves (1996, p. 61). Fullan and Hargreaves (1996) stress the importance of collaboration in the process of teaching and planning for improvement, as through collaboration, the participants willingly share their tacit knowledge and expertise.

All the factors briefly described above are relevant to this study as trainee teachers need to be aware of the characteristics needed for developing adaptive expertise. Adaptive expertise helps them to teach effective within the pressures in their schools. As scholars suggest (Hammerness et al., 2005; Menter, 2016), trainee teachers need to understand the reasons for the constraints and to find ways to teach effectively within them. I explain next the conceptual framework applied to the study.

3.4 The Theoretical Framework Applied to the Study

The theoretical framework, on which initially the study was based, consists of Topic Professional Knowledge and Skills (TPK&S) framework (Gess Newsome, 2015) and a range of teaching and learning theories previously discussed in this chapter. The study is in alignment with views according to, PCK is a transformative process in which the components are separated but integrated. The study also took Woolfolk Hoy, Davis, and Anderman's (2013) view that learning to teach is a complex process and there is not a single best explanation of learning. PCK models are based on a constructivist approach to learning. Often, PCK models are criticised for being too generic and not being related to teachers' practice (Kind, 2015, p. 204).

It can be seen from the PCK models (Table 3) that different scholars attempted to clarify PCK conceptualisation focusing on different aspects of teacher knowledge (different components included in PCK). Though, all the models agree with Shulman' s definition of transformation of content into forms understandable to students and view the components as a combination between content and pedagogy or other knowledge components for teaching. Magnusson, Krajcik and Borko (1999) suggest that any attempt to clarify a PCK component is a matter of focus, and no model should be considered the right one.

Table 3. A summary of some PCK models

Components of PCK	Shulman (1987)	Grossman (1990)	Tamir (1988)	Magnusson (1999)	Park and Oliver (2008)	Mavhunga (2012)
Content Knowledge	k					x
General Pedagogical Knowledge	k					x
Contextual Knowledge	k					
Curricular knowledge	k	x	x	x	x	
Knowledge of instructional strategies/Instruction	x	x	x	x	x	x
Knowledge of learners	x	x	x	x	x	x
Knowledge of assessment			x	x	x	
Orientations/Purposes/Beliefs	k	x		x	x	x
Teacher efficacy					x	
Science practices/skills						

k – component in teacher knowledge base; x- component included in PCK

As science teaching is complex and not straightforward, this study took an inclusive approach using the Consensus Model -Teacher Professional Knowledge and Skill (TPK&S) that includes components from all the models (Kind, 2015). The model was chosen for this study because it departs from a given set of components for PCK and includes both the knowledge bases (the public or canonical knowledge) and the skills (the act of teaching or personal PCK) for teaching. The model seemed more appropriate for the aim of the first study of this thesis that sought to identify effective approaches to developing science teachers'

PCK. The first study of this thesis included a synthesis of multiple studies that focused on different aspects of teacher knowledge. The adapted Consensus Model better served as a lens into all those knowledge aspects addressed by the studies included in the review. The Consensus Model enabled flexibility as it does not explicitly dictate what the model comprises (Neumann, Kind and Harms, 2018, p.10). I drew on this lack of clarity to include subcomponents from other models to serve as priori codes for data analysis in the first study (Table 4). Apart from the Consensus Model of PCK as a guiding tool for the study, all the theories of learning discussed in this chapter were relevant to this study because they helped in exploring and understanding how teachers learn to teach and develop PCK during their education programmes. A summary of the theories and their relevance to the study is presented as follows:

Lortie's (1975) model of apprenticeship of observation (prior beliefs and experiences) was useful for the study because it helped in highlighting the importance of prior beliefs and experiences in shaping teachers' future learning.

Berliner's (2001) stages of teacher development gave insight into how teachers move through stages of development starting from the initial stage, that of a trainee teacher. Educators must be aware of the initial stage when teachers acquire context-free knowledge and skills to develop self-efficacy before teaching in real context.

Lave and Wenger's (1991) social participation in the school culture was relevant to this study because trainee teachers were newcomers to teaching profession. The theory offered insight into how teachers move from periphery towards full participation within the school culture. The theory helped in gaining insight into trainee teachers' experiences in their school placements and how those experiences impacted on their development.

Table 4. The PCK framework of the study adapted from Topic Professional Knowledge and Skills (TPK&S) (Gess-Newsome, 2015, p. 31).

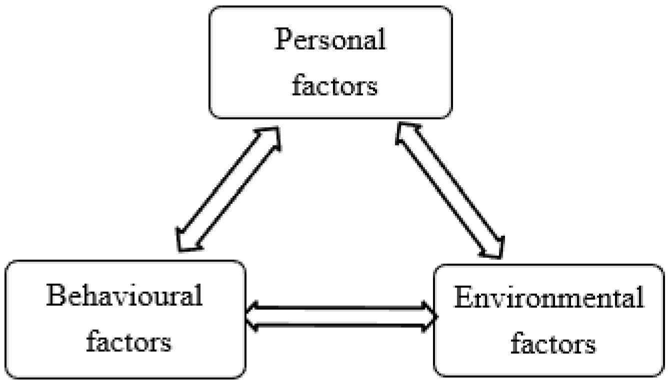
Public and Canonical Knowledge components from TPK&S	**Priori Codes (Gathered from the PCK models)**
Knowledge of content	Substantive and syntactic knowledge/Content Representations
Pedagogical Knowledge	Classroom management/Organisation of class
Curricular Knowledge	Science aims, goals, and objectives/ Curriculum programme and materials/Resources/ Vertical and horizontal curricula/Curriculum saliency
Knowledge of Instructional Strategies	Methods of instruction/Representations /Analogies/Explications/ Demonstrations/Investigation/ Modelling/Illustrations/Examples
Knowledge of Learners	Prior knowledge and background/Conceptions and misconceptions/Learning difficulties/ Requirements for learning/Motivation and interests/ Individual needs
Knowledge of assessment	Methods of assessment/ Dimensions of science learning to assess
Science Practices/Skills	Teaching skills/Planning skills/Diagnostic skills
Amplifiers	Beliefs about purposes of learning science /Beliefs about nature of science/Decision-making /Habits of mind/ Motivation and behaviour/ Self-efficacy /Outcome expectancy Orientations/ Classroom context

Bandura's (1977; 1993) **sources of self-efficacy** (mastery experiences, vicarious experience, and support: social persuasion, and emotional and psychological states) helped in understanding how trainee teachers develop self-efficacy beliefs during their training programmes. Self-efficacy beliefs are predictors of teachers' behaviour, the choices, and decisions they make about teaching. Given that self-efficacy is malleable early in learning, the support trainee teachers receive during their training programmes is critical to the development of their efficacy. Thus, educators should be aware of the sources of self-efficacy so that they create opportunities for trainee teachers to experience success in teaching.

Bandura' s (1989) observational learning theory helped in understanding learning through cognitive modelling. Bandura (2001) explains that people have an advanced capacity for learning from varied models. Through cognitive modelling, teachers learn new behaviours, knowledge, and skills from their educators as models or from their more experienced peers.

Bandura (1978; 1999) explains human behaviour in terms of reciprocal determinism or causation. In Bandura's model of reciprocal causation three determinants (personal factors, behaviour, and environment) interact and influence each other bidirectionally (see Figure 10).

Figure 10. Bandura's Triadic Reciprocal Causation model (1978, p. 345).



According to the model, teachers' personal factors (e.g., beliefs, expectations, prior knowledge, goals) guide their behaviour or action (Personal factors - Behavioural factors). The consequences of their behaviour or behavioural experiences affect their personal factors in terms of thoughts and emotional reactions (e.g., perceived capabilities for teaching). On another segment of bidirectional influence in the triadic model (Personal factors – Environment), teachers' personal factors develop and change under the influence of the social environment. The social environment provides teachers with information through modelling, instruction, and social persuasion. These social influences activate teachers' different emotional reactions (e.g., increased self-efficacy).

Finally, behaviour and the environment influence each other. Bandura contends that unless people activate the environment through a particular behaviour, the environment does not operate as an influence on their behaviour. For example, the environment does not change teachers' practice if they do not have good models of effective teaching. Moreover, teachers' behaviour influences their environment through the selection of teaching activities according to their own preferences and competences. Through the selection of activities, teachers 'create as well as select environments' (Bandura, 1989. p. 4). For example, a selection of student-centred activities is more likely to create an effective teaching environment. The theory and the triadic causation model highlight the importance for educators to plan opportunities for effective modelling, making their reasoning visible to initial teachers so that they can avoid adopting blind practices.

Vygotsky's (1978) Zone of Proximal Development (ZPD): scaffolding and social interactions. The concept of ZPD was useful in this study as it helped in understanding teachers' need for consistent guidance and support during their education programmes.

Reflection (Schon, 1983; Dewey, 1933) was relevant to the study because reflection is a teaching skill, and like other skills, takes time to develop through practice until it is mastered. Dewey contends that teachers learn from reflecting on experiences. Therefore, teachers need opportunities to practice reflection as a skill by learning from their experiences during their education programmes (Dewey, in Reale, 2016). As Reale (2016) states, teachers try out teaching by doing, and by repeated teaching they learn how to teach.

Following the application of the initial PCK framework to data analysis in the first study (the review study), a new PCK based framework was developed. The newly developed framework was named *Learning to Teach Framework (LtTF)*. *Learning to Teach Framework* replaced the Topic Professional Knowledge and Skills framework and guided the subsequent synthesis in the first study. The newly developed *Learning to Teach Framework* also guided the development of collection instruments (the questionnaire and interview schedule) and data analysis of the second study. The newly developed framework is explained in detail in Chapter 5.

Additionally, from the findings of the review study, a new framework - *Triadic Framework for Learning to Teach,* was developed. The second newly developed framework provided an *interpretive* lens to better understand why the PCK approaches were effective in preparing teachers and how teachers developed PCK during their education programmes. Both newly developed frameworks guided the second study of this thesis and are advanced as a comprehensive model for initial teacher training programmes. The first study of the thesis – the Systematic Review - is introduced in the next chapter.

Chapter 4. Systematic Review Study. Aims and Methodology

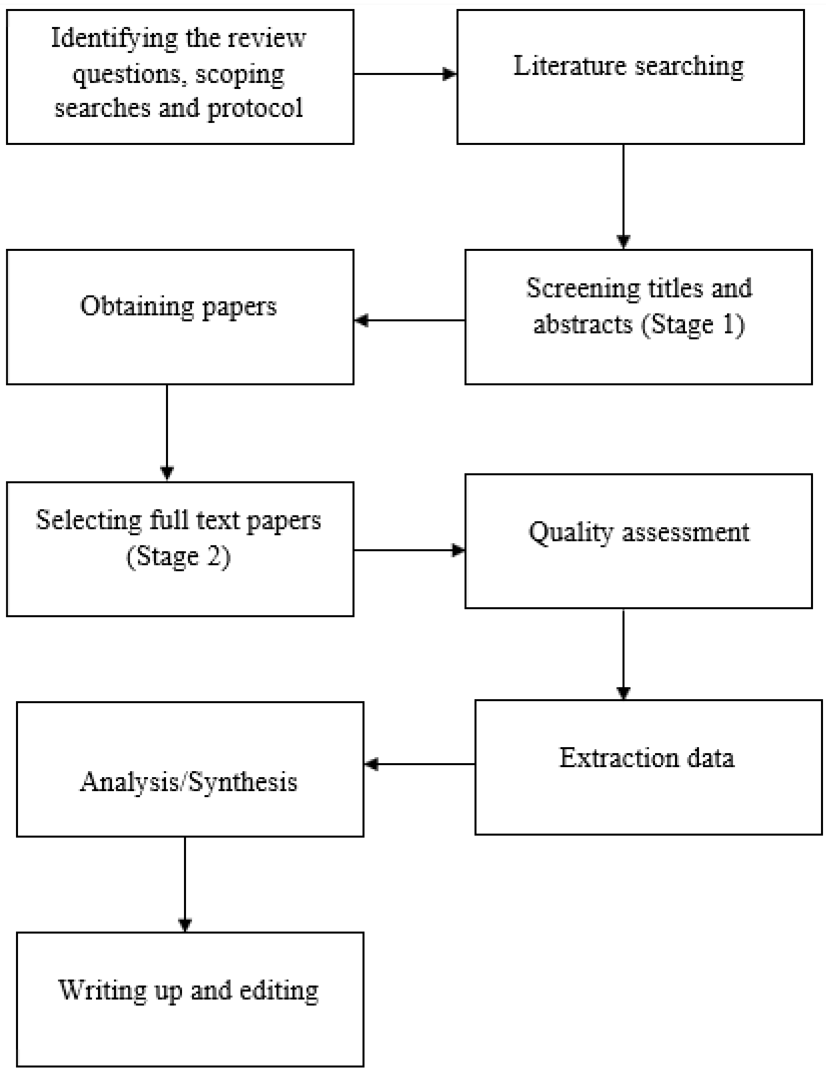
This thesis consists of two studies aiming to identify how initial teacher training programmes can better prepare trainee teachers to teach science in secondary schools. This chapter presents the first study – A Systematic Review. The chapter is structured into three sections. The first section provides a brief introduction into the systematic review methodology, describes the mapping review caried out in advance to inform the main review, and explains the rationale for the research questions. The second section describes and justifies the methods used in the review. The third section reports on the quality of the studies included in the review.

4.1 Introduction

A Systematic Review is an evidence-based methodology, 'a research methodology in its own right' (Boland, Cherry and Dickson, 2017, p. 3). As a methodology, a systematic review starts with writing a protocol, a plan that shows the steps taken for carrying out the review to answer the research question (Petticrew and Roberts, 2005; Boland, Cherry and Dickson, 2017). Boland, Cherry and Dickson (2017) explain that the advantage in having a protocol is to limit the bias occurring in the review, and to focus and structure the review. In this study, the protocol is mainly guided by the key steps suggested by the above authors. The steps are presented in Figure 11 and described in this chapter.

The Systematic Review started with a search of the relevant literature after the research questions were identified and the literature on the topic of interest was mapped. The studies were screened against the inclusion and exclusion criteria and only the eligible studies remained for the inclusion in the review. Relevant data from each study was extracted in a single format and analysed through a thematic approach, processes guided by the theoretical framework of the study.

Figure 11. Key steps in conducting a Systematic Review (Boland, Cherry and Dickson, 2017, p. 25)



Unlike a literature review, a systematic review systematically reviews and synthesizes the findings of multiple studies to reveal the best available evidence related to a specific research question (Boland, Cherry and Dickson, 2017). A systematic review is also known as research synthesis – 'putting together parts to make up a complex whole' (OED Online, 2015, in Oliver and Tripney, 2017, p. 454). A systematic review uses explicit and transparent methods so that it can be replicable. Andrews (2005) states that it is this transparency that makes systematic reviews more valid compared with traditional literature reviews. In this study, the systematic review selected, analysed, synthesised, and appraised the literature on PCK approaches to enhancing secondary science teachers' development during their education programmes. As single studies addressed different components of PCK, a systematic review gathered multiple studies, concerned with teachers' PCK development, in a complex whole.

Systematic reviews have been commonly used in healthcare to gather exclusive quantitative evidence for clinical effectiveness (Major and Savin-Baden, 2010; Boland, Cherry and Dickson, 2017). However, preponents of systematic reviews notice an increased focus on qualitative evidence. Gradually, systematic reviews have evolved to a more integrative approach including both qualitative and quantitative evidence (Major and Savin-Baden, 2010; Boland, Cherry and Dickson, 2017). Compared to systematic reviews of quantitative evidence which are more prescriptive, leaving little room for interpretation, systematic reviews of qualitative evidence have a more flexible methodology **(**Boland, Cherry and Dickson, 2017). However, systematic reviews of qualitative evidence are new and therefore 'less developed' (Thomas and Harden, 2007, p. 4). Moreover, the findings from systematic reviews of qualitative evidence have issues of generalisability; the findings do not easily transfer across contexts as they are specific to a particular context, participants, and time (Thomas and Harden, 2007). Yet, given the potential of systematic review to usefully inform policy and practice, efforts have been made to develop methods that preserve the context. Thomas and Harden (2007) outline that thematic synthesis is one specific approach to bring together the findings of qualitative research to inform policy and practice. Similarly, Major and Savin Baden (2010) argue that systematic reviews of quantitative evidence are more replicable, yet they do not provide rich and thick description of lived experiences as qualitative methodology does.

The articles included in this review were in majority qualitative in nature. Yet, to allow for quantitative and mixed studies to be included, the review adopted an integrative approach. An integrative approach brought all the studies with different methodologies into the same model. Through a combination of qualitative and quantitative evidence, the review sought to increase the confidence in the findings by comparing the findings across studies with different methodologies.

Mapping the literature before conducting a comprehensive systematic review is a 'good practice' (Arksey and Lisa O'Malley, 2005; Petticrew and Roberts, 2005, p. 48). A scoping review, also called 'mapping review' is a type of review used to map the existing literature in a specific area (Booth, 2016, p.14). A mapping review provides an overview of the existing evidence. It is often used to inform the methodology of the main systematic review in terms of deciding on the search strategy, study selection strategy and data extraction. Scoping reviews help in refining and revising the review questions. Arksey and O'Malley (2005) state that a scoping review is 'a process of summarizing a range of evidence to convey the breadth and depth of a field' – 'a technique to map the relevant literature in the field of interest' (p. 4). In short, a scoping review determines whether the topic chosen is suitable for a full review (Boland, Cherry and Dickson, 2017). Boland, Cherry and Dickson (2017) state that for the topic to be suitable for a review, there must be enough volume and type of evidence available for the synthesis.

A scoping review was performed as part of this study to map the literature available on science teachers' PCK development (Appendix A). The scoping review took Arksey and O'Malley's (2005) approach with five-stage methodological framework. The scoping review had the advantage to retrieve an appropriate number of papers to cover the broadness of the field on PCK for science teachers. Scoping review revealed not only a broad literature on PCK for science teachers, but also showed a scarcity of syntheses on supporting science teachers' practice. Limited reviews identified through the scoping review had a different focus. For example, Schneider and Plasman (2011) conducted a review about how teachers develop PCK over time in the form of learning progressions. The authors examined the development of teacher knowledge across the professional phases for science teachers from the preparation phase to teachers becoming leaders or mentor teachers. Another review conducted by Kind (2009) took a methodological approach addressing PCK conceptualizations. More recently, Chan, Rollnick and Gess-Newsome (2019) conducted a systematic review on the use of rubrics in PCK research, proposing a Grand PCK Rubric as a tool for measuring science teachers' PCK. Evens, Elen and Depaepe (2015) carried out a review with a focus on the evaluation of intervention studies that aimed to promote PCK development. Their review was broader including studies across disciplines and both primary and secondary teachers from different settings and with different level of teaching experiences. Thus, the present systematic review fills the gap in the literature on syntheses of the literature on enhancing secondary science teachers' PCK development during their education programmes.

Given the broadness of the literature on PCK, the scoping review helped in refining the review questions and in developing the inclusion and exclusion criteria. Initially, the intent was to review studies aiming to develop primary and secondary science teachers' PCK during their education and professional development programmes. Based on what was found through the scoping review, I decided to include in the main review only those studies which involved secondary science teachers as research participants and caried out only in science education programmes. The decision was made to keep the volume of journals at a manageable level in terms of number of relevant studies and time.

4.1.1 Rationale of the Systematic Review

The aim of the systematic review was to fill the gap in the literature on what is effective and why in enhancing science teachers' PCK development during their education programmes. The best way to achieve the aim was to carry out a synthesis of multiple studies addressing the same topic. Authors of systematic review literature (Petticrew and Roberts, 2005; Major and Savin Baden, 2010; Boland, Cherry and Dickson, 2017) highlight the advantages of this methodology in: - managing the information explosion; - addressing the problem of knowledge fragmentation; - identifying gaps and omissions; - and allowing for the development of evidence-based practice and policy.

As the literature on PCK is vast, the systematic review helped in managing the explosion of PCK literature by carefully selecting and synthesizing the relevant information that answered the research questions. Scholars found that rarely individual studies address all the components of PCK and the integration between them (Jong, Van Driel and Verloop, 2005). The literature on PCK agrees that the gain in one component does not transfer to another (Magnusson, Krajcik and Borko, 1999). In many single studies, PCK components are separated from one another and not always integrated. The systematic review helped in solving this problem of knowledge fragmentation by gathering all the components together in a complete whole.

Furthermore, the call for evidence-based practice has increased over the last decade (Furlong, 2013; Carter, 2015; Menter, 2016). The systematic review helped in gathering a set of evidence-based practices that help in fostering trainee science teachers' development which in turn improves the quality of teaching. Given the scarcity of synthesis studies on enhancing trainee science teachers' development, this review may be valuable in advancing practice and informing policy and research.

The review was guided by the PCK theoretical framework of the study, an adapted version of the Consensus Model of PCK (Gess-Newsome, 2015) described in Chapter 3, Table 4. The study drew on PCK framework because PCK is the professional knowledge base for teaching much agreed in the literature, and it offers a good framework for the organisation of knowledge for teaching (Shulman, 1986). PCK framework has widely been used as a tool to accelerate teachers' knowledge and skills development during their education programmes (Abel, 2007; Kind, 2009). Thus, the review selected and synthesised studies that addressed at least one knowledge component of PCK frameworks.

The PCK framework based on the Consensus Model - Teachers' Professional Knowledge & Skill (TPK&S) (Gess-Newsome, 2015) guided the review helping in decisions on the research questions, data extraction, and analysis. The framework helped in the identification of the evidence for teachers' improvement in the PCK components targeted by the individual studies included in the review. The subcomponents of the framework served as priori codes that facilitated the extraction of evidence (codes) from each single study. Bandura's sources of self-efficacy theory guided the deductive categorisation of the inductively developed themes on effective instructional features from the selected studies.

4.1.2 Research Questions

Systematic reviews start with the identification of the review questions (Boland, Cherry and Dickson, 2017). The review questions for this review were born from a genuine interest in science area as explained in the first chapter. Questions regarding how best teachers can be prepared to teach science in secondary schools seemed to best be answered through a systematic review. The research questions were guided by the PICOSS tool (Population, Intervention, Comparator, Outcomes, Study design and, Setting) and PCK framework of the study. The main research question addressed by the review was:

- What PCK approaches are effective in preparing secondary science teachers?

To answer this question, two sub-questions were addressed:

- What is the evidence for teachers' PCK development during their education programmes in different contexts?
- What learning opportunities contribute to teachers' PCK development during their education programmes?

4.2 Methods

This section describes the methods used in the review.

4.2.1 Searching Strategy

Two electronic databases were chosen as primary sources for searching the published evidence: Education Database as part of Pro-quest Central and Web of Science Database. The two databases were chosen due to their potential to generate sufficient relevant studies to be included in the review. In addition, a search of relevant studies was carried out in the reference list of the studies included in the review and identified by hand searching. Devising a search strategy was challenging because a search strategy proved to be more complex than introducing relevant words on Google engine as Boland, Cherry and Dickson (2017) had warned. Therefore, there were more attempts to identify the search terms to be included in the search strategy.

In devising the strategy, I used key words developed from the initial scoping review and words related to PICOSS tool described in Table 5. A combination of free text words, using the Boolean operators AND and OR, were used to capture the relevant studies on PCK conducted in science education programmes. The keywords (utilised for the literature searching in titles and abstracts in both databases) were a combination of ‘pedagogical content knowledge’ in conjunction with AND ‘preservice science teachers’ OR ‘trainee science teachers’, AND ‘science education programme’, OR ‘field practicum’, OR ‘science education course’.

Table 5. PICOSS Table

Population	teachers preparing to teach science in secondary schools (chemistry, biology, physics).
Intervention	any activities/strategies/approaches with the aim to improve teachers’ PCK
Comparator	pre, post-test, before-after, at least two data sources from different points of time to allow for comparison
Outcomes	impact/effects of any activity on teachers’ PCK development
Study design	all
Setting/Context	education/training programmes (education courses/teaching practice in schools)

The search covered the last two decades (from 2000 to 2020) to include changes in curricula and Teachers' Standards. The key words were piloted to check if relevant studies identified through the scoping review were among the results (Boland, Cherry and Dickson, 2017). The search took place in two stages. The first and main stage took place in 2019 when the study started, covering the period from 2000 to 2019. The second stage of the search covered the period 2019 -2021 to include the most recent relevant articles. Two most recent articles were included through the second search (Rutt and Mumba, 2019 and Ekiz-Kiran, Boz and Oztay, 2021). The search process was supplemented by hand searching in Google Scholar using only 'pedagogical content knowledge' and 'science education' as key words.

4.2.2 Study Selection Criteria

A scoping review was helpful in refining the review questions and developing the inclusion and exclusion criteria. Inclusion and exclusion criteria are attributes that a study must have to be included in the review. For this review, I adopted the inclusion and exclusion criteria generated by PICOSS table (Table 5). PICOSS table is recommended for studies about effectiveness (Petticrew and Roberts, 2005; Boland, Cherry and Dickson, 2017). The tool is comprehensive for interventions studies being useful in the selection of relevant studies to the review. As the review included studies with different designs, I made a single alteration to PICOSS to include the context which is specific to qualitative research. In this study, setting is used as a synonym for context.

The elements of PICOSS were chosen purposefully to answer the research questions. The population included science teachers preparing for teaching in secondary schools. The focus was on secondary science teachers for a few reasons. First, research shows that secondary teachers face more challenges than their primary colleagues (Hutner and Markman, 2016). For example, there is more pressure on them to prepare students for tests and they need more support in finding a balance between preparation for tests and making science relevant to students. Evidence from research shows that, at secondary level, students' attitudes and aspirations in science has decreased constantly over the last decades (Osborne and Dillon, 2010; DeWitt and Archer, 2015). Because of the pressures to raise students' achievements, secondary science teachers are more likely to withdraw from teaching profession in their first years of teaching (Allen and Sims, 2017).

The review had to be further narrowed due to the broadness of research on PCK and time and word-count restrictions. To be included in the review, the studies had to address at least one component of PCK models. Studies were included if they used at least two data sources (e.g., pre, and post-surveys, tests, or questionnaires) and documented changes in teachers' PCK and efficacy beliefs by comparison (provided evidence regarding the extent to which teachers' knowledge and/or practices and their self-efficacy were improved). These criteria were considered important because the focus of the study was to identify learning opportunities that have the potential to change teachers' practice. The study aimed to delve not only in what works, but also in what works more effectively.

Lastly, to be included in the review, the studies had to be conducted in a teacher education programme (science course, education course, methods course, or teaching practice) with the goal of developing science teachers' PCK in a short time frame. The argument for this criterion was that training programmes for teachers are short in duration and an emphasis must be placed on the variation and the quality of the learning opportunities for teachers (Guerriero, 2017).

Apart from these criteria, the review was further narrowed by selecting only the studies published in peer-reviewed journals and written in English language. Although many qualitative studies may not be found in peer review, this criterion was chosen to keep the volume of journals at a manageable level in terms of number of relevant studies and time, and for the purpose of selecting and analysing studies with the potential of being of better quality. Essays, literature reviews, editorials, book chapters, technical reports, conference proceedings and meta-analysis were not included. The studies that focused exclusively on Technological Pedagogical Content Knowledge (TPCK) were excluded as TPCK is not part of the PCK models.

The inclusion and exclusion criteria were used to create a selection tool for screening the studies to determine their eligibility for inclusion in the review. The tool is detailed in Table 6 and was first piloted on a few studies to ensure that the selected studies were relevant to the review questions (Boland, Cherry and Dickson, 2017).

Table 6. Screening and Selection Tool

	Include	Exclude
Population	teachers preparing to teach science (chemistry, biology, physics) in secondary schools in different countries.	primary/elementary science teachers in-service science teachers
Intervention	any activities/strategies/approaches with the aim to improve teachers' PCK	evaluation of courses/activities
Comparator	pre and post-test, before-after test, at least two data sources from different points of time to allow for comparison	pre-test only only one source of data
Outcomes	impact/effects of any activity on teachers' PCK development	did not report any impact or effect
Study design	all	--
Setting/Context	education/training programme (course/ teaching practice)	was not a science programme/course

4.2.3 Screening Titles and Abstracts

The screening process took place in two stages. To maximise the chances of obtaining relevant full-text studies, a greater attention was given to abstracts rather than titles. All the studies that had in their titles and/or abstracts one or more eligible key terms, such as PCK, secondary science teachers or education programme, were selected and downloaded in EndNote software and in Ref Works, respectively. Where the studies had some of the eligible key words in their titles and abstracts, but also specified exclusionary key words such as elementary or primary science teachers, the studies were not selected. The studies judged as eligible for inclusion in the review were then identified, obtained, and downloaded in a folder.

In the second stage of screening, the selected full studies were read and assessed against the inclusion and exclusion criteria to ensure that they fit the scope of the review and answer the research questions (EPPI, 2007; Gough, 2007). The studies that did not meet the inclusion criteria were excluded with reasons for their exclusion. All the selected studies were classified according to the subject area, aim of intervention, context, and PCK approach taken. This classification allowed the context of each study to be preserved in the report of the findings and conclusions.

4.2.4 Data Extraction

Having all the full studies screened against the exclusion and inclusion criteria, the relevant data from each study was extracted and stored in a single format – Data Extraction Table (Boland, Cherry and Dickson, 2017). Boland, Cherry and Dickson (2017) recommend reading the selected studies in full to make sense of data. Data was read in full several times in two rounds to gain a sense of the text within the studies and to decide upon the data to be extracted. I kept a list with all the characteristics of the studies identified through the scoping review. I added new characteristics to this list as they were identified during the first round of readings and cross readings of the studies included in the review. To ensure that all the relevant data was extracted and to make sense of it, I read and analysed each study separately.

Based on the types of data identified in the first round, I developed a series of questions that guided the extraction of data in the second round of readings. Among the questions were: What is the context of the study? What is the number of participants? Who conducted the instruction? What is the aim? What component/s of PCK are targeted? What are data collection tools? What is the design? What are the approaches used? What are the instructional features of the intervention? What are the findings? What are the limitations? All the information that answered these questions was loaded in a standard template in Excel.

The extraction form was continuously processed as new information became relevant during the readings. The questions were also chosen to extract the relevant data that answered the research questions and to facilitate a cross-study comparisons. All data extracted in this form represented a vertical extraction that allowed for the assessment of the studies' quality and their relevance to the review. The form with an overview of the selected studies allowed an identification of some themes regarding the focus of each study in the review. Data extracted was grouped on three categories: descriptive data (identification and characteristics of the studies) analytical data (findings) and data about the quality of the studies (methodological soundness). More details of data extraction are found in Appendix B.

4.2.5 Data Analysis and Synthesis

Boland, Cherry and Dickson (2017) argue that synthesis of qualitative data is influenced by researchers' bias, perspectives, and beliefs. To avoid or limit researchers' bias, data extraction, analysis and interpretation must be situated within a theoretical standpoint. The study is situated within a constructivist view as detailed in Chapter 3. The thematic analysis proposed by Braun and Clarke (2006) was chosen because it is a method compatible with a constructivist view. Braun and Clarke (2006) posit that thematic analysis reports 'experiences, meanings, and the reality of participants' (p. 9). This review was concerned with what is effective in preparing science teachers from their own and researchers' perspective. Therefore, a thematic analysis within a constructivist approach was suitable for the aim of this review.

Compared to other methods (such as Grounded Theory) which require a detailed theoretical and technological knowledge of approaches, thematic analysis allowed more flexibility in summarising the qualitative data that addressed the research questions (Braun and Clarke, 2006). However, thematic analysis, widely applied to individual studies, has limitations when applied to research synthesis. Thomas and Harden (2007) communicate some of such limitations. The authors posit that there are concerns with the lack of transparency, a lack of clear separation between descriptive and analytical themes. Moreover, the method is limited to summarising themes from primary studies and does not allow a development of higher order thematic categories. The authors attempted to address these limitations in their review. They coined the concept of 'thematic synthesis' to delineate a clear separation between descriptive themes and analytical themes (p. 3). This delineation is important in 'going beyond' the content of the primary studies whilst preserving the context (p.13). In this study, the context was preserved by providing sufficient details of each study so that readers of the review to be able to judge for themselves whether the context of the studies in the review are similar with their own (Thomas and Harden, 2007).

This study drew on Braun and Clarke's (2006) concept of thematic analysis and Thomas and Harden's (2007) concept of thematic synthesis. A thematic analysis, guided by the steps presented by Braun and Clarke (2006), was applied to the review studies to identify descriptive themes across the studies. First, I identified the type of evidence to be extracted from the review studies. The type of evidence that answered the first research sub-question took the form of textual data/individual statements related to changes in science teachers' PCK development in the context of each individual study. Then, the type of evidence that answered the second research sub-question took the form of textual data/statements related to effective instructional features as contributing factors to teachers' PCK development in the context of each study. The two types of evidence that answered the two sub-questions was extracted from each study separately and recorded in a table of evidence (Appendix C).

The thematic analysis adopted an inductive-deductive approach. First, the relevant data, that answered the research questions, was searched, extracted, and coded from the findings of each study, participant's quotes, and authors' interpretations/discussions (Boland, Cherry and Dickson, 2017). The descriptive themes from all the studies were then synthesised to develop analytical themes. I describe next the steps for the thematic analysis and how the analytical themes were developed through a thematic synthesis.

Familiarization with data. Braun and Clarke (2006) suggest an immersion in data to the extent that enables a good familiarization with the depth and breadth of the content. This involves repeated reading of data, in an active way (searching for meanings/patterns). In line with these suggestions, each study was repeatedly read, making annotations, and highlighting the relevant information considered to answer the research questions. After several readings, an idea about the relevant data to the research questions, and coding schemes were developed.

Generating codes. This stage involves the production of codes from data (Braun and Clarke, 2006). Coding can be done manually or electronically. Although many software tools are available to assist in managing the coding process electronically (NVIVO or ATLAS), a manual coding was preferable. A manual rather than electronic coding was chosen because of a deep familiarization with the text of each individual study and the inclusive approach taken in the coding process. As familiarization and developing expertise in using a new tool requires time, a manual search seemed to be in more control.

Coding process involves copying extracts of data from individual studies (Braun and Clarke, 2006). In this study, the codes were extracted in the form of individual statements of science teachers and/or educators in the context of each study. Where not sufficient information was found in the findings, additional information was added from the discussion section of the study, especially when the study reported on numerical data. The initial codes were assigned an abbreviation of the PCK components from the framework that guided the analysis (see the PCK framework of the study in Table 4, Chapter 3). For example, the statement from the text, 'teachers' ideas about learners' difficulties became more sophisticated' (Aydin et al., 2013), was highlighted, copied, and assigned the code KoL (Knowledge of Learners). The list of codes was extended as new codes emerged from the text and there were not priori codes in the initial analytical framework to match them. For example, many codes related to aspects of 'awareness' and 'acknowledgements' appeared from the text. These codes were assigned an abbreviation and were included in a new developed category named 'Understandings'. To increase the consistency of the coding process, the codes from the findings and discussion rubrics of each individual study were repeated for any omission until there were no other codes to add. Therefore, the codes were revised and adjusted continually over the duration of the study. Coding data inductively was not difficult as data relied on the components of PCK frameworks that mostly matched the priori codes of the framework used in the analysis. For the second research sub-question, the coding scheme was a bit more challenging given the variety of instructional features used in the studies, and no priori codes were used.

Generating themes. This stage involved a categorisation of the different codes into common themes and a collation of all the relevant codes within the identified themes (Braun and Clarke, 2006). Searching and identifying themes are usually made in relation with the research questions and analytical framework. In this study, the initial codes that answered the first research sub-question were identified and abbreviated according to each component of the framework used in the analysis. The codes were grouped based on similarity in twenty-two subthemes. The twenty-two subthemes were further grouped in five themes (a sample of the coding scheme is presented in Table 7).

Table 7. A sample of the coding scheme for research sub-question 1

Theme	Sub-themes	Evidence for changes in Knowledge as in the text
Knowledge (Acquisition of knowledge bases)	Content	'identified correctly the 'Big Ideas' Mavhunga, 2016; '
	Instructional strategies	'wrote down and discussed instructional strategies considered potentially useful to enhance students' understanding (Jong, Driel and Verloop, 2005).
	Learners	'provided important insights into the learning characteristics of students' (Hume and Berry, 2013).
	Assessment	'adopting a variety of strategies to assess students' science learning' (Adadan and Oner, 2014)
	Curriculum	'included curriculum objectives that indicated her knowledge of curriculum' (Demirdöğen, 2016).

The five themes were abbreviated and used as an analytical tool for the cross-studies synthesis. Evidence of any gain in one or more themes validated the effectiveness of a particular strategy for PCK development.

To answer the second research sub-question, first, what counted as learning opportunity was determined. A learning opportunity was defined using Grossman (1990) sources of PCK development (e.g., teaching experience) and Kleickmann et al. (2013) classification of the sources for development of professional knowledge based on their level of formalisation. Thus, a learning opportunity was counted as any formal or informal activity teachers were engaged in during their education programmes with the aim to develop knowledge, skills, and confidence for teaching science. As the aim of the study was to identify effective learning opportunities, only those activities which were related to PCK development were selected to answer this research question. The findings and discussion rubrics of each study were searched for any statements that related to learning opportunities that contributed to PCK development.

An open coding identified, highlighted, and listed all the codes that reported on effective features that contributed to PCK development. An open coding was done manually in the original electronic text. The identified codes were highlighted and then copied verbatim in the table of evidence. With each study, new codes were added to the list of codes. The codes based on similarity were grouped in forty-two subthemes. The sub-themes represented the effective strategies for PCK improvement selected from the findings, discussion, and conclusion rubrics of each study from the researchers' and/or teachers' statements. An example of code that relates to a strategy for learning was 'explicit demonstrations.' The code was selected from the text, 'explicit demonstrations of the breaking down of the TSPCK construct into its individual components has been useful' (Mavhunga, 2016). The code was included in the sub-theme ‘Demonstrations’, the theme ‘Modelling learning’ and in category ‘Vicarious experiences.’ The relationships between themes were also noted. In the above example, the explicit demonstrations impacted on teachers’ understanding of transformation of content. To group them into themes, the sub-themes were looked for similarities and differences. According to the emphasis that each study gave in developing teachers’ PCK, the outcomes were related to one or more themes and sub-themes. Eight descriptive themes resulted from data, and these are discussed in detail in the next chapter. A sample of the coding scheme for the second research sub-question is presented in Table 8.

Table 8. A sample of the coding scheme for research sub-question 2

Theme	Explanations of evidence (codes) as in the text
Lesson Planning	‘the CoRe aspect of the practicum enabled participants to articulate their PCK and forced them to connect the components due to its matrix format’ (Aydin et al., 2015).
Teaching	‘Improvement due to teaching experience’ (Bektas et al., 2013)
Observations	‘observing peers’ microteaching helped them to realize the importance of learners’ prerequisite knowledge, difficulties, and misconceptions’ (Aydin et al., 2013).

Reviewing themes. Braun and Clarke (2006) state that data within themes should cohere together meaningfully while there should be clear and identifiable distinctions between themes. The themes were carefully refined by further readings, first, for a match of the theme with the data set of codes, and second, for identifying missing codes.

Defining and naming themes. Braun and Clarke (2006) recommend for going back to collated data extracts for each theme and organising them into a coherent and internally consistent account with accompanying narrative in relation to the research questions. In line with these suggestions, the themes were shortly described to give an overall sense of their meaning. The descriptions of the themes were checked by comparing them with the codes in the context of each study to ensure that the descriptions reveal the studies' accounts in an accurate way.

To go beyond the content of the original studies, four synthesis categories (analytical themes) were created by looking at the causal relationships between the descriptive themes. The studies that contributed to each of the four synthesis categories were counted and grouped according to common key features of their interventions. These analytical themes are discussed in the next chapter.

4.3 Quality Assessment

To identify effective strategies which impact on science teachers' PCK development, quality assessment is an important step of a systematic review (Boland, Cherry and Dickson 2017). Boland, Cherry and Dickson (2017) recommend that quality of studies should take place before data extraction if it is to exclude poor-quality studies. This review did not plan to exclude studies based on their quality but to provide a description of quality of the evidence base, as part of the analytic process (Jones, 2004; Gough, 2007). However, the identified poor and medium quality studies were examined in depth and accounted for in the interpretation of the results. The quality assessment proved to be a challenging aspect of the systematic review. There was an attempt for assessing the studies using standard checklists or scales. However, it became clearer that there is much debate on the appraisal and synthesis of qualitative research. Boland, Cherry and Dickson (2017) noted that in qualitative research there is more complexity and flexibility than in quantitative research where exists clear methods of synthesis and standard checklists for appraisal. Systematic reviews are well known as ways of gathering quantitative evidence-based practice to determine what interventions works best. Systematic reviews of qualitative evidence, instead, explore in more depth how an intervention works (Boland, Cherry and Dickson, 2017). Systematic reviews of qualitative evidence ask questions that go beyond of what works, asking questions about why and how a particular intervention works (Boland, Cherry and Dickson, 2017).

Jones (2004) notices that often, methods best suited to systematic review of quantitative studies are transposed into qualitative ones leading to 'producing a kind of mission drift in many qualitative systematic research reviews' (p. 96). The author went further to say that systematic reviews of qualitative research are best served by reliance upon qualitative methods themselves. As this systematic review included studies with all types of design (quantitative, qualitative, and mixed), I drew on Jones's (2004) suggestion and adopted and inductive approach to developing an inclusive assessment tool. More specifically, the assessment tool is based on Jones's Signal and Noise technique that recognizes the flexibility and inclusionary nature of qualitative research (2004). This technique is mainly based on the methodological soundness of each study. According to Jones (2004), the usefulness of this technique is that the studies are not eliminated on basis of their level of evidence or certain methodological weaknesses. The author uses the terms of high 'noise' level and strong 'signal' to highlight that some articles may have a suspect design but important findings (p. 99). This approach was helpful in including studies which initially were eliminated because of their unclear elaboration on their interventions (e.g., Hume and Berry, 2011). The signposts (aims and objectives, reflectivity, ethical considerations, narration, usefulness, and dialogue) and starting questions proposed by Jones (2004) were used in developing the assessment tool for this review. Questions and sub-questions from Critical Appraisal Skills Programme (2019) for qualitative research were also used to judge more accurately on the quality of each individual study (Table 9).

Table 9. Assessment tool based on Jones's (2004) signposts and questions from Critical Appraisal Skills Programme (2019) for qualitative research.

Signposts	Questions	Sub-questions
Aims and objectives	Does the study have a clear aim and objectives?	
Reflectiveness	Does the study use collection methods that invite to dialogue and transparency? (An interview is an opportunity to dialogue)	Where is (are) the study's researcher(s) coming from? What are the backgrounds and beliefs? How are these limitations? In what way are these revealed? In what way is the researcher transparent? (Description and justification of data collection process, recruitment, analysis process). Are the findings made explicit?
Ethical considerations	Does the study clearly delineate the ethical issues?	How are ethical issues clearly delineated? In what way is attention paid to the wider cultural context?
Narrative	Does the study have a clear interpretative analysis?	Does the narrative include roadblocks, false steps, described in a helpful way? In what way it is a good story? Does the research seek to interpret or illuminate the actions and/or subjective experiences of the participants?

To summarise, this chapter covered the methodology of the first study - the Systematic Review. An introduction into systematic reviews was presented to understand how they compare with traditional literature reviews and scoping reviews. The chapter described the protocol for carrying out the systematic review starting with the research questions and literature mapping. Primary research was identified by searching two major bibliographic databases. The studies were selected based on their eligibility criteria. Relevant data that answered the research questions was extracted in a single format. The analysis and synthesis followed a thematic approach guided by the theoretical framework of the study. The results of the systematic review are presented in the next chapter.

Chapter 5. Systematic Review. Findings and Discussion

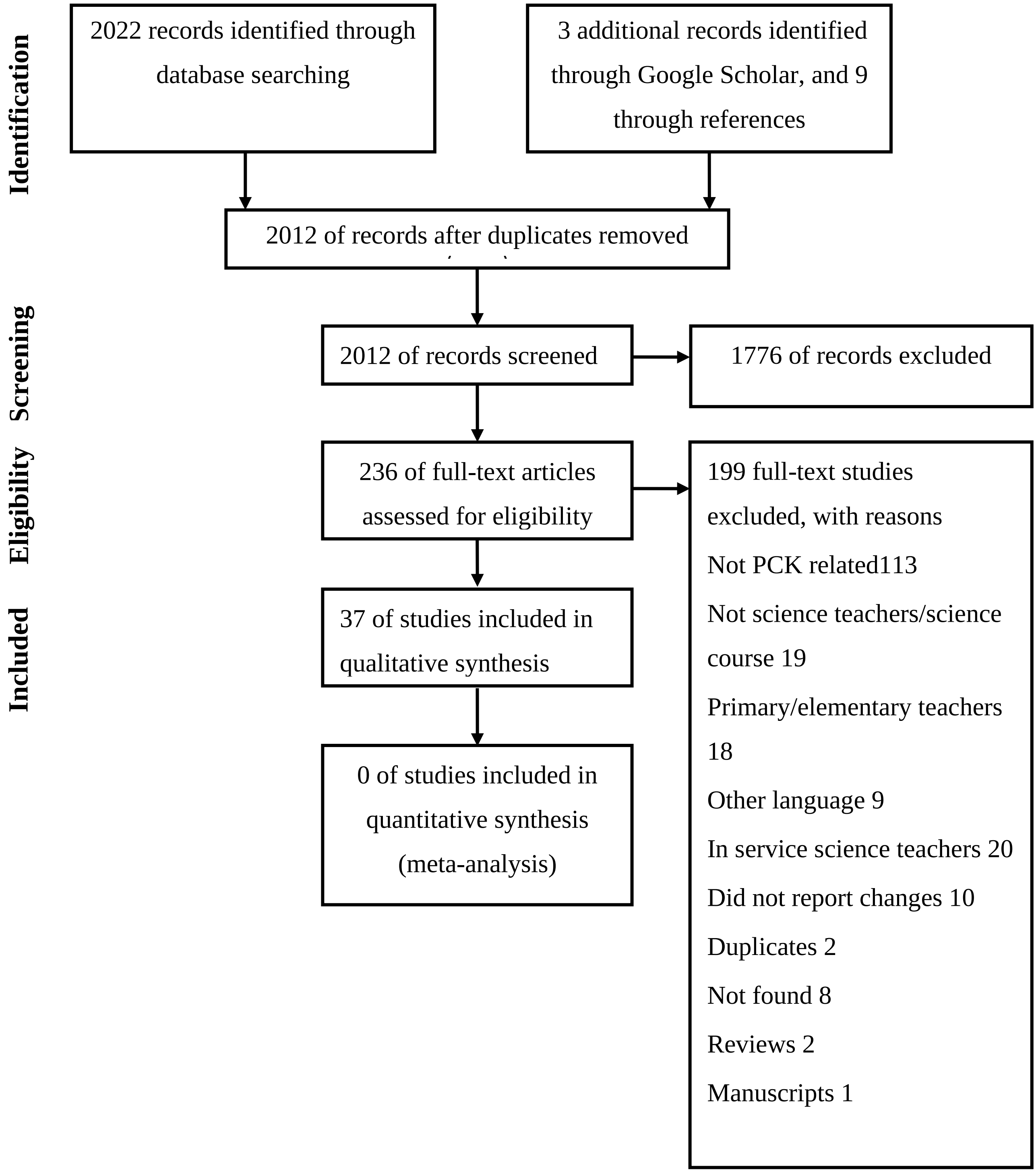
To identify effective ways for enhancing trainee science teachers' development, a systematic review was performed to examine empirical studies carried out in the last two decades (2000-2020) with science teachers as participants enrolled on teacher education programmes around the world. The previous chapter presented the protocol (methods) used in performing the systematic review. This chapter presents the findings and discussion of the systematic review study. The findings are presented into five sections. The first section describes the studies included in the review. The second section reports on the quality appraisal of the studies included in the review. The third section reports the findings that answer the research questions. The chapter ends with a discussion and conclusion of the review study.

5.1 Description of the studies

5.1.1 Identification of the Studies

Following the electronic searches of the two databases, Education (Pro-quest) and Web of Science databases, a number of 2110 citations was yielded. All the identified citations were exported directly into the bibliographic software (EndNote) where the duplicates were removed. The titles and abstracts of the identified studies were assessed for their relevance to the review. 224 studies remained for further selection. The full texts of all these studies were obtained and indexed in an excel spreadsheet. The process of selecting the literature through each stage of the review is presented in a Prisma diagram (Figure 12). The reference lists and citations of the retained studies generated a further number of nine articles and another three were added from Google Scholar through hand searching. A total of 236 full text articles remained for further analysis. A template with the exclusion and inclusion criteria served as a guide in selecting relevant studies to be included in the review.

Figure 12. Prisma Flow Diagram (Liberati et al., 2009; Boland, Cherry and Dickson, 2017)



Following the application of the inclusion and exclusion criteria, thirty-seven studies remained for in depth analysis. The studies from the final data set were included in a separate list (Appendix D)**.** The studies that did not meet the criteria were excluded with reasons.

5.1.2 Characteristics of the Studies

The characteristics of the studies are presented in Table 10. A table with more characteristics is found in Appendix B1 and B2.

Country of the studies. The country in which each study was conducted varied. Most PCK interventions were carried out in Turkey (n=10) and Germany (n=8). Five studies were conducted in South Africa, three studies were carried out in USA and another three in New Zealand. Two studies took place in Norway and The Netherlands, and one single intervention study was identified in the UK, Canada, and Indonesia. The small number of interventions in some countries may be attributed to the way in which PCK concept provides clarity and relevance for teacher education programmes (Settlage, 2013; Kind, 2015). Kind (2015) argues that PCK is ‘prone to individual researchers’ interpretations’ (p.123). Therefore, its absence from some countries may be because of the lack of clarity in the PCK conceptualisation.

Study design. Twenty of thirty-seven studies included in the review employed a qualitative design using mainly individual or focus groups interviews, lesson plans, field notes, reflection papers and self-completion questionnaires to collect data. A thematic approach to analysis was used in most of the studies. Twelve studies employed a mixed design with seven designs taking a quasi-experimental approach. The collection instruments varied from interviews to standard and open-ended questionnaires/tests. Data was analysed both qualitatively and quantitatively. Another five studies employed a quantitative design.

The collection instruments consisted mainly of paper and pencils tests, open ended questions, and other instruments. The other four studies were categorised as observational because the intervention activities were conducted by teacher educators of the training programmes rather than researchers.

Aim of the studies. Among the thirty-seven studies included in the review, ten studies focused on developing PCK in Biology topics, sixteen studies in Chemistry topics and six studies in Physics topics. Another five studies focused on developing PCK for NOS with three studies at general level and two studies at topic level. The studies selected for the review focused on different aspects of PCK. Most of the studies aimed at developing teachers' PCK in one, a few, or all the components of PCK framework used in their study at topic level. Some studies focused exclusively on the integration or interplay between components (e.g., Mavhunga and Rollnick, 2013), transformation or transfer to other topics or disciplines (e.g., Mavhunga, 2016; Mavhunga et al., 2016), learning progressions (Adadan and Oner, 2014) and relationships with orientations (e.g., Mavhunga and Rollnick, 2016; Demirdöğen, 2016). Three studies introduced technology in their intervention (Donnelly and Hume, 2015; Milner-Bolotin, Egersdorfer and Vinayagam, 2016; and Rutt and Mumba, 2019).

Context of the studies. The studies included in the review took place in different settings and contexts. Nine studies applied their intervention activities during the teaching practice in schools. Most of the intervention studies (n=17) were carried out during the coursework of the programme. Six studies covered both coursework and teaching practice in schools. Three intervention studies added synchronous and asynchronous online activities and two studies applied interventions activities in an outreach lab module. A total number of

1399 science teachers were counted as research participants in the studies. The duration of the interventions lasted from two hours to two years.

Type of intervention activities. The intervention activities varied across the studies. Six studies gave a greater focus on teaching experiences such as teaching in the classroom, microteaching and observation of others' teaching followed by discussions and reflections on experiences. Most of these studies covered both coursework and teaching practice in schools. Another eighteen studies approached their intervention from a collaborative perspective. The studies used a cyclical collaborative planning, teaching and reflection approach using pedagogical tools to guide focus and discussions like CoRe, PCK, prompts and questions. The repetead nature of the activities and learning in collaboration with peers and mentors was a main feature among most of these studies. A large number of these studies carried out their interventions over the coursework of the programme with a few including planning with school mentors (e.g. Hume and Berry, 2011; 2013). Another nine studies gave a greater focus on the integration of the PCK components into planning and teaching. These intervention studies were mostly carried out over the coursework of the programme and included activities modelled by educators and were related to teachers' practice. Such activities included explicit collective reflection, explanations, and demonstrations of transformation of content for teaching. A small number of studies emphasised the importance of a mentoring framework as the most effective approach to the development and integration of all PCK components. The studies included many of the activities mentioned previously such as CoRes, explicit PCK introduction, microteaching, and reflection coplemented troughout by an intensive educative mentoring. The intervention activities mostly took place in the teachers' school placements where the school mentors played a central role in helping them to develop PCK.

Table 10. Characteristics of the studies

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
1. Adadan and Oner, 2014/Turkey	Mixed Multiple Case Study	Methods course /One semester/2	To identify and describe the progression of chemistry teachers' PCK representations on the topic
2. Aydin et al., 2013 Turkey	Qualitative Case Study	Practicum course//14 weeks/3	To identify which aspects of the practicum course contributed to teachers' development
3. Aydin et al., 2015 Turkey	Qualitative Case Study	Practicum course/14 weeks/3	To examine how a CoRe-based mentoring-enriched practicum supported the developing interaction of PCK components in teachers

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
4. Aydeniz and Kirbulut, 2014/Turkey	Qualitative Case study	Teacher-education programme / 60-hour course/30	To design an instrument as teaching tool to enhance science teachers' topic specific PCK
5. Barnett and Friedrichsen, 2015/ USA	Qualitative Case study	Practicum/ 9.5 weeks/ 1	To describe the strategies used by a secondary biology mentor teacher to support the development of a teacher's PCK
6. Bektas et al., 2013/ Turkey	Qualitative Case study	Practice teaching course/ 14 weeks/ 7	To investigate chemistry teachers' pedagogical content knowledge of the nature of science (NOS) in the content of the particle nature of matter
7. Brown, Friedrichsen and Abell, 2013/USA	Qualitative Case Study	Teacher education programme/one year/4	To investigate science teachers' knowledge development at the subject specific level

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
8. Demirdögen and Uzuntiryaki-Kondakçi, 2016/Turkey	Qualitative Case study	Education programme/2 semesters/30	To investigate how chemistry teachers' science teaching orientations change during a two-semester intervention
9. Demirdöğen, 2016/ Turkey	Qualitative Case study	Education programme One semester/8	To investigate the interaction between orientation and other PCK components
10. Demirdöğen et al., 2016/Turkey	Qualitative Case study	Education programme two-semesters/30	To investigate the development and nature of chemistry teachers' PCK for NOS
11. Donnelly and Hume, 2015/New Zealand	Qualitative Case study	Teacher education course One year/7	To investigate how a collaborative technology, a wiki, may enhance existing and new opportunities for teachers' (PTs) to develop PCK

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
12. Ekiz-Kiran, Boz and Oztay, 2021/ Turkey	Case study Action research	Practicum /One semester/4	To improve pedagogical content knowledge (PCK) of chemistry teachers using a school experience course enriched with PCK development tools
13. Grospietsch and Mayer 2018/ Germany	Quantitative Comparison design	University course 12 weeks/57	To investigate to what extent a university course developed in accordance with a professional conceptual change model can reduce biology teachers' endorsement of neuromyths
14. Günther et al., 2019/Germany	Mixed Experimental control group design	Training programme three parts, with two of 90-min sessions/173	To develop an elaborate understanding of models and modelling for scientific inquiry

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	**Research design**	**Setting/Duration/ Participants**	**Aim**
15. Hume and Berry, 2011/New Zealand/Australia	Qualitative Case study	Teacher education course 30 weeks /9	To build the foundations on which novice teachers can begin developing their pedagogical content knowledge (PCK).
16. Hume and Berry, 2013/New Zealand Australia	Qualitative Case Study	Practicum/One year/4	To explore how collaboration with school-based mentors on teaching practice might impact on this process and student teachers' development of their pedagogical content knowledge (PCK
17. Jong, Driel and Verloop, 2005/The Netherlands	Qualitative instructional design	Teacher education/One year/12	To promote teachers' PCK of using particle models in teaching chemistry topics
18. Juhler, 2016/Norway	Mixed Case study, Design experiment	Practicum/One year /14	To study teachers' planning of a Physics lesson through the means of Lesson Study

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
19. Juhler, 2018/Norway	Mixed Case study, Design experiment	Practicum/One year/4	To describe and discuss an intervention in which Lesson Study was used in combination with Content Representation in teachers' school placement.
20. Jufri et al., 2019/ Indonesia	Quantitative Lesson-study - Action research	Teaching Biology course One semester /32	To analyse Lesson Study effects on development of science teachers' scientific literacy and PCK indicators
21. Karal and Alev, 2016/ Turkey	Qualitative Case study	Teacher training programme 3 academic terms/6	To investigate the development of physics teachers' pedagogical content knowledge (PCK)

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
22. Mavhunga and Rollnick, 2013/ South Africa	Mixed methods Case study	Teacher education/ methodology class/6 weeks/16	To improve the quality of PCK in chemistry teachers in a specified topic
23. Mavhunga and Rollnick 2016/South Africa	Mixed-methods-research Case study	Teacher education Programme- methodology class /6 weeks /16	To investigate the relationship between TSPCK and underlying science teacher beliefs following an intervention targeting the improvement of TSPCK in the topic chemical equilibrium
24. Mavhunga, 2016/ South Africa	Mixed-methods Case study research	Chemistry methodology class 6 weeks/36	To develop the competence of teachers to transform concepts in the topic of particulate nature of matter

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
25. Mavhunga, 2018/South Africa	Qualitative Case study	Chemistry methodology course 6 weeks/15	To improve the quality of PCK in core chemistry and physics topics, one of which is chemical equilibrium
26. Mavhunga et al., 2016/South Africa	Qualitative Case study	Physics methodology class 6-weeks /10	To investigate the transfer of the competence to transform content knowledge learned in electric circuits to a new topic in either chemistry or physics
27. Milner-Bolotin, Egersdorfer and Vinayagam, 2016/Canada	Quantitative Action research study	Physics methods course 13 weeks/ 8	To investigate how physics teachers' engagement with designing, answering, and commenting on conceptual multiple-choice physics questions via a PeerWise platform influenced their PCK development in physics.

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
28. Rutt and Mumba, 2019/ USA	Mixed	History of science course One semester /11	To describe the effects of an online history of science course on teachers' perceptions of and content and pedagogical knowledge for history of science–integrated science instruction.
29. Scharfenber and Bogner, 2016 /Germany	Mixed method Quasi-experimental	Outreach lab module 3 days /92	To investigate the impact of a teacher education module in an outreach lab on individual PCK development
30.Scharfenberg and Bogner, 2019/Germany	Mixed Quasi experimental	Outreach lab module 3 days/36	To investigate how teachers might develop more adequate tutor–student interactions
31. Schechter and Michalsky, 2014/Columbia	Mixed Quasi-experimental	Practicum /24 workshops/ 124 students /36 mentors	To explore the construct of PCK in relation to LFP (Learning from problems) and LFS (Learning from successes)

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
32. Smit, Rietz and Kreis, 2018 /Germany and Switzerland	Quantitative Quasi-experimental	Teacher education Two years/ 121	To determine the effects of a teacher training module on content-focused peer coaching
33. Smit et al., 2017/ Germany and Switzerland	Quantitative Quasi-experimental	Teacher education/One year/ 121	To investigate the longitudinal relationship between teachers' knowledge and attitudes on scientific inquiry teaching
34. Tolsdorf and Markic, 2017/Germany	Qualitative Cross-level study	University teacher training/108	To examine diagnostic competence in chemistry trainee teachers.
35. Wheeldon 2017/UK	Qualitative Case study	Teacher education/2 hours session/ 92	To support PSCT in rejecting the 'conservation of force' AC and replacing this with scientific causal arguments

Table 10. Characteristics of the studies (Continued)

Author/s Date of publication/ Country	Research design	Setting/Duration/ Participants	Aim
36. Weitzel and Blank, 2019/Germany and Switzerland	Mixed- method quasi-experimental	Teacher education /four workshops of 90 minutes/121	To examine the extent to which Content-Focused Peer Coaching (CPC) supports biology teachers in planning lessons for teaching scientific methods
37. Van Driel, Jong and Verloop, 2002/ The Netherlands	Qualitative	Teacher Education /one semester /12	To investigate the development of PCK among chemistry teachers

5.2 Quality of the Studies

In accordance with Jones's (2004) statement that systematic reviews of qualitative research are best served by reliance upon qualitative methods themselves, the studies were assessed according to their reported methods as part of the analytic process of a systematic review (Gough, 2007). The studies were assessed on five criteria of methodological soundness according to the assessment tool developed and presented in Chapter 4. The assessment score of individual studies is found in Appendix E. The five criteria were:

Aims and objectives. The aim and objectives were clearly articulated in all the studies.

Reflectiveness. To score yes for this criterion, the studies were appraised against whether: - they used transparent methods for data collection and analysis process; - there was a justification and adequate description of the methods used for data collection and analysis process; - the findings were made explicit and the author/s recognised limitations/challenges of the study with respect to the findings and their own background and beliefs (self-reflection).

Most of the studies scored *yes* at this criterion of reflectiveness. The methods for data collection and analysis process were made transparent. All the studies used triangulation to ensure the validity of their data. The interviews were the most common source of primary data. Other sources like lesson plans, written reflections and observations were used to capture the participants' knowledge and views. Many studies used transparent methods for analysis with an adequate description. Studies used one or more strategies to ensure clarity and minimise bias in collecting data and/or in the analysis according with their own design and methodology. Among these strategies were discussions with peers (peer debriefing), feedback from independent raters/researchers/experts, agreement among the authors, reducing the impact of familiarity by revising the codes after a time, triangulation, long term engagement, member check, written protocols, or the use of established statistical formulas, methods and packages in quantitative studies, pilot application. Where the studies reported on numerical data, the authors made a clear discussion of the results. Less reflectiveness was found on researchers' own background and beliefs. Although details about the participants' age and gender were mostly given, their background or ethnicity was inconsistent among studies.

Ethical considerations. To score yes at this criterion, a study had to have ethical considerations clearly delineated regarding the context and selection of the participants. Although many studies did not report on ethical issues regarding the consent from the participants, and confidentiality and anonymity, this was implied since each study was taken from peer reviewed journals which is assumed to adhere to ethical guidelines before starting the study. In all studies which reported on their recruitment strategy, the participants were recruited from the cohort enrolled in the science programme. The selection targeted information rich cases/volunteers based on convenience sample, science teaching efficacy beliefs scale, participants who completed subject matter courses/ and other required courses, purposeful sampling; similar background (no previous teaching experience or taken the same courses (Donnelly and Hume, 2015; Scharfenberg and Bogner, 2016).

Narration. The studies were assessed on a clear descriptive /interpretative stance, an attempt to illuminate the experiences of the participants, and in what way it was a good story. Many studies took the form of a familiar plot seeking to interpret the actions of the research participants. Studies were easy to follow and included roadblocks and challenging steps. The participants' actions/knowledge was captured through diverse collection instruments. Some studies were more descriptive rather than interpretive in nature due to their design where the evidence for the participants' gain in PCK was represented more numerically than textual.

Usefulness. This criterion was concerned with the extent to which the studies made a useful contribution or impact to the body of knowledge, to research or practice. Their findings had impact on practice and research contributing to the advance in knowledge and practice of teaching science. The findings were relevant to education programmes that aimed to develop science teachers' PCK, providing evidence of the strategies that work and why.

Overall quality of studies

Overall, most of the studies were judged according to quality criteria as being good methodological soundness studies (Table 11). Two studies were judged as medium (Tolsdorf and Markic, 2017) and poor (Jufri et al., 2019) methodological soundness studies. The first study was limited in illuminating the participant's perspectives and answers using limited sources of data. The second study failed to give an adequate description of their methodology and it was not clear how the activities were delivered and nor the participants' experiences were clearly portrayed. Both studies were kept in the review due to their relevance to the research questions. When accounted for in the conclusion section, their findings did not change the conclusions of the results. Their findings were in the same line with other findings.

Table 11. Methodological quality of the studies

Quality	N = 37
Good methodological soundness studies	35
Medium methodological soundness studies	1
Poor methodological soundness studies	1

5.3 Findings from the Analysis of the Systematic Review

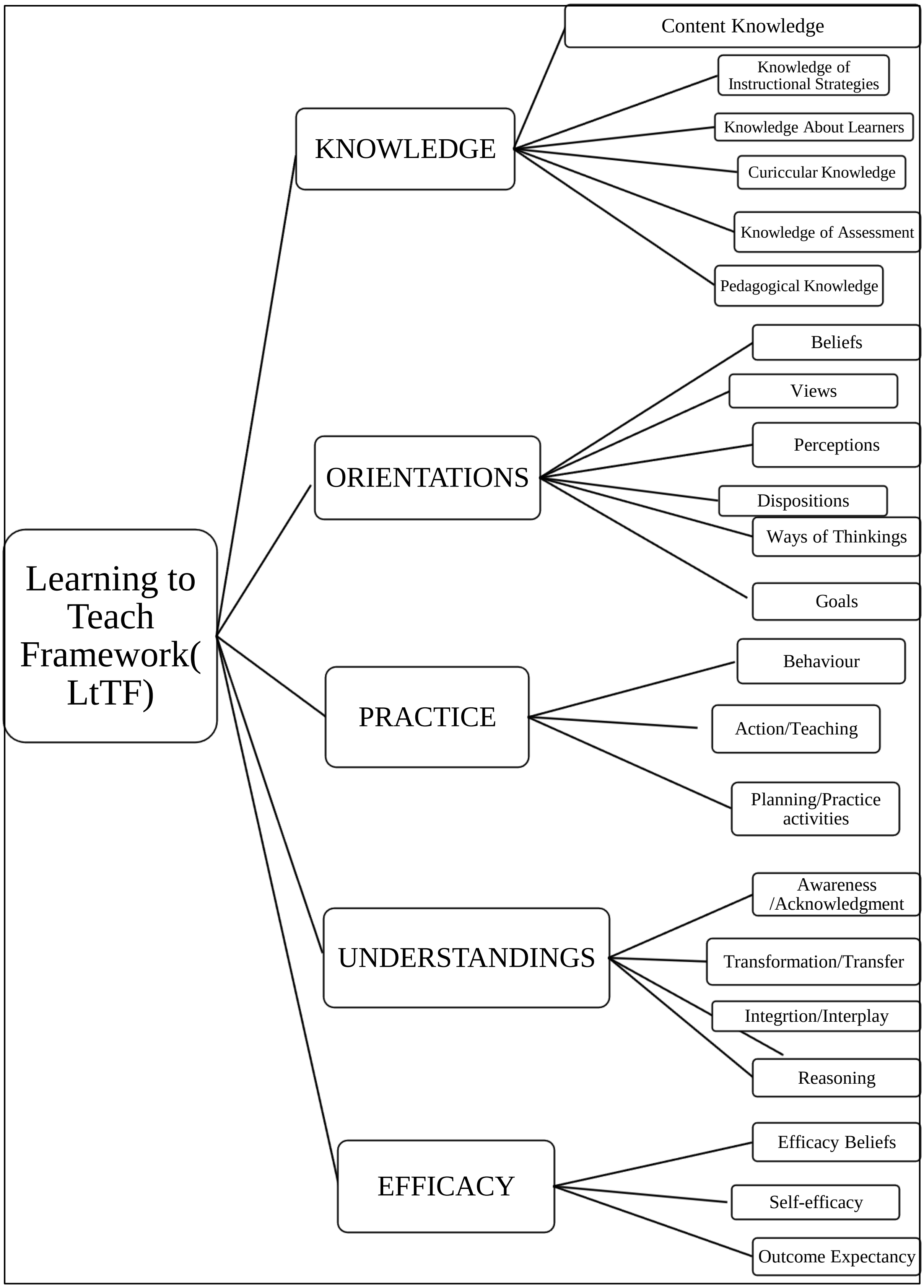
This section addresses the findings of the systematic review according to the research questions. The main research question addressed by the review was: What PCK approaches are effective in preparing science teachers? To answer this question, two sub-questions were addressed: What is the evidence for teachers' PCK development during their education programmes in different contexts? What learning opportunities contribute to teachers' PCK development during their education programmes?

5.3.1 Research Sub-Question 1. Evidence for Gains in Teachers' PCK

The first research sub-question sought to gather the evidence for teachers' PCK development during their education programmes. The evidence for teachers' PCK development was extracted from each study included in the review in the form of individual statements concerning gains in the components of PCK. The analysis revealed that the intervention activities mostly had a positive impact on teachers' PCK development. The evidence for teachers' gains in PCK components was grouped in five main themes resulting from the analysis. The five themes as types of evidence for teachers' PCK development were organised in a new PCK based framework - *Learning to Teach Framework (LtTF)*. The five types of evidence or themes comprising the *Learning to Teach Framework* were: *Knowledge base* for teaching a given science topic; *Orientations* for teaching a given science topic; *Practice Skills* for planning and teaching the topic; *Understandings* - the steps taken for the transformation of the content for teaching, integration of different components in planning and teaching, reasoning and reflection on the topic and limitations as well as acknowledgements; and *Efficacy* in teaching the topic. Each type of evidence represented a theme (component) and each theme included sub-themes (sub-components) (see Figure 13).

The sub-themes within the *Knowledge* theme were knowledge of content, knowledge of instructional strategies, knowledge of curriculum, knowledge of learners, knowledge of assessment and knowledge of pedagogy. The sub-themes of O*rientation* theme were beliefs, views, perceptions, dispositions, goals, and ways of thinking. The sub-themes for P*ractice* were planning, action, behaviour, and teaching.

Figure 13. Learning to Teach Framework (LtTF) developed in the study



The *Understanding* theme included reasoning, transformation, transfer, interplay, and integration. The *Efficacy* theme included self-efficacy, outcome expectancy, and confidence. Learning to Teach Framework was used as analytical strategy in the cross-studies synthesis (see Table 12). The five themes with their sub-themes as evidence for teachers' gains in PCK are described as follows:

Gaines in Knowledge

The *Knowledge* theme comprised gains in conceptual knowledge of content, learners, instructional strategies, assessment, and curriculum. Nine studies reported gains in content knowledge in terms of identifying, developing, and organizing the topic into big ideas (Adadan and Oner, 2014; Aydin et al., 2015; Mavhunga, 2016; Mavhunga and Rollnick, 2016) or displayed, adjusted and made decisions about the content (Hume and Berry, 2013; Mavhunga, 2016). A significant increase in content knowledge was reported in two quantitative and one mixed studies conducted by Grospietsch and Mayer (2018); Jufri et al. (2019) and Günther et al. (2019), all in biology topics. Karel and Alev (2016) reported an increase in subject matter knowledge due to teaching experiences over the course. Gaines in curriculum knowledge was less addressed. In one study, teachers were able to make certain decisions about what to exclude (Adadan and Oner, 2014). The most addressed type of knowledge was knowledge of learners. Significant gains were reported on learners' difficulties and misconceptions. Some studies found that teachers were able to recognize the sources of misconceptions as their ideas about learners' difficulties became more sophisticated (Aydin et al., 2013; Adadan and Oner, 2014; Mavhunga, 2016). Also, teachers were able to identify, anticipate and discuss concepts that could cause potential difficulties for learners (Jong, Driel and Verloop, 2005; Mavhunga, 2016).

Table 12. Learning to Teach Framework (LtTF) – the Analytical Strategy

Topic Specific PCK Components	Learning to Teach Framework Components				
	Knowledge	**Orientations** (Beliefs/Habits of mind)	**Practice** Planning/Teaching	**Understandings** Reasoning/Reflection/integration	**Efficacy** (Self-efficacy/ Outcome expectancy)
Curriculum	Programmes Materials	Goals	Selection of materials	Curriculum saliency/links	Anticipatory Cognitive motivators
Content	Academic and school content	Beliefs Views	Concepts maps	Transformation/integration /Sequencing	Outcome expectations Self-efficacy
Learners	Difficulties Misconceptions	Beliefs about learners	Searching alternatives and misconceptions' sources	Integration in planning	Outcome expectations
Instructional Strategies	General and specific instructional strategies	Inquiry Discovery	Selecting/ practicing strategies	Integration in planning Limitations	Outcome expectations Self-efficacy
Assessment	Methods of assessment	Beliefs about assessment	Designing tests/ questions	Integration in planning Limitations	Outcome expectations Self-efficacy

In another studies, teachers addressed and tried to correct misconceptions during their teaching (Aydin et al., 2013; Barnett and Friedrichsen, 2015; Mavhunga, 2018).

Knowledge of instructional strategies was also a common knowledge targeted by authors of the review studies. In some studies, teachers explained the importance of instructional strategies (Barnett and Friedrichsen, 2015) and wrote down and discussed those strategies that they considered potentially useful to enhance students' understandings (Jong, Driel and Verloop, 2005; Scharfenberg and Bogner, 2016). Scharfenberg and Bogner (2016) also observed that teachers changed their strategies to overcome students' difficulties.

Only one study focused exclusively on assessment knowledge (Juhler, 2018). The study reported only a limited effect of the intervention on teachers' focus on assessment. In the study, only one student of three used some evidence as the basis for assessing the lesson. Progress in knowledge of assessment was also reported in other studies. Aydin et al. (2013), Bektas et al. (2013) and Adadan and Oner (2014) noticed that teachers intended to employ multiple assessment strategies to assess students' science learning and respectively developed knowledge of assessment in terms of what to assess. Barnett and Friedrichsen (2015) noticed that one teacher redesigned a question to better assess students' knowledge while in another study (Demirdögen and Uzuntiryaki-Kondakçi, 2016) teachers co-examined and revised previous unit examination questions to better assess students' understanding. A couple of studies reported gains in assessment knowledge in terms of more uniform focus compared with the control group (Juhler, 2016; Jufri et al., 2019).

Changes in Orientations

The *Orientation* theme included teachers' changes of thoughts, views, goals, and beliefs due to an activity designed to help teachers develop PCK. Sixteen studies targeted the orientation component of PCK. Three studies had an exclusive focus on this component

(Demirdögen and Uzuntiryaki-Kondakçi, 2016; Demirdöğen, 2016; Scharfenberg and Bogner, 2019). These studies reported on teachers' progress towards more student-centred orientations due to the intervention activities. Demirdöğen (2016) noticed that some teachers expressed sophisticated views about Nature of Science. Teachers changed their views from a teacher-centred pedagogy of 'telling', to a more constructivist view.

A shift from traditional towards more student-centred beliefs was also noticed by Aydin et al. (2015) and Mavhunga and Rollnick (2016). Barnett and Friedrichsen (2015) noticed that teachers reconsidered the lesson and proposed a way to make it more learner centred. Aydin et al. (2013) reported that teachers aligned the strategies with their orientations for teaching and Adadan and Oner (2014) observed that teachers set the development of science process skills as a goal for teaching. Brown, Friedrichsen and Abell (2013) found that science method course helped teachers to expand their ideas. Similarly, Grospietsch and Mayer (2018) observed a decline of transmissive beliefs in the post-test intervention. In Smit et al. (2017) and Smit, Rietz and Kreis's (2018) studies, teachers demonstrated slightly higher attitudes regarding scientific inquiry teaching.

Gains in Practice

The *Practice* theme included gains in teaching, diagnostic, and planning skills. Although teaching opportunities were scarce across the studies, many studies used Content Representation (CoRe) framework as a tool to engage teachers in individual or collective planning. In some studies, CoRe was the primary method for collecting data through which the authors measured teachers' PCK development. A few studies followed and observed teachers in the classroom (Brown, Friedrichsen and Abell, 2013; Karal and Alev, 2016).

CoRe framework helped teachers to develop their practical skills showed in the design of experiments and other activities in studies carried out by Karal and Alev (2016), Demirdöğen (2016), and Demirdöğen et al. (2016). Hume and Berry (2013) found that teachers developed their ability to refine and adjust planning as they tested, evaluated, and modified their initial CoRe. The authors noticed that one teacher incorporated all the additions and changes made to the second draft after teaching and reflection had finished. Similarly, Weitzel and Blank (2019) noticed that teachers engaged in discussions about numerous modifications during their planning dialogues. The number and range of changes recorded in the lesson plans was found significantly higher in the intervention group. Other authors found that teachers included a detailed account in their planning which showed their expanded developed repertoire (Jong, Driel and Verloop, 2005).

In Brown, Friedrichsen and Abell's (2013) study, during the planning process, teachers considered multiple opportunities for students. They were able to combine ideas about discovery learning with evidence-based explanations to create more sophisticated ideas about students' learning. While teaching, teachers were noticed to provide students with multiple opportunities for learning as per their planning. In their study, Hume and Berry (2011) observed that teachers tackled CoRe with more purpose. Donnelly and Hume (2015) claimed that CoRe encouraged teachers to think more about possible misconceptions. In Jong, Driel and Verloop's (2005) study, teachers modelled activities to students. Karal and Alev (2016) found that one teacher, in his teaching session, spotted students' misconceptions and tried to eliminate them by asking questions to students and using a range of representations. Progress in teachers' ability to plan and teach was also reported in the study conducted by Schechter and Michalsky (2014).

Gaines in Understandings

The *Understanding* theme was in terms of teachers' awareness, acknowledgment, transfer, transformation, and interplay/integration between PCK components. Some studies had a particular focus on teachers' understandings while others included this component in their broad aim of developing teachers' PCK. The studies found that, during the programme, teachers developed their awareness about some requirements for teaching and learning science. Teachers became aware of students' misconceptions, their learning difficulties as well as about the importance of eliciting students' prior knowledge (Aydin et al., 2013; Brown, Friedrichsen and Abell, 2013; Mavhunga and Rollnick, 2013; Demirdöğen, 2016). Mavhunga (2016) claimed that expanded explanations of the main concepts increased awareness of what concepts are difficult for learners to understand. Van Driel, Jong and Verloop (2002) found that teachers became aware of students' difficulties in distinguishing between macro and micro levels and developed a growing awareness of the nature of atoms and molecules as models. A better understanding of the use of models was also found in another study conducted by Jong, Driel and Verloop (2005). Some authors affirmed that teachers became aware of the components of PCK being able to give more explanations and elaborations within CoRes (Hume and Berry, 2011). By using CoRe, teachers became aware of their limitations on learning difficulties in Hume and Berry's (2013) study. A similar finding was found by Milner-Bolotin, Egersdorfer and Vinayagam (2016). The authors reported on teachers' awareness of their own knowledge deficiencies during the online activity on designing multiple choice questions.

Nine studies focused on the integration of PCK components. The findings of these studies indicated an increase in the participants' connections between the PCK components. Bektas et al. (2013) and Aydin et al. (2015) found that the participants developed knowledge about how to connect knowledge of curriculum with knowledge of assessment and knowledge of learners, and to integrate aspects of NOS. Demirdöğen (2016) noticed an interaction of the purposes related to teaching science content with all the other PCK components: knowledge of curriculum, instructional strategies, learners, and assessment. In other studies, in their lesson plans on NOS, the participants successfully aligned knowledge of instructional strategies, of learners, and of assessment with teaching orientation (Demirdöğen et al., 2016; Demirdögen and Uzuntiryaki-Kondakçi, 2016). In Mavhunga's (2016) study, teachers were noticed to interactively draw on different PCK components to develop detailed explanations. Similar evidence was found in Mavhunga's (2018) and Mavhunga and Rollnick's (2013) studies. The authors reported on teachers' ability to make connections between the components of PCK in a complex manner when 'the interplay with other components emerged naturally'.

In some studies, a considerable attention was given to the transformation and transfer of knowledge. Mavhunga (2016) noticed that teachers were able to successfully apply their understandings about transformation of content knowledge in the topic given. Teachers were able to give detailed explanations of the main concepts and to transfer the knowledge from one topic to another by engaging with the new topic in the same approach as in the intervention. Transformation of knowledge was also demonstrated by explanations, elaborations, diversification, and description of representations in other studies conducted by Mavhunga and Rollnick (2016), Karal and Alev (2016) and Mavhunga (2018). Hume and Berry (2011) noticed that the explanations and elaborations within the CoRe plans were more detailed and teachers developed skills which appeared to be transferable. In Mavhunga and Rollnick's (2013) study, teachers improved their ability to reason about the topic. Finally, Wheeldon (2017) stated that the training activities helped teachers to elaborate on explanations using analogies.

Gaines in Efficacy

The fifth theme, *Efficacy* was not a major focus among the review studies. However, the activities and successful experiences usually have direct impact on teachers' efficacy beliefs or self-efficacy (Bandura, 1977). In the context of PCK, only a few studies gave explicit attention to teachers' self-efficacy. Hume and Berry (2011) noticed that teachers tackled CoRe design with more purpose and confidence, more readily located relevant information, and showed increased independence. In Schechter and Michalsky's (2014) study all the treatment groups improved in the components from STEBI-B (Science Teachers Efficacy Beliefs Instrument Variant B) whilst Smit et al. (2017) found moderate control and affective beliefs.

In summary, this sub-section answered the first research sub-question that sought to identify the evidence for teachers' gains in the PCK components targeted by the individual studies included in the review. The authors of the review studies claimed that teachers' gains in the five components of *Learning to Teach Framework* were due to the features of their interventions. The evidence for teachers' development identified through the analysis comprised: - teachers' gains in knowledge of the topic used in the review studies (conceptual knowledge); - gains in planning and teaching a particular topic (practice knowledge and skills); - gains in understandings of how to plan and teach the topic (procedural knowledge); - gains in efficacy for teaching; - and changes in orientations from traditional towards more student-centred approach. The next section addresses the effective features that contributed to science teachers' gains in the above components for teaching and answered the second research sub-question.

5.3.2 Research Sub-Question 2. Effective Features for Learning to Teach

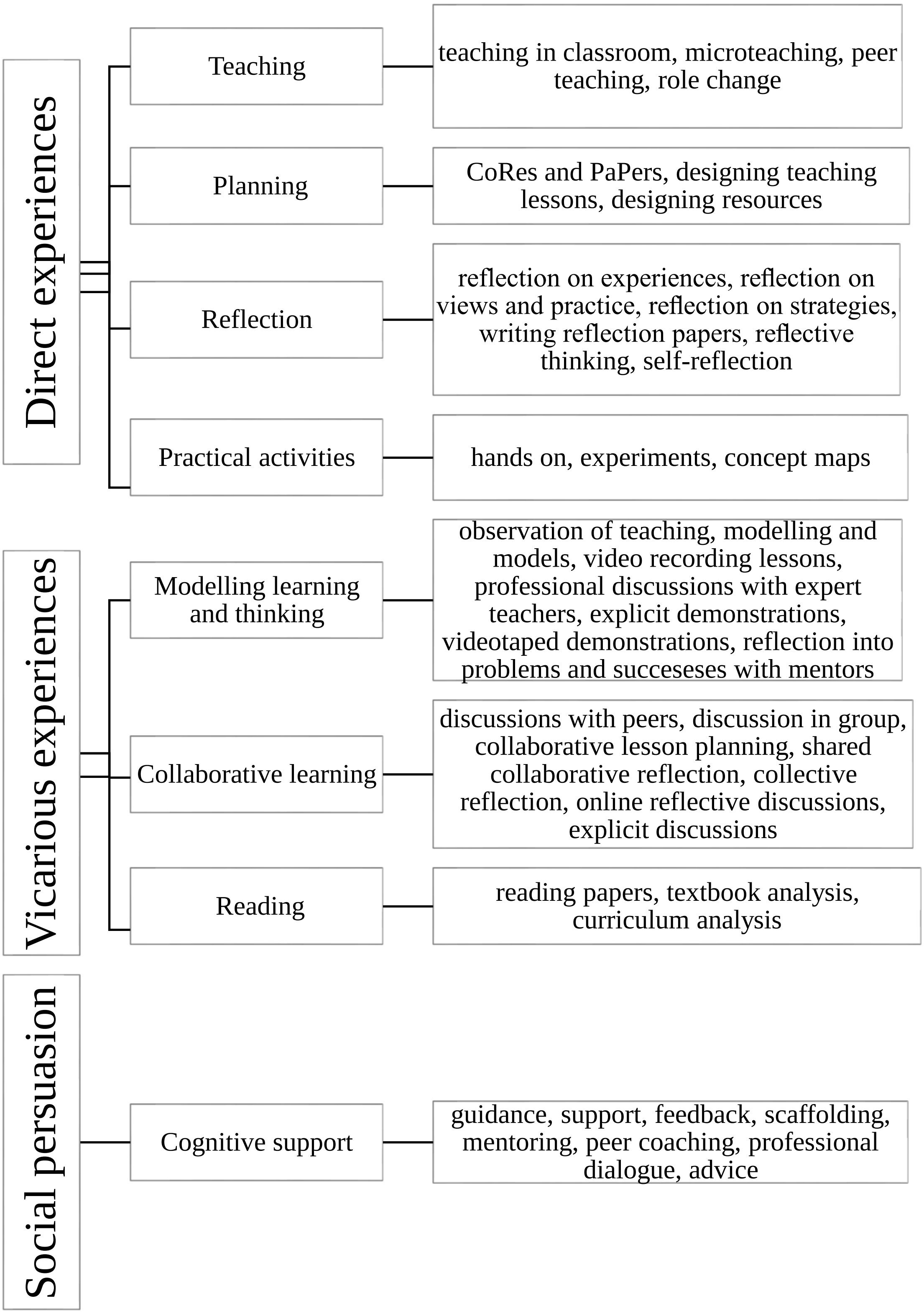
This section addresses the second sub-question of the review study that sought to identify the learning opportunities that contributed to science teachers' PCK development during their education programmes. The effective features, identified from the review studies, were learning opportunities or strategies with the greatest impact on teachers' development in the five components of *Learning to Teach Framework*, namely *Knowledge, Orientations, Practice skills, Understandings,* and *Efficacy*. The inductive thematic analysis resulted in eight common themes of effective features. The eight themes were then deductively grouped into three categories according to three of Bandura's (1977) sources of self-efficacy. The three categories of effective features were Direct Experiences, Vicarious Experiences and Social Persuasion (Figure 14).

Direct Experiences

Opportunities for direct experiences were found in most of the studies in different combinations.

Reflection was one of the mostly used strategy for developing teachers' PCK. Reflection was used in many forms. Adadan and Oner (2014) and Barnett and Friedrichsen (2015) offered teachers opportunities to critically reflect on their experiences by sharing ideas with peers. An explicit reflective instruction and discussions contributed to the increase in the percentage of participants with informed views on majority of NOS aspects in studies carried out by Demirdögen and Uzuntiryaki-Kondakçi (2016), Demirdöğen (2016), Demirdöğen et al. (2016) and Grospietsch and Mayer (2018). Explicit reflection with an emphasis on reflection on models was also used by Günther et al. (2019).

Figure 14. Identified Effective Features for Learning to Teach Science grouped in Bandura's three sources of self-efficacy.



Group reflection contributed to significant increase in teachers ‘scientific literacy and PCK competencies in the study conducted by Jufri et al. (2019). Also, collective reflection was found to be useful in Schechter and Michalsky’s (2014) and Mavhunga’s (2018) intervention studies. Schechter and Michalsky (2014) applied dual reflection into both problematic and successful events, and reflection together with mentors and peers. Reflection with peers was also found in Weitzel and Blank’s (2019) study.

Reading, as another learning strategy contributed to teachers’ PCK improvement in some studies. Van Driel, Jong and Verloop (2002) reported on activities, such as readings and discussions on research literature, in relation to teachers’ own beliefs and teaching experiences. Jong, Driel and Verloop (2005) found that teachers expanded their PCK due to opportunities to analyse and discuss sections of a chemistry textbook. Bektas et al. (2013) noticed that teachers prepared their teaching plans using chemistry textbooks as source of information. Science teachers were given opportunities to examine the national curriculum and some available materials in the study conducted by Adadan and Oner (2014). The authors observed that teachers became aware of students’ conceptions of the behaviour of gases by individually reading several papers about misconceptions. Karal and Alev (2016) reported improvement due to direct contact and communication with students themselves, textbooks, and curriculum. Similarly, Grospietsch and Mayer (2018) asked teachers to analyse conceptual change texts.

Lesson Planning was a main strategy for developing teachers’ teaching skills. In many studies, CoRe served as a framework for planning. Aydin et al. (2015) noticed that the matrix format of CoRe enabled the participants to articulate their PCK and ‘forced’ them to make connections between different components. Similarly, Juhler (2016) found that Lesson Study (LS) and CoRe determined teachers to focus more on learner-centred approach in planning**.** Donnelly and Hume (2015) noticed that teachers found CoRe helpful in generating big ideas and structuring concepts in a way to avoid misconceptions. Planning with CoRe was also used with positive impact in studies conducted by Mavhunga (2018), Mavhunga and Rollnick (2013) and Mavhunga and Rollnick (2016). In some studies, teachers planned in collaboration with mentors (Hume and Berry, 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015). Brown, Friedrichsen and Abell (2013) applied in their intervention a method for learning guided by five phases of enquiry (5Es - Engage, Explore, Explain, Elaborate and Evaluate), offering teachers opportunities to experience and design 5E instructional sequences. Milner-Bolotin, Egersdorfer and Vinayagam (2016) offered teachers opportunities to design teaching resources.

Direct Teaching in the form of microteaching, peer teaching, first-hand experiences, and role-change approach allowed teachers to practice teaching and to improve their PCK. The studies conducted by Aydin et al. (2013) and Bektas et al. (2013) reported on improvement in teachers' PCK due to teaching experiences. Jufri et al. (2019) found that practicing teaching in groups provided opportunities for teachers to improve their content knowledge and PCK competencies. Karal and Alev (2016) claimed an increase in test due to teachers' teaching experiences. Similarly, Van Driel, Jong and Verloop (2002) and Scharfenberg and Bogner (2016) reported improvement in teachers' PCK due to hands-on experiences, role change approach, and classroom teaching experience. In a few studies, teachers had opportunities to organize the knowledge using PCK maps, concepts maps, and mind maps **(**Aydin et al., 2015; Mavhunga et al., 2016; Jufri et al., 2019).

Vicarious Experiences

Vicarious experiences provided teachers with opportunities to observe teaching and modelled activities, and to learn from collaboration and reflection with peers and mentors. When teachers had opportunities to observe teaching and modelled activities, they were found to improve their knowledge and confidence in teaching. Observations of teaching, modelling, video recording lessons, video annotations, professional discussions with expert teachers, videotaped demonstration, reflection into problems and successes with mentors were all useful strategies to improve teachers' PCK development. Aydin et al. (2013) engaged teachers in microteaching. Observations of peers' microteaching helped teachers to realize the importance of learners' prerequisite knowledge, difficulties, and misconceptions. Bektas et al. (2013) created activities for teachers to observe their mentors and other teachers' teaching about NOS. Karal and Alev (2016) reported improvement in PCK due to observations of another teacher's teaching. Milner-Bolotin, Egersdorfer and Vinayagam (2016) applied peer instruction approach and Scharfenberg and Bogner (2019) peer-tutor play. Approaches and strategies for teaching were modelled by Adadan and Oner (2014) and Barnett and Friedrichsen (2015). Mavhunga (2016) found written evaluations of video-recorded lessons and explicit demonstrations of the breaking down the Topic Specific Pedagogical Content Knowledge (TSPCK) construct into its individual components very useful. Models were also employed by Günther et al. (2019). Schechter and Michalsky (2014) offered teachers opportunities for reflection with mentors and peers. Wheeldon (2017) supported teachers with prompts and analogies as models.

Collaboration was a commonly employed feature to increase teachers' PCK. Discussions with peers, discussions in groups, collaborative lesson planning, shared collaborative reflection, collective reflection and collaborative learning were found to improve teachers' PCK development in many studies. Adadan and Oner's (2014) focused on peer learning, an approach in which teachers worked with their peers to create CoRe lessons and share their readings on students' misconceptions on the topic. Similarly, peers' tutor play approach has been argued both to 'effectively stimulate substantive reflection,' and to be 'useful for developing a critical stance toward instruction' in Scharfenberg and Bogner's

(2019) study. Many studies engaged teachers in group discussions on various aspects such as: sections of a chemistry textbook (Jong, Driel and Verloop, 2005), explicit-reflective discussions of PCK for NOS components (Demirdöğen et al., 2016), discussions about transformation of topic concepts (Mavhunga and Rollnick, 2013), discussions about representations as one of the components of the TSPCK construct (Mavhunga and Rollnick, 2016) or meaningful discussions and collaboration on designing teaching resources (Milner-Bolotin, Egersdorfer and Vinayagam, 2016). In some studies, the focus was on discussions and collaboration with mentors. In studies conducted by Barnett and Friedrichsen (2015) and Hume and Berry (2013), teachers planned lessons in collaboration with their mentors while in Donnelly and Hume's (2015) study, teachers discussed CoRe lesson plans with their mentors and reasoned on the selection of instructional strategies.

Various discussions with mentors were also found in studies conducted by Van Driel, Jong and Verloop (2002) and Schechter and Michalsky (2014). Jufri et al. (2019) noticed an increase in the number of students engaged actively in group discussions. Only two studies used social media as preintervention - interactions with mentors before teaching. For example, in Mavhunga and Rollnick's (2013) study, some tutorial sessions were held on a voluntary basis outside the formal class time on the interactive online platform called Blackboard ignite (BBignite). On BBignite teachers were organized in same groups as in the class, and within groups, they could chat online through written texts. Teachers were engaged in online collaborative learning in another three studies (Donnelly and Hume 2015; Milner-Bolotin, Egersdorfer and Vinayagam, 2016; Rut and Mumba 2019).

Social Persuasion

In many studies, teachers benefited of cognitive support for developing PCK. In studies carried out by Aydin et al. (2015) and Barnett and Friedrichsen (2015), teachers benefited of guidance from mentors during a collaborative planning. Mentoring support, in terms of feedback on CoRe and suggestions for planning the topic for teaching, was a main feature in the studies conducted by Hume and Berry (2011) and Hume and Berry (2013). Mentoring support was also found in studies conducted by Schechter and Michalsky (2014) and Tolsdorf and Markic (2017). Jufri et al. (2019) observed that facilitation and guidance from the educator led to more meaningful and effective student interactions. Aydeniz and Kirbulut (2014) and Milner-Bolotin, Egersdorfer and Vinayagam (2016) found that teachers sought confirmation of their understandings from their peers. Scaffolding strategies were also employed by Scharfenberg and Bogner (2016) and Juhler (2018).

In summary, the identification of the effective learning opportunities (direct experiences, vicarious experiences, and social persuasion), that contributed to the development of the five components of *Learning to Teach Framework*, answered the second research sub-question of this study. The effective learning opportunities are further discussed (in the following section) in relation with the five components of the framework to determine the effectiveness of PCK approaches and to answer the main question of the study.

5.3.3 The Main Research Question. Effective PCK Approaches

This sub-section answers the main research question of the review study: What PCK approaches are effective in preparing science teachers during their education programmes? The main research question was answered by analysing the relationships between the identified effective learning opportunities and their impact on teachers' improvement in the five components of *Learning to Teach Framework*. The analysis resulted in four synthesis categories (analytical themes) based on similarity in the approach taken (key features of the interventions). This section gives details on individual studies to understand their unique context and the contribution of each study to each category of findings. The four synthesis categories identified as effective approaches to science teachers' development were: ***Teaching Experiences; - Collaborative Planning, Teaching, and Reflection in Cycles; - Integration and Transformation; - and Consistent Cognitive Support.***

Teaching Experiences

Several studies pointed to direct teaching experiences as the most effective approach to science teachers' development (Table 13).

Table 13. Teaching Experiences

Effective PCK approach	Key features	Studies
Teaching Experiences	Direct teaching in the classroom	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic 2017; Ekiz-Kiran, Boz and Oztay, 2021.
	Observing mentors and peers' teaching	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021.
	Reflections on teaching	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Ekiz-Kiran, Boz and Oztay, 2021.
	Readings/Discussions	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021

Teaching experiences included teaching in the classroom, microteaching, and observations of others' teaching followed by discussions and reflections on experiences. Teaching experiences were emphasized mostly by studies that covered both coursework and teaching practice in schools.

Bektas et al. (2013), in an observational study, investigated teachers' understandings of Nature of Science (NOS) for particle nature of matter in chemistry during fourteen weeks of practice teaching course. The practice teaching course included content embedded NOS instruction with the aim to improve teachers' teaching about NOS by making connections between NOS and specific chemistry content. The authors examined teachers' views on aspects of NOS and PCK in relation with knowledge of learners, knowledge of instructional strategies, and knowledge of assessment. During their teaching practice course, teachers had opportunities to engage in discussions about NOS aspects and to write reflection papers on their teaching experiences. They had opportunities to plan lessons, observe teaching, and teach both in the classroom and in microteaching sessions at the university. Teachers' written observations, lesson plans, and interviews indicated that teaching experiences (teaching and observing mentors' and peers' teaching) were the most helpful features for teachers to develop knowledge and understandings on NOS over the course. Less progress was noticed in knowledge of assessment compared to knowledge of instructional strategies. Teachers showed variation in the level of development and the integration of NOS aspects in lessons.

The findings support those in Van Driel, Jong and Verloop (2002) and Jong, Van Driel and Verloop (2005). Van Driel, Jong and Verloop (2002), in a semester of education programme, focused on developing teachers' knowledge of specific conceptions, students' learning difficulties and knowledge of instructional strategies. The authors found classroom experience with the most powerful impact on teachers' PCK development. As in previous studies, teachers experienced teaching in the classroom and observed their mentors' and peers' teaching. Through discussions with their mentors, teachers developed awareness about instructional strategies, about students' learning difficulties, and use of language. Their expansion of representations following teaching was attributed to students' posed questions, students' responses to tests and assignments, and observation of others' teachings. During workshops at the university, teachers participated in reflections on their teaching experiences. They also developed understandings of students' learning difficulties by reading academic papers. The less progress and variation were explained by insufficient NOS subject knowledge of the topic taught.

The same focus on student's learning difficulties and instructional strategies on particle models in chemistry was also found in Jong, Van Driel and Verloop's (2005) study. In an experimental course module, the authors captured teachers' development of PCK through reflective reports on series of lessons taught. The authors found that teachers improved the PCK components due to classroom experiences. The authors emphasised 'learning from teaching' rather than 'learning of teaching' (p. 952). The differences between teachers were attributed to mediating processes such as reflection and enactment on three domains of teacher learning connected with each other: personal (observed difficulties), external (textbook analysis) and practice (authentic classroom teaching experiences).

Karal and Alev (2016), in an observational study carried out over one year teacher training programme, observed that teachers' PCK development depends directly on their teaching experiences in the classroom. The authors found deficiencies in various types of knowledge and inability to integrate the knowledge bases into one as PCK. The reason behind this inability was attributed to the lack of synchronisation between courses, the gap between the university and secondary level physics content, and the absence of microteaching during subject matter courses. Teachers' subject matter knowledge increased over the course due to opportunities to teach and/or observe others' teachings during teaching practice in schools.

Tolsdorf and Markic (2017), in a cross-level study including different phases of the university teacher training programme, focused on diagnostic competence as part of PCK. Diagnostic competence refers to abilities to interpret students' learning. Teachers' diagnostic competence was measured on four domains of knowledge: conditional knowledge (which defines teachers' knowledge about students' backgrounds), technological knowledge (which defines the ability to select the most appropriate data collection for the actional phase), knowledge of change (refers to strategies to deal with students' learning experiences or behaviour), and competence knowledge (which includes the awareness of and attitudes towards diagnostics). The authors found that teaching experiences in schools had the highest influence on teachers' PCK development. Teachers had opportunities to diagnose chemistry classes and lessons and used the collected data to improve their own teaching. The authors concluded that practical experiences and discussions with mentors influenced teachers' diagnostic competence on 'high level'. However, the authors found that diagnostic competence varied widely from one group of teachers to another. The differences were attributed to explicit influences of university teacher training programmes on teachers.

Ekiz-Kiran, Boz and Oztay (2021), in a study reporting on a redesigned school experience course, applied pedagogical tools like Content Representation (CoRe) and observation forms to help teachers to develop an integrated PCK. The tools were shown to focus teachers' attention to mentors' teaching methods and questioning techniques. Teachers had to prepare a lesson plan on the topic, observe mentors' teaching, revise their lesson plan, teach the lesson in the classroom, and then write a reflection on their experiences. Their mentors' teaching observations forms were then critically evaluated in discussions during coursework. Teachers' improvement was mainly due to observations of mentors' teaching guided by the observation form which was based on the PCK components. The observation form provided teachers with a structured way to observe each PCK component that needed to be considered for effective teaching. The findings showed an 'uneven' PCK development among the participants (p. 13). The uneven development was attributed to the idiosyncratic nature of PCK. By the end of the course, the participants improve the components of PCK except for orientations. The author emphasised the importance of school experience course for teachers' PCK development and the usefulness of the pedagogical tools (observation form and CoRe) in facilitating their development.

Collaborative Planning, Teaching, and Reflection in Cycles

An increase in PCK development was reported in many studies that adopted a cyclical collaborative planning, teaching, and reflection approach. Eighteen studies approached their intervention activities from this perspective (Table 14).

Juhler (2016; 2018), in a design experiment study, reported on Lesson Study, a method for planning (a method initiated in Japan instruction) to develop teachers' PCK in physics lessons. Lesson Study is a method that starts with setting out the goals for teaching followed by planning and then teaching by a member of the group to students whilst others observe and collect data about students. Data is then discussed in groups and the lesson is refined and repeated. The cyclical nature of the lesson study enabled teachers to focus on the content knowledge being taught and guided their thinking and planning towards students' perspectives. Discussions took place in relation to learning outcomes and ways of teaching. To maximize the impact, the authors added CoRe framework that enabled teachers to engage with planning stage in 'more profound way'. The combination between lesson study and

CoRe framework enabled teachers to focus more on students' understandings and on the assessment of students' understandings during the planning process, while spending less time on instructional strategies than in the 'current state of practice' (p. 548).

Table 14. Collaborative Planning, Teaching and Reflection in Cycles

Effective PCK approach	**Key features**	**Studies**
Collaborative Planning, Teaching and Reflection in Cycles	Collaboration in Planning /Discussions, Reflections with peers and mentors	Hume and Berry, 2011; 2013; Schechter and Michalsky, 2014; Milner-Bolotin, Egersdorfer and Vinayagam, 2016; Wheeldon, 2017; Rutt and Mumba, 2019.
	Collectively reflecting on both problems and successes	Schechter and Michalsky, 2014; Günther et al., 2019.
	Using pedagogical tools to guide focus and discussions (CoRe, PCK, prompts, questions)	Hume and Berry, 2011; 2013; Adadan and Oner, 2014; Aydeniz and Kirbulut, 2014; Donnelly and Hume, 2015; Juhler, 2016; Wheeldon, 2017; Juhler, 2018; Rutt and Mumba, 2019.
	Repeating learning for mastery	Scharfenberg and Bogner, 2016; Juhler, 2016; 2018; Scharfenberg and Bogner, 2019; Jufri et al., 2019.

The planning framework provided a better link between theory and practice. The authors observed that when the lesson study was used without CoRe, the focus in the planning process occurred in ‘quite a rudimentary manner, disregarding or downplaying many important teaching concerns when planning’ (p. 548).

Positive results in using the Lesson Study approach were also reported by Jufri et al. (2019) in biology topics. The cycle of the lesson study focused on developing strategies for teaching, basic competences in science lesson (PCK components) and scientific literacy. Each student teacher took the role of a teacher presenting their task through microteaching. The other student teachers took on the role of observers of student activities. In the final stage of the lesson study, teachers were asked to discuss the learning activities taught by others. The discussions focused on supporting the observer students to talk and present what they recorded during their observations. The authors observed an increase in scientific literacy and in PCK components.

A collaborative approach to planning in the form of peer coaching was employed by Smit et al. (2017) and Smit, Rietz and Kreis (2018) in a longitudinal project involving participants from three universities. The studies aimed to determine the effects of collaborative lesson planning on teachers’ attitudes and knowledge for teaching science inquiry. The intervention group in these studies was trained for coaching activities during planning and reflection. The coaches were responsible for the preparation of lesson plans. Coaches were supported by cognitive tools such as Core Issues of lesson planning (a set of questions about four important dimensions of teaching). The authors found that the theoretical input on science inquiry teaching led to an increase in teachers’ PCK, but the collaborative learning session did not lead to an effect on PCK. Teachers’ attitudes were measured on three levels: cognitive beliefs, self-efficacy, and affective states. The authors found no relationship between content knowledge and pedagogical content knowledge. The lesson planning had little effect or none on teachers’ professional knowledge. The quality of peer coaching sessions in the study varied and not all dialogues were constructive. The findings showed that more experienced teachers exhibited less positive scientific inquiry attitudes compared with teachers with less experience and strong efficacy beliefs. The explanation was that teachers' perceived efficacy beliefs are more likely to decline when teachers confront with the realities and complexities of teaching tasks in the classroom. Consequently, teachers became more controlling following teacher training, and they might not have a clear understanding of the ways to teach science through inquiry in the classroom. Analysing the planning dialogues, the authors found that teachers focused more on general pedagogical knowledge, such as time management, and less on PCK. The unsuccessful intervention was attributed to a short time given for clearer reciprocal effects between the coach and coaches. In addition, the coach lacked coaching expertise. The teachers in the studies were not used to plan lessons collaboratively. The authors suggested that teachers found it difficult in the role of the coach. They lacked critical skills needed to stimulate the coaches to be more innovative with respect to science inquiry teaching.

Peer-coaching in planning for teaching scientific methods in biology had similar results in the study carried out by Weitzel and Blank (2019). In a quasi-experimental intervention study, lesson-planning dialogues between peers were examined with respect to PCK. The study found a great variety between intervention and non-intervention groups. The intervention group discussed a greater number and a wider range of issues than the control group. The intervention group more commonly addressed explicit ways to support students in planning and conducting experiments. However, not always the intervention group differed from the control group. These findings support those from the previous study. To be successful in peer coaching, both the coach and coaches must have similar knowledge in the topic to be taught. Clearly, in this study, the unequal relationship between peers was a limitation for the more experienced peers. Overall, the groups rarely modified their lesson plans regarding relevant aspects of PCK. The approach was suggested to bring more positive results if there was an anticipatory reflection between peers in the elaboration of lesson plans. The findings support the outcomes of previous studies suggesting that scientific methods are challenging to teach.

Collective Reflection

Schechter and Michalsky (2014) conducted a study on reflective teaching. The authors adopted dual reflection approach into both problematic and successful events after each lesson taught during teachers' practice in schools. Teachers were required to complete a five-step reflection format after each lesson taught in physics. They needed to identify a problematic or successful event during the lesson, reconstruct actions that led to the outcome, identify critical turning points, craft principles of action based on problematic or successful actions, and identify unresolved action for further inquiry. The approach followed four reflective methods groups for comparison. Some groups reflected both on problematic and successful events, another group only on problematic events, another group reflected together with the mentor and peers, and another group only with the mentor. The authors found that the group that integrated both problems and successes with the mentor and peers outperformed the group which worked only with the mentor, on all PCK measures (comprehension, design, and teaching). Similarly, the group that inquired into problems with the mentor and student teachers outperformed the group that inquired into problems with only the mentor, on all PCK measures. These findings suggest that reflections with mentors and peers provide teachers with the capacity to expand their teaching perspectives. The findings also indicated that integration of learning from problems and successes is more effective in fostering both components of self-efficacy (science teaching efficacy and teaching outcome expectancy) than learning exclusively from problems.

Planning, reflecting, and learning from positive and problematic events was found to be effective in another experimental study conducted by Günther et al. (2019). The authors integrated the case method into the training programme to foster teachers' model competence (CK) and knowledge of methods and strategies for diagnosing and fostering their students' model competence (PCK). The case method consisted of Learning Cases. Learning Cases described the plan and the realization of a biology lesson with the aim to foster students' model competence. Each learning case included information about students, the content of the lesson, and materials. Learning cases included fictional dialogues between teacher and students as well as descriptions of problems and events, all based on teaching guidelines. The method enabled teachers to reflect on teaching of the lessons. The findings indicated an increase in PCK from pre- to post assessment, especially in the experimental group, due to the combination of practical elements and explicit reflection during the programme.

In a case study approach, Wheeldon (2017) used training activities during half day university-based taught sessions (of about 2 hours) as part of an initial teacher education course to support trainee chemistry teachers in rejecting the 'conservation of force' alternative conceptions (AC) and replacing this with scientific causal arguments. The activities consisted of Socratic questioning and bonfire analogy supported by a Focus - Action - Reflection approach. The activities were carried out in groups supported by prompts from the educator. The participants reflected on the usefulness and applicability of the analogy. The authors found the activities as being effective in causing many teachers to reject the 'conservation of force' AC. The changes before and after the session were found statistically significant.

Online Collaboration

Three studies attempted to increase teachers' PCK through collaborative online activities. In a case study, Donnelly and Hume (2015) aimed at enhancing teachers' PCK with Wiki technology. Prior the online activities, teachers participated in several workshops to develop understandings about the use of CoRe framework. They worked in small groups to design a lesson plan in a chemistry topic. For another topic, they were encouraged to use the CoRe in the design of the lesson plan and to work in collaboration with peers on the online platform. For a third topic they were asked to collaborate with their school mentors and to use the lesson plan in their classroom. Wiki worked in asynchronous way meaning that that it was live over a period of time. This way enabled teachers to expand their knowledge by sharing ideas with their peers. The findings revealed that teachers mostly exhibited teacher centred orientations to teaching. The authors noticed that wiki technology had a limited effect on teachers' PCK development. Online collaboration was limited by periods of inactivity explained by teachers' exhaustion of knowledge. The authors showed the usefulness of CoRe with technology but also pointed to the lack of chat functionality that may have hindered teachers' ability to critique each other's work. In designing CoRe lesson plans, the online activities were shown to work more effectively when combined with face-to-face interactions.

The effectiveness of combining online with face to face activities was found in another study conducted by Milner-Bolotin, Egersdorfer and Vinayagam (2016). In a pre- and post-test mixed method action research in a secondary physics methods course, the study aimed to determine if physics teachers' PCK improve over thirteen weeks of a PeerWise intervention. PeerWise was an online platform for hosting teacher-authored multiple-choice questions to promote teachers' engagement through online collaboration. The course required teachers to design conceptual questions and participate in online discussions to improve their questions by receiving feedback from their peers. A problem was selected and posed by educator so that the participants could engage with common student difficulties and with essential physics concepts. As in the previous study, the online platform functioned in an asynchronous way. The asynchronous nature of the online platform was more beneficial in this study. It allowed the participants to consider the problem individually reflecting on and constructing their responses before submitting them online. The more fruitful collaboration between peers on the online platform was attributed to the facilitation process by the educator. The conceptual questions included common misconceptions as distractors to reveal the participants' knowledge gaps and misunderstandings. Through discussions with peers and a voting system, the participants were able to discover the correct responses, experience potential student difficulties, and generate multiple ways of explaining relevant concepts. The online comments were followed up with facilitated class discussions to help teachers develop critical analysis, reasoning, and argumentation. The discussions were linked to the application in practice of what has been learned. The participants experienced Peer Instruction both as learners and as teachers. The findings indicated that the participants improved their conceptual and pedagogical knowledge through the development of more effective questioning skills. The key factor of the successful intervention was considered Peer Instruction which made the participants aware of their and other's gaps in science content knowledge. Furthermore, the combination of the online platform with in-class discussions during the methods course allowed for more in-depth conversations on the same issues. The participants learned how to provide and receive feedback in a positive and constructive manner by justifying their reasoning and clarifying their initial ideas.

Rutt and Mumba (2019) carried out a semester-long history of science online course intervention to develop teachers' conceptual understanding of and pedagogical knowledge for incorporating history of science into science teaching. The course covered the general history of science and key historical concepts in biology and physics. The intervention included weekly readings related to the theme of each week which covered history of science content and strategies for integrating history of science in science teaching. The readings provided teachers with examples and demonstrations of how the methods are applied in the classroom. Following each reading, science teachers engaged in online reflective discussions in small groups. The discussions were guided by prompts provided by the educator. Teachers were also engaged in planning activities to develop their instructional planning abilities of integrating the history of science (HOS) into science teaching. For a first planning, the authors chose three different approaches to model alternative ways for teaching history of science. Storyline approach focused on developing a story of one event using the launch, explore, and summarize approach. Through argumentation approach, teachers identified a historical debate in their content areas and developed an activity that would allow students to understand both sides of the debate and argue or advocate for a position. For a second planning, teachers were engaged in creating resources to use in the classroom. Teachers' understandings of the history of science were gathered in an electronic portfolio with all their revised work completed during the coursework. The findings indicated that the online history of science course developed teachers' understandings of history of science content, pedagogy, and positive perceptions about history of science–integrated science teaching. By the end of the course, teachers demonstrated confidence in their abilities to teach HOS-integrated science and acknowledged its importance in science education.

Collaborative Planning with Pedagogical Tools

Adadan and Oner (2014), in a multiple case study mixed design during a Methods Course in Chemistry, reported positive findings regarding teachers' PCK development. The participants were found to have increased their repertoire of representations in all the PCK components on the topic of chemistry over the course. Some factors that contributed to teachers' progress were mentioned. CoRe offered teachers an explicit tool in developing understandings of the nature of PCK components. CoRe framework allowed teachers to consider all the possible aspects of PCK in planning of a given topic in collaboration with their peers. Teachers' progress was also attributed to opportunities with first-hand experiences with inquiry strategies and to reflection on those experiences. The participants' ideas about diverse chemistry topics were challenged by being engaged in conflicting situations. Reading research on students' conceptions in various science topics and critical reflecting on their experiences helped science teachers to develop understandings of misconceptions and to transform their views.

In a cross-case study approach, Hume and Berry (2011; 2013) reported on an ongoing action research project intended to enhance teachers' PCK development for teaching chemistry using CoRe framework for planning. During workshops, teachers worked in collaboration with peers and the course lecturer to design CoRes lessons. In the second study (2013), teachers were required to individually prepare a lesson and to collaborate with their school mentors to develop and enact the PCK from their CoRes. Discussions with school mentors added to their improvement of CoRes before teaching. Each teacher planned and taught a series of lessons based on the modified CoRes supported by their school mentors. The authors highlighted the usefulness of CoRe in enabling authentic professional discussions between teachers and school mentors. These discussions allow teachers to expand their PCK due to school mentors' input into the CoRe design.

In another case study approach, Aydeniz and Kirbulut (2014) developed and tested an instrument called Secondary Teachers' Scientific Pedagogical Content Knowledge

(STCPCK) with the purpose to enhance teachers' PCK on curriculum, instruction, and assessment in chemistry topics. The participants enrolled on a teacher education programme were taking pedagogical courses after they had completed the required subject-matter courses. The instrument served as analytical tool and provided a 'shared language' for science teachers to discuss what counts as 'reform-based teaching' (p.159). From responses to the prompts given in the STSPCK and from collegial conversations during collective analysis of each other's responses to the instrument, the authors found that the participants developed deeper understandings of the elements of reform-based curriculum, instruction, and assessment. The instrument was found effective in forcing teachers to 'decompose a complex practice as the teaching of science' (p. 159). By doing this, teachers became aware of the complexities of teaching science, of their limitations in conceptual understanding, and of their misconceptions related to inquiry. By engaging in discussions through the STSPCK, science teachers could enhance their PCK because of the exposure to diverse ideas, and the feedback they received from their peers.

Integration and Transformation

Integration and transformation, as the third approach to developing teachers' PCK, was adopted by nine studies aiming to help teachers to integrate the PCK components in planning and teaching (Table 15). The studies assumed that a good teaching comprises a rightful integration of all the PCK components. These review studies were mostly carried out during the coursework of the programme.

Demirdöğen et al. (2016), over two semester methods courses, focused on the integration of the PCK components for Nature of Science (NOS) in lesson planning. The participants in the study exhibited multiple orientations to teaching and learning science. Due to explicit reflective NOS instruction, the percentage of participants with informed views

NOS-related orientations increased. After a PCK intervention for NOS maps, the participants developed knowledge about how to teach NOS, yet not all the components of PCK for NOS were translated into their lesson plans. The reason was related to teachers' efficacy, understandings, and enactment of PCK.

Table 15. Integration and Transformation

PCK approach	Key features	Studies
Integration and Transformation	Explicit reflection on NOS and NOS content -embedded	Demirdöğen et al., 2016; Demirdögen and Uzuntiryaki-Kondakçi, 2016; Demirdöğen, 2016; Grospietsch and Mayer, 2018.
	Conceptual change texts for changing orientations	Demirdögen and Uzuntiryaki-Kondakçi, 2016; Grospietsch and Mayer, 2018
	Strengthening content knowledge	Demirdöğen, 2016
	Modelling activities and relating them to practice	Grospietsch and Mayer, 2018
	Explicit explanations and demonstrations of transformation of content /Focus group reflection/ Collaborative planning	Mavhunga and Rollnick, 2013; Demirdöğen, 2016; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga et al. 2016; Mavhunga, 2018.

The greatest success was found in the consistency between orientation and knowledge of instructional strategies. The greatest area of difficulty was found in integrating the knowledge about learners into lesson plans. This difficulty appeared because of teachers' lack of classroom experiences and consequently of low efficacy. Despite the differences in teachers' PCK for NOS, the methods course framed by PCK for NOS was helpful in developing teachers' practical knowledge for teaching NOS.

In another case study, Demirdögen and Uzuntiryaki-Kondakçi (2016) reported on teachers' changes in orientations and how their orientations were translated into practice during a PCK-based NOS education course. The intervention consisted of NOS teaching and PCK for NOS teaching. The findings indicated that teachers exhibited naive views about NOS aspects and their views remained resistant to change even after explicit-reflective NOS teaching. Teachers' resistant beliefs were attributed to difficulties in understandings, personal and social motivational factors, background experiences, and worldview. A substantial increase in the percentage of participants with informed views, on most of the NOS aspects, was due to authentic science experiences such as argumentation, inquiry, and history of science. The authors found that the participants showed multiple orientations over the course, and there was an increase in NOS-related orientations. The change in orientations was due to conceptual change approach which created dissatisfaction with their initial orientations. The translation of teachers' orientations into the other PCK components was different for each PCK component, both at the application and the knowledge level. Factors that may have contributed to this variation were related to their central goals compared to peripheral ones.

The interaction between orientation and other PCK components was also a focus in a case study undertaken by Demirdöğen (2016) over one semester course education. In this study, the author used CoRe framework as a tool to capture teachers' integration of orientations into the other PCK components. As in the previous study, the authors found that the participants had multiple purposes and goals for teaching science. Most of the teachers' beliefs about science teaching and learning were found to be 'responsive and reform-based' but their beliefs about NOS did not translate into their planning because they did not interact with their goals and purposes of science teaching. Content-related purposes were found to have the most interactions among the participants while their knowledge of curriculum, instructional strategies and assessment were low. According to the authors, some goals and purposes might have dominated the instructional decision-making process, and hence influenced all the PCK components. Other goals, like scientific skill development, remained peripheral and might have been less influential, and therefore, interacted with fewer PCK components. Beliefs about science teaching and learning mostly interacted with knowledge of instructional strategies. In a few cases, teachers' beliefs about science teaching and learning were related to their knowledge of curriculum and assessment. The positive changes were due to the key features of the intervention such as meaningful and explicit experiences with PCK during the study. Meaningful opportunities, offered in this study, were reflection on orientations, collaborative planning, and opportunities for strengthening subject matter knowledge. The participants in the study selected for planning a topic in which they felt confident. In addition, they were given a week to strengthen the content for the topic. The author, as researcher, provided scaffolding to the groups during CoRes design to stimulate teachers' PCK development and translation of their PCK into the CoRes. The author concluded that teachers' beliefs about the nature of science did not directly interact with their PCK, unless those beliefs related directly to the purposes of teaching science. Moreover, explicit reflection on orientations stimulated the interaction between orientations and the other PCK components.

The conceptual change model approach was also a focus in a quantitative comparison design, in a twelve-week university course in neuroscience, undertaken by Grospietsch and Mayer (2018). In this study, conceptual change model was used as a process of combining different types of knowledge in one whole. The authors combined three knowledge bases related to learning of the brain into one as PCK (content knowledge about curricular content in neuroscience, psychological–pedagogical knowledge about the psychology of human learning and instructional strategies for sustainable learning). The study aimed to reduce biology teachers' misconceptions in neuroscience. Using conceptual change texts in the university course context, the authors found significant increase in addressing explicit the neuromyths in the intervention group, in all three areas of professional knowledge, compared to the comparison group. The key features for success were attributed to a better link between professional knowledge, personal experiences with learning theory, and explicit reflection on individual misconceptions. Furthermore, the content was taught with reference to teachers' later roles as biology teachers. Moreover, the teaching materials had a focus on PCK, and the conceptual change texts allowed teachers to translate the content by using a common language.

Mavhunga and Rollnick (2013), in a case study design, aimed at developing teachers' reasoning on the topic of chemical equilibrium in terms of five content-specific components of Topic-Specific PCK. The features of the intervention were collaborative discussions of the content-specific components of Topic-Specific PCK into groups. The discussions were followed by whole class explanations and demonstrations of the application of the knowledge components to teaching, using key concepts in chemical equilibrium. The Content Representation (CoRe) was introduced to the participants and used as tool to capture the reasoning on the five PCK components. Additional optional discussions, especially on misconceptions in chemical equilibrium and suggestions for tackling them, took place on the interactive online platform Blackboard ignite (BBignite). The findings of the study indicated that, due to explicit discussions, the quality of Topic-Specific PCK improved significantly.

In another case study extended over a period of six weeks, Mavhunga (2016), in a chemistry methodology class, aimed at developing TSPCK in the particulate nature of matter. The author employed explicit explanations on the transformation of content knowledge as a step in the process of pedagogical reasoning. The five content-specific components of TSPCK identified in a previous study were first presented to teachers. The five components were learner prior knowledge, curricular saliency, what is difficult to understand, representations, and conceptual teaching strategies. The five components of TSPCK were discussed one at a time in relation to the key concepts of the topic. Content Representation (CoRe) was used as tool to gather and organize teachers' thoughts during their planning. The findings revealed significant improvement in the quality of the five components of TSPCK. Teachers' generated responses in the post-TSPCK tool were found to be more detailed. The key feature of the successful intervention was the explicit demonstrations of the breaking down the TSPCK construct into its individual components. Teachers first learned the topic from the perspective of each component. Then, they learned to bring together all their understandings from all the components into their lesson plans.

Integration of PCK components proved to be effective when teachers took the route of 'manageable bits per topic' in the case study undertaken by Mavhunga and Rollnick (2016, p. 852). In a pre- and post-test design intervention, Mavhunga and Rollnick investigated the relationship between TSPCK and science teachers' beliefs to improve TSPCK in the topic of chemical equilibrium. The study focused on the transformation of content in relation with the five components of PCK on the topic. Each component was addressed in turn. First, there were discussions on each knowledge component and how it is applied in chemistry. Then teachers practiced the component in groups applying it to the topic. The task was moderated by the researcher in a way to stimulate teachers' thinking. Any challenges were brought to the attention of the whole class and solved through discussions. During the activities, other components, such as common misconceptions, were brought to teachers' attention to understand how PCK components interact. The four groups of teachers were given a task to explain, using a combination of symbolic and sub-microscopic representations. On the completion of the intervention, majority of teachers had a 'developing' TSPCK in chemical equilibrium with most of them shifting their beliefs from traditional towards more student-centred approach. The key feature of the intervention was the focus group reflection session in which teachers reasoned through the content using the five components of TSPCK. Also, the authors observed that the implementation of PCK at topic level helped teachers to transform the concepts of the topic into forms suitable for teaching. The intervention activities impacted positively on teachers' beliefs about teaching science.

Mavhunga (2018) built on the previous study to improve teachers' PCK in learning to transform the content by reasoning though the five components of TSPCK. In this study, CoRe framework for planning was used as tool to capture and organize the thoughts about how to teach the topic. The author found that teachers created arrangements with vary combinations in interactions between PCK components. This led the author to argue on idiosyncratic nature of component interactions at topic-specific level. The observed idiosyncratic nature in the TSPCK sequences was attributed to teachers' personal PCK. Their individually generated responses in the lesson plan were converted into one agreed exemplary CoRe on chemical equilibrium to serve as a model that reflects the shared best practice in teaching the topic. According to the author, the complex nature of the component interactions was influenced by two factors, namely, the quantity of different components and their structural arrangement. The components of TSPCK were found to interact among one another in clear and connected arrangements. The component interactions that exhibited sophistication emerged mostly from teachers' tasks to articulate their reasoning on the transformation of the content for teaching. The author suggested that the use of such tasks in PCK-based teacher education programmes would promote a sophisticated transformation of content knowledge.

Mavhunga et al. (2016), in a physics methods course over six weeks intervention, investigated teachers' ability to transfer the skills of transforming content knowledge between topics. The five content-specific components of TSPCK were discussed one at a time starting with learners' prior knowledge, followed by curricular saliency, what is difficult to understand, representations, and teaching strategies. At the end of the intervention, CoRe was introduced as tool to organise and represent the knowledge related to all the TSPCK components. The authors found that teachers consistently demonstrated a higher performance in the TSPCK components in the topic of their choice. Also, some components of TSPCK appeared to be more accessible than others. The author found that content knowledge was essential but not enough to facilitate the transfer of the skill to transform the content knowledge. In the authors' view, two factors may have contributed to the transfer of the topic: either a good understanding of the content knowledge in the topic, or because teachers enjoyed the topic. The intervention and increased familiarity with the CoRe tool applied to the chosen topic were the main factors that led to teachers' improvement.

Consistent Cognitive Support

A consistent cognitive support, as the fourth PCK approach to preparing teachers, was applied by three studies (Table 16). The studies highlighted the importance of a mentoring framework as the most effective approach to developing and integrating all the PCK components. For example, Aydin et al. (2013), in an action research approach, designed a fourteen - week content representation (CoRe)-based mentoring-enriched practicum course. The purpose was to investigate the development of teachers' knowledge base for science teaching on the rate of reaction topic and to identify effective aspects of the practicum course for teachers' development.

Table 16. Consistent Cognitive Support

PCK approach	Key feature	Studies
Consistent Cognitive Support	Educative mentoring framework	Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015

Their intervention consisted of several strategies such as CoRe, explicit PCK introduction, microteaching, reflection, and intensive educative mentoring. The authors drew on Feiman-Nemser's (1998) concept of educative mentoring. Educative mentoring requires mentors to be familiar with learner-centred instruction and science standards based on inquiry teaching. Educative mentoring approach draws the attention more on teachers' thinking and understandings. The revised practicum course provided two basic teaching opportunities for teachers: weekly microteaching sessions and teaching in a school placement. The microteaching sessions were followed by reflections on, and evaluations of the lessons taught. In their school placements, teachers taught chemistry lessons and observed veteran teacher's practices. The findings indicated that the set of research-based practices (CoRe design, explicit PCK introduction, microteaching, reflection and educative mentoring) during teaching practice in schools promoted teachers' professional knowledge. Due to mentoring structure, teachers moved from fragmented PCK, which was more based on pedagogical knowledge, to more integrated knowledge. As in other studies, this study highlighted the uneven development of PCK, indicating that the growth in one component may not be accompanied by the growth in others. The findings of this study revealed that educative mentoring was the most effective source for development in all the components of PCK. Also, the CoRe-based mentoring-enriched practicum course helped teachers to move from tacit knowledge of teaching to more explicit one. The authors concluded that educative mentoring practices based on CoRe have the potential to be a 'lifesaver' for teachers with insufficient PCK for teaching science (p.927). When teachers were provided with a set of research-based practices, their views of teaching changed from simple transmission of content to more complex ideas.

Aydin et al. (2015), in a secondary analysis of the previous study, focused on how a CoRe-based mentoring-enriched practicum developed teachers' skills to integrate the PCK components. The authors noticed that teachers, at the beginning of the semester, had understandings of separate PCK components. During the course, the support provided through educative mentoring, such as planning with mentors, helped teachers to integrate all the components in their lesson plans. The author emphasised the importance of the CoRe in enabling teachers to articulate their PCK and forcing them to connect the components. Although, the interactions among the PCK components increased during the teaching practice course, the interplay among PCK components was found idiosyncratic.

Barnett and Friedrichsen (2015), in an observational case study approach, described the strategies used by a secondary biology mentor teacher to support the development of one teacher's PCK. The findings revealed positive results due to the strategies used by the mentor to help the teacher to improve in all the components of PCK. The mentor attempted to change the teacher's beliefs and practices by making a comparison between teacher-and student-centred approaches. The mentor modelled critical reflection on instructional choices providing the teacher not only with activities for immediate application, but also with strategies for long term development such as reflection on own practice.

The findings presented in this section revealed four effective PCK approaches to preparing science teachers. The four approaches are discussed in the next section to highlight their practical implications for teacher education programmes.

5.4 Discussion

The aim of the systematic review was to gather the available evidence for effective PCK approaches to preparing science teachers during their education programmes internationally. Data analysis revealed five main components which teachers were found to draw upon in their learning to teach. Their learning to teach was much influenced by their: ***previous knowledge, orientations, practice skills, understandings, and perceived efficacy.*** The five components were organised in a new framework - *Learning to Teach Framework* (LtTF) as a developed model for preparing teachers during their education programmes. The framework is relevant to initial teacher training programmes because it gives insight into the components that teachers need to develop before entering the real classroom context. The findings of this study revealed that teachers develop the five components identified in Learning to Teach Framework through four main approaches: ***Teaching Experiences; - Collaborative Planning, Teaching and Reflection in Cycles; - Integration and Transformation; - and Consistent Cognitive Support.*** In this section, the findings are discussed on four synthesis categories according to the above four approaches to learning to teach to highlight how teachers develop the Learning to Teach components through each approach. Practical implications resulting from each approach are also discussed.

The studies that contributed to the first synthesis category ***- Teaching Experiences -*** emphasised PCK development from teaching experiences and reflections on those experiences. Teaching experiences included teaching in the classroom, microteaching, and observation of teaching in schools. These studies claimed that PCK develops mainly through teaching experiences. In some studies, teachers had opportunities to gain teaching experience from teaching in the classroom and from microteaching sessions (Bektas et al., 2013). In other studies, teachers were offered opportunities to teach and observe teaching in the classroom and reflect on their experiences during coursework at the university (Jong, Van Driel and Verloop, 2002; Van Driel and Verloop, 2005; Karal and Alev, 2016; Tolsdorf and Markic, 2017). Karal and Alev's (2016) and Ekiz-Kiran, Boz and Oztay's (2021) studies emphasised the development of PCK from observations and critical reflections on mentors' teaching. The commonality of the findings of these studies was that teachers had underdeveloped PCK before the intervention and improved their PCK over the course due to teaching experiences. However, teachers' PCK improvement was unequal, both among the components of PCK and participants. There are several reasons for this variation. A first reason may be the nature of the topic taught. Some topics, such as scientific inquiry teaching or NOS, were found to be more challenging to teach than others (Bektas et al., 2013). Second, insufficient content knowledge hinders teachers' development (Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013 and Karal and Alev, 2016). Given that content knowledge is a prerequisite for developing PCK, the findings are not surprising, further supporting those from the wider literature (Van Driel, Jong and Verloop, 2002; Abel, 2008; Kind, 2009). Another reason for unequal development points to the idiosyncratic nature of PCK (Magnusson, Krajcik and Borko, 1999; Karal and Alev, 2016). Furthermore, teachers may be influenced by mediating processes like meta-reflection and enactment (Jong, Van Driel and Verloop, 2005). Personal and professional characteristics like prior knowledge, prior experiences, and self-efficacy have diverse influences on teachers' learning (Jong, Van Driel and Verloop, 2005). Finally, teachers' learning is influenced by their orientations and/or beliefs. Ekiz-Kiran, Boz and Oztay (2021) found that teachers' orientations were difficult to change whilst Karal and Alev (2016) noticed that they were prone to change under the influence of learning experiences and mentors' way of teaching. The findings from this category indicate that learning solely from teaching experiences may not be enough. Although valuable, teaching experience alone does not lead to solid knowledge bases for teaching (Hagger et al., 2008; Friedrichsen et al., 2009). For example, Jong, Van Driel and Verloop's (2005) 'learning by teaching' may be a 'restricted view of learning from experience' (Hagger et al., 2008, p 176). Hagger et al. (2008) posit that a restricted view of learning from experience does not lead to teachers developing 'confidence, expertise, and habits necessary for critically examining their developing practice and thinking' (p. 176).

Teaching experiences designed around the PCK framework coupled with reflections, may instead, provide teachers with a useful framework for developing the components for teaching. Communication and interactions with students during their teaching experiences are a good opportunity for teachers to acknowledge their limitations. Questions and responses from students allow teachers to reflect more on aspects of teaching that create confusion or are difficult to understand (Van Driel, Jong and Verloop, 2002). By observing others' teaching, teachers learn more ways of teaching through modelling (Bandura, 1971). Yet, the observation of others does not always lead to learning. It is thus important to focus teachers' observation on esential aspects for teaching by providing them with tools such as observation forms (Ekiz-Kiran, Boz and Oztay, 2021). Through direct teaching experiences, observing mentors and peers' teaching and reflecting on experiences, teachers can expand their teaching repertoire.

From this synthesis category, some implications for practice can be drawn. First, the studies' findings showed that teachers' development may be hindered by deficiencies in knowledge. Thus, to develop PCK through teaching experiences, teachers need good knowledge in all the components of *Learning to Teach Framework*. Since PCK development depends on the quality and quantity of content knowledge, readings and reflections are good sources that may 'trigger subject matter development' (Van Driel, Jong and Verloop, 2002, p 584). Readings and discussions on academic papers promoted teachers' understandings of students' learning difficulties and misconceptions in Van Driel, Jong and Verloop' s (2002) study. Second, to develop a good conceptual understanding, there is a need for a better coherence between coursework content and school content. Although, Jong, Van Driel and Verloop (2005) and Bektas et al. (2013) claimed that teachers benefited from the analysis of a chemistry textbook, using school content only may not be as effective as Karal and Alev (2016) suggested. As evidence from research shows, comparing secondary school science content with higher academic content when preparing lessons is more effective (Nilson, 2008 in Karal and Alev, 2016). By extracting information from several sources, teachers can gain more content knowlege, conceptual understanding, and more effectively develop teaching skills. On the other hand, the development of *Learning to Teach Framework* components is much facilitated when teachers are supported with tools that focus their attention on all the components. Such tools like CoRe and observation checklists, have the potential to better link coursework with teaching practice in schools, provide a shared science discourse, and raise awareness of the essential aspects of teaching (Ekiz-Kiran, Boz and Oztay, 2021). Moreover, reflection is an important feature in teaching. However, an explicit reflection, rather than implicit, can help teachers to better understand more challenging topics such as inquiry or NOS (Tolsdorf and Markic, 2017).

The studies that contributed to the second synthesis category **–** ***Collaborative Planning, Teaching, and Reflection in Cycles*** - emphasised the development of *Learning to Teach* components through cycles of collaborative planning, teaching, and reflection. The studies found that teachers develop the components of *Learning to Teach Framework* when they have opportunities to work in collaboration with peers and mentors and to repeat what they learn. The cyclical nature of collaborative approach to planning, teaching, and reflection give teachers opportunities to rehearse practice and to master it. Mastering practice is the most important source for increasing teachers' self-efficacy (Bandura, 1977). Coupled with support received through collaboration with both peers and mentors, teachers are pushed to move beyond their 'zone of proximal development' increasing their confidence in their teaching capabilities (Bandura, 1971; Vigotsky, 1978).

Scharfenberg and Bogner's studies (2016; 2019) provided evidence that, even in a short time, teachers can develop the components for teaching if they are engaged in meaningful and authentic experiences. In their study, the lab environment simulated the real context of the classroom, and the repeated learning sequences placed teachers both in a position of a teacher and of a student. Teachers could enlarge their views and understandings from both perspectives. Similar positive outcomes come from Lesson Study approach applied in studies conducted by Juhler (2016; 2018) and Jufri et al. (2019). Lesson Study coupled with CoRe tool for planning focused teachers' attention on all the knowledge bases for teaching. The approach was effective in guiding teachers' thinking and planning around students' perspectives. Teachers more effectively learn from their own teaching experiences when pointed to focus on successful and problematic events. Such focus was found more likely to increase their self-efficacy and outcome expectancy (Bandura, 1977; Schechter and Michalsky, 2014). These findings are supported by those from other areas. For example, in a mathematics programme, Biza and Nardi (2019) found that trainee teachers developed their reflective skills by participating in individual and collective reflections on critical classroom incidents identified from their own experiences.

However, a strong self-efficacy is not always corelated with practice. Smit et al. (2017) and Smit, Rietz and Kreis (2018) found inconsistences between teachers with strong self-efficacy and their practice. Teachers with strong self-efficacy did not apply in the classroom what they have learned. This was because they were not previously confronted with the realities and complexities of real context. The authors found that science teachers tended to be more ‘controling’ focusing more on ‘survival’ in terms of class management than on PCK (Juhler, 2016, p. 548; Smit et al., 2017, p. 491; Smit, Rietz and Kreis, 2018, p. 632). As Tschannen-Moran and Hoy (2007) found, teachers perceived self-efficacy tends to decline during the first year of teaching due to ‘reality shock’ (p. 946). Thus, it is important for teachers to be engaged in authentic experiences that make connections with real classroom practice and students. Günther et al. (2019) showed that authentic experiences carried out during coursework can be successful in connecting teachers with the realities of the classroom. The authors used Learning Case method to introduce teachers in fictional dialogues between teacher and students. A Learning Case includes descriptions of problems and events as in real classroom. The study showed that a better link between theory and practice more effectively develops teachers’ teaching components. The approach was also applied successfully in other subjects. Biza, Gareth and Nardi (2015) developed classroom scenarios that combined content knowledge with behaviour management to trigger deep reflection in the context of a mathematics programme. Trainee teachers were asked to work individually and then to participate in a collective whole class reflection on their responses. As the authors stated, classroom scenarios have the potential to avoid ‘the pitfall of single-minded enculturation’ into the practices of a single school (Biza, Gareth and Nardi, 2015, p. 5). Clearly, through collective reflection, teachers expand their knowledge, develop new understandings, and may change their orientations by being exposed to multiple and conflicting views (Adadan and Oner, 2014). This in turn develops a better sense of teaching efficacy.

Planning is an important aspect in teaching science (Hagger et al., 2008) and 'the most pervasive instructional activity used in teacher education programmes' (Lederman and Niess, 2000, p. 57). Studies found that planning is a consuming cognitive process (Hagger et al., 2008). With limited experience in planning, teachers find it difficult to focus on what is essential in teaching (Smit, Rietz and Kreis, 2018). Thus, it is important for teachers to benefit of planning models during their training programmes (Hume and Berry, 2011; 2013). Planning and reflection were found to be more effective when teachers plan and reflect in collaboration with both peers and mentors than only with peers or only with mentors. When teachers collaborate only with peers, their learning may be limited (Donnelly and Hume, 2015; Smit et al., 2017; Smit, Rietz and Kreis, 2018 and Weitzel and Blank, 2019). Teachers' unequal and limited knowledge and lack of critical thinking skills were found to be the main limiting factors in peer face to face and online collaboration. In contrast, when peer collaboration is facilitated, scaffolded, and guided by educators, learning is more effective (Hume and Berry, 2012; 2013; Adadan and Oner, 2014; Wheeldon, 2017). When teachers plan in collaboration with mentors, their thinking and perspectives are more challenged. When used, CoRe framework for planning further facilitates the process by providing a common discourse of practice, a shared language between peers and educators (Hume and Berry, 2011; 2013).

Given teachers' limited experience in reflection processes, facilitation is also important in group reflections. Teachers need prompts or questions to challenge their thinking (Aydeniz and Kirbulut, 2014; Wheeldon, 2017). This strategy may also be relevant to the online activities. Milner-Bolotin, Egersdorfer and Vinayagam (2016) and Rutt and Mumba (2019) provided evidence for effective online collaboration when the discussions were guided by prompts and scaffolding offered by educators. The asynchronous nature of the online activities in the above studies, allowed time for teachers to reflect on and construct their responses before participating in online learning. This is in accord with Bandura's concepts of mastery and social persuasion. Bandura (1971) states that success comes from mastery experiences. The support given by more knowledgeable persons contributes to social encouragement that moves teachers to a next level of development.

Some implications for practice can be drawn from the second synthesis category on developing the Learning to Teach components through a collaborative approach. First, teachers add to their knowledge bases when they have useful tools that focus their attention more explicitly on what is important for teaching. Such tools like CoRe for planning and explicit introduction to PCK components were found useful in guiding teachers' focus (Hume and Berry, 2011; 2013; Adadan and Oner, 2014). Next, science teachers change their orientations and increase their understandings when they have opportunities to reflect collectively on real problematic and successful experiences. Furthermore, planning and reflecting on planning and teaching is more effective in collaboration with school mentors. This finding supports studies showing that teachers better develop understandings, planning, and teaching skills if they have access to mentors' thinking (Bandura, 1971). Lastly, teachers are more likely to develop their teaching components in a short time when they have opportunities to repeat their learning for mastery (Bandura, 1971; Scharfenberg and Bogner, 2016; 2019).

The studies that contributed to the third synthesis category – ***Integration and Transformation*** - focused on the integration of orientation in PCK components as well as the integration of PCK components in lesson planning (Demirdögen and Uzuntiryaki-Kondakçi, 2016; Demirdöğen, 2016; Grospietsch and Mayer, 2018). The studies showed that participants varied in changing their beliefs, and in some studies, their beliefs were found to be resistant to change (Demirdögen and Uzuntiryaki-Kondakçi, 2016). Translation of teachers' orientations into PCK components varied for each component with the most interactions for content and instructional strategies and less for students' learning (Demirdöğen, 2016). Some of the factors that hindered teachers' ability to integrate their orientations in lesson planning were related to lack of teaching experience, multiple purposes and goals for teaching, difficulties in understanding, and other personal and social motivational factors. The findings of these studies are consistent with the literature on teachers' beliefs showing that teachers enter the education programmes with some beliefs that are resistant to change (Kagan, 1992b; Pajares, 1993). Though, teachers' orientations were found to be prone to change if there are explicit and authentic science experiences such as the ones used in these studies: conceptual change approach, content taught that relates to teachers' role as science teachers, good knowledge of content for teaching, and classroom experience.

Other studies, that focused on the integration of NOS aspects in PCK components, found that the integration depended on the level of knowledge of NOS and level of understanding or application in lesson planning (Bektas et al., 2013; Demirdöğen et al., 2016). The lack of knowledge and understandings of NOS aspects has been often a barrier for teachers' development of PCK (Abd-Khalik, 2012). As such, teachers were found to have low self-efficacy for teaching NOS. To develop content knowledge and understandings for teaching NOS, teachers need meaningful experiences such as content embedded NOS.

Several studies focused on the transformation of the five components of Topic Specific Pedagogical Content Knowledge (TSPCK) in a particular topic (Mavhunga and Rollnick, 2013; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga, 2018). Transformation was based on pedagogical reasoning through the content related to the five components of TSPCK. The studies identified some common features that helped teachers to successfully transform the content knowledge. Such features were explicit explanations and demonstrations of breaking down the content, explicit discussions and reflections in groups and whole class for clarifying ideas, and discussions of the components of TSPCK in turn to give the participants the opportunity to practice each component in groups. Moreover, an important aspect for improvement was the moderation of the discussions by the authors of the studies. The CoRe tool was useful in capturing teachers' thoughts in all the studies. The common findings showed that teachers changed their beliefs towards more student centred approach and improved their interactions of the components of TSPCK, although the development was idiosyncratic due to personal knowledge for TSPCK.

Adequate subject matter knowledge is a prerequisite for a developed PCK (Abell, 2008; Magnusson, Krajcik and Borko, 1999). In some studies, teachers were allowed to select the topic in which they felt confident before integrating all the PCK components in lesson planning (Mavhunga et al., 2016). Mavhunga et al. (2016) noticed that teachers showed higher performance in transformation, integration, and transfer of the components of TSPCK from one topic to another when they had opportunity to choose their own subject and topic. In acord with Bandura' concept of mastery experiences (Bandura, 1977), teachers' confidence in the topic increases their self-efficacy which is vital before engaging in more complex and challenging tasks. Also, tools like CoRe framework for planning were valuable in helping teachers to transform and transfer the content more successfully.

There are some implications for practice that can be drawn from this synthesis category. First, teachers' orientations must be elicited and challenged through explicit (rather than implicit) reflection and authentic experiences related to everyday teaching contexts (Bektas et al., 2013; Demirdöğen et al., 2016). As the development of PCK components is often found to be idiosyncratic, teachers need to gain knowledge for each of the components of PCK before integrating them. Thus, to master the skill of knowledge integration, teachers must be given enough time to strengthen the content for teaching. The use of CoRe tool and guided planning further increase teachers' PCK (Loughran, 2014). The integration of NOS aspects into PCK components is more effective when teachers can make connections between NOS content and the content of the topic (Bektas et al., 2013; Demirdöğen et al., 2016). Lastly, to develop knowledge and understandings of the complexity of teaching, teachers need to learn to sequence the content. This is more effective when explicit demonstrations of transformation of the content are modelled for them (Bandura, 1971; Mavhunga, 2016; Mavhunga and Rollnick, 2016).

The studies that contributed to the fourth synthesis category **–** ***Consistent Cognitive Support* -** focused on intensive mentoring support during teaching practice in schools. (Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015). These studies used the concept of educative mentoring to highlight the importance of a framework or structure for support in all the aspects of teaching and learning during teachers' practice in schools. The studies promoted a cognitive apprenticeship in which teachers were encouraged to come with ideas and to be innovative. When teachers were adequately and constantly guided, they could develop sophisticated PCK. An important implication for practice resulted from this synthesis category. Because teachers enter the education programme with limited PCK, they need procedural knowledge of how to teach. Modelling activities and consistent guidance were found the most effective features that help teachers to learn procedural knowledge.

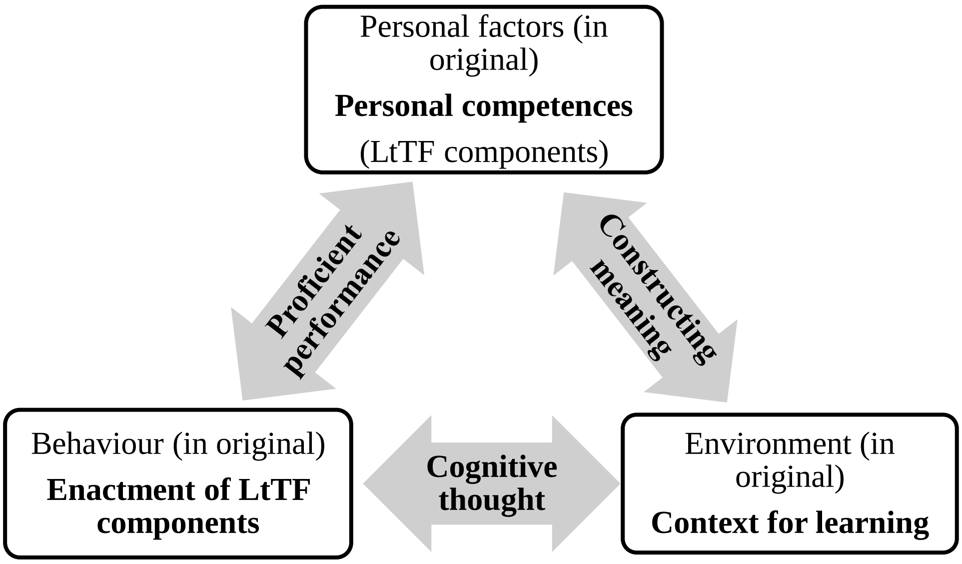
In summary, the findings and the implications resulting from the review study suggest that learning to teach is a complex process and there is not a single best way to learn how to teach. However, there are some essential aspects that makes learning more effective. Teachers learn better when they understand the content, have opportunities to practice their skills, and are adequately and constantly guided in the process of learning to teach. These findings support Woolfolk Hoy, Davis and Anderman' s (2013) four pillars for teaching that contribute to high quality learning. In the authors' view, the four pillars for effective learning are constructivist, cognitive, and behavioural approach embedded in socio-cultural contexts. The four pillars for learning to teach are better explained through the lens of Bandura's (1978; 1999) triadic causation discussed in Chapter 3.

The triadic causation model (Bandura, 1978) helps in understanding how teachers in the review study developed the components of the *Learning to Teach Framework* (LtTF). *Learning to Teach Framework* was developed from data analysis, and it highlights five components that teachers need to develop during their education programmes, namely *Knowledge, Orientations, Practice, Understandings, and Efficacy*.

The five components together with their subcomponents represent teachers' personal competences that are developed in the process of learning how to teach. Based on Bandura's triadic causation, in the process of learning to teach, first, teachers need to transform the knowledge bases for teaching to make sense of it (**constructing meaning/ constructivist approach**). In this study it was clear that the knowledge bases for teaching were derived from many sources in the environment providing opportunities for teachers to develop their PCK (e.g., direct experiences, social persuasion, vicarious experiences). The constructed knowledge was translated into action through a conception-matching process. Bandura explains that conceptions are internal standards that guide proficient action. This is the stage when teachers remembered what they have understood (**cognitive thought** /cognitive approach). Teachers had to practice and apply their new skills and understandings to make them more fluid and automatic and a permanent part of their repertoire (**behavioural approach**). In the process of development of teaching skills, teachers' enactments of their personal competences were complemented by feedback (from educators, peers, and students). The feedback provided teachers with the information that allowed them to acknowledge, identify, and correct the mismatches between conceptions and action. Based on this information, behaviour (the teaching skill) was modified to achieve a close match between conception and action. Bandura suggests that cognitive guidance is the most influential in the early phases of the development of skills. Bandura acknowledges that situations are rarely alike, and people must develop generative conceptions to suit diverse purposes. That enables them to enact skills in varied ways rather than in a rigid fixed manner (Bandura, 1999). With continued practice, the skills become fully integrated and easy to apply in practice **(proficient performance**). The above perspective underpinning the interpretation of the review findings was represented in a new framework based on Bandura's (1978) original triadic causation. The newly developed framework was named *Triadic Framework for Learning to Teach* (Figure 15).

This newly developed framework alongside the *Learning to Teach Framework* guided the second study. Both newly developed frameworks have high relevance to initial teacher training programmes as they provide the essential components (the *Learning to Teach Framework* components) that teachers need to develop, and a lens that enable educators to observe, acknowledge, and consider the important factors that influence teachers' learning (factors from the *Triadic Framework for Learning to Teach*). The three factors in the *Triadic Framework for Learning to Teach* are: personal competences, the context for learning, and enactment of the Learning to Teach Framework (LtTF) components.

Figure 15. Triadic Framework for Learning to Teach (based on Bandura's Triadic Reciprocal Causation model, 1978, p. 345).



Personal competences include LtTF components (teachers' initial knowledge, orientations, practice skills, understandings, and efficacy). **Context for learning** provides teachers with sources of information and support. These sources consist of:

- Bandura's sources of self-efficacy: mastery experiences (teaching experiences, planning) vicarious experiences (observations of others' teaching, collaborative planning, reflection, modelling) social persuasion (support/feedback) (Bandura, 1977; 1993).
- Social participation in school culture (Lave and Wenger, 1991) – collaboration with school mentors, access to resources, access to information about school, students, etc.
- Social interactions - Scaffolding (Vygotsky in Cole et.al. (eds.) (1978) – collaboration with peers and mentors.
- Individual and collective reflection on practice (Dewey, 1933; Schon, 1983)

Behaviour refers to **teachers' enactment of their personal competences** (the new knowledge, the skills learned, the new understandings). Their enactment is accompanied by feedback and support which provides teachers with information and guidance for improving the skills till they become proficient.

5.5 Conclusion

The review study, guided by the inclusion and exclusion criteria, identified, and included thirty-seven empirical studies aiming to enhance science teachers' PCK development during their education programmes. Data analysis was initially guided by the Consensus Model of PCK (Gess-Newsome, 2015) which was adapted to include priori codes from other PCK models. A new framework as analytical tool was developed from this systematic review and it was subsequently used as a guide for the subsequent cross-studies synthesis.

Five descriptive themes and three categories of effective instructional features were identified through the analysis. The five themes (Gains in Knowledge, Change in Orientations, Gains in Practice, Gains in Understandings, and Gains in Efficacy) comprised the evidence base for gains in teachers' PCK. The three categories of effective instructional features (Direct Experiences, Vicarious Experiences, and Social Persuasion) contributed to the positive changes in teachers' PCK components targeted by the individual studies included in the review. The interrelationships between the changes in teachers' PCK and the instructional features as contributing factors to teachers' PCK development were discussed on four synthesis categories resulting from the analysis that highlighted effective PCK approaches to preparing science teachers: Teaching experiences; - Collaborative Planning, Teaching, and Reflection in cycles; - Integration and Transformation; - and Consistent

Cognitive Support. The contribution of each study to the findings of the review was also provided. Each category of findings generated important implications for practice. The findings and their implications were integrated in the cross-study synthesis in Chapter 8 to compare them with the findings of the second study (detailed in the next chapters). Though, it is important to note that the evidence of what works best and why in preparing science teachers comes from different contexts of science education programmes around the world. As findings from qualitative research are context bound, it cannot be assumed that what has been found through the systematic review can simply be applied in preparing science teachers in other contexts.

However, comparative international studies show that there are similarities between science education programmes across countries. Based on these similarities, educators, responsible for the preparation of teachers, may judge on what would work in their own context. To facilitate a transfer from one context to another, the systematic review gives sufficient detail about the context of each study included in the synthesis. In addition, to be able to enhance trainee teachers' learning, educators must have a good understanding of their own context. A starting point it would be to assess trainee teachers' individual and collective learning needs by eliciting their views of their learning experiences in the programme. The literature on trainee teachers' views of their own experiences is scarce. Therefore, the next two chapters address this gap by extending the search on what is effective in preparing science teachers, but this time using an exploratory case study design with trainee science teachers enrolled on an initial teacher training programme in England.

Chapter 6. Exploratory Case-Study. Research Design

The first study, covered in the previous two chapters, gathered, and synthesised the available international evidence on effective approaches to preparing science teachers during their education programmes through a systematic review methodology. Though, the learning strategies that work in one context may not work in another. For this reason, before borrowing and adapting learning strategies from other contexts, it is necessary to identify trainee teachers' learning needs in the local context. Therefore, this chapter introduces the exploratory case-study on trainees' views of their learning experiences in a School Centred Initial Teacher Training (SCITT) programme in England. This chapter outlines the research design and credibility of the study.

6.1 Introduction

Currently, in England, the Initial Teacher Training programme is complex and diverse, as revealed by the literature in Chapter 2. Perhaps this complexity draws the attention more towards structural changes and less to trainee teachers' experiences and how the experiences add up to their knowledge, skills, and efficacy. What happens inside the programme may give a better understanding of how trainee teachers are effectively prepared and may address issues with the quality of teachers and teaching. Much of the limited existing literature on trainee teachers' experiences focus on trainees' experiences with mentoring in school (Hobson, 2002; Shields and Murray, 2017; Mena, Hennissen and Loughran, 2017). Other studies (Laker, Laker and Lea, 2008) focus on the support structures utilised by trainees during teaching practice in their school placements. Hobson's et al. (2008) focus on trainees' perceptions across the routes and disciplines to identify how they are similar or different in the experiences encountered. Previous limited research on trainees' experiences highlights the value of the practical work for trainee teachers compared with the theoretical part of the programme.

In science, Blackmore, Howard and Kington (2018) focus on trainee primary science teachers' experiences, reporting limited learning opportunities for practice that impact on their overall development. Research on trainee science teachers preparing to teach in secondary schools is even scarce. Roychoudhury and Rice (2013) focus on secondary science teachers' teaching and reflections during a master programme to examine how secondary science teachers' views of teaching and their practice evolve during their education programme in the USA. The authors noticed that most teachers' views of teaching became more complex and student-centred oriented.

In the UK, Knight (2015) reports on postgraduate student teachers' conceptions about theory and its relation to classroom practice. The author found that trainee teachers entered the training with traditional views to teaching but with an openness to new ways of learning coming to increasingly value theory over time. Teaching science in secondary schools can be challenging and demanding as secondary science teachers are often required to teach outside their specialism (Kind, 2014). Their voice would help to identify what is more effective in their preparation from their perspectives. The voice and experiences of trainee science teachers are underexplored. Therefore, this study fills this gap in the literature.

6.1.1 Aim and Research Questions

The aim of the study was to identify how ITT programmes can more effectively prepare science teachers to teach science in secondary schools. To achieve the aim, the following questions guided the design of this study:

- What learning opportunities enhance trainee teachers' knowledge, skills, and self-efficacy during their training programme?
- What challenges and barriers trainee teachers encounter during their training programme?

The questions were answered through a qualitative case-study research design outlined next.

6.2 Research Design. A Qualitative Case-Study Approach

Qualitative case-study research was chosen for this second study to explore trainee teachers' learning experiences in a school-centred initial teacher training programme. Whilst systematic reviews rely on secondary data and begin with a protocol, a qualitative approach relies on first-hand data and begins with 'assumptions and interpretive lens' (Creswell, 2013, p. 44). A qualitative case-study approach supplements the research synthesis and fills the gaps to provide a more holistic picture and a greater understanding of the problem under investigation (Creswell, 2013). The corroboration of the findings from different sources better identifies effective strategies for preparing science teachers. Compared to systematic reviews, qualitative research can elicit silent voices and interpretations, identify variables not easily measured through other methods, and reveal an understanding of a complex issue or problem in detail and in depth in a natural setting (Creswell, 2013; Merriam and Tisdell, 2016). This study was concerned with the participants' views of their learning experiences during their training programme. A qualitative case-study approach allowed for eliciting their voices through multiple data sources (observations, interviews, questionnaires). Also, a qualitative case-study approach identified affective characteristics like emotions, attitudes and other feelings which could not be elicited through the systematic review methods. The use of qualitative methods (semi-structured interviews) with an open-ended format allowed for an 'emerging world view to be explored' (Merriam and Tisdell, 2016, p.110). As teacher preparation programmes are complex, a qualitative approach has been the most appropriate way for getting insight into a complex issue. Apart from its advantages, some methodological characteristics, highlighted by proponents of qualitative research, were also relevant to this study.

First, qualitative case-study research is conducted in a natural setting where the participants experience the issue or problem to be studied. In this study, data collection took place over nine months of the SCITT programme covering both the coursework and teaching practice in school placements. Data was collected by immersion in the field (coursework) and gathering first-hand information based on ethnographic principles. Immersion in the field allows for observing the participants' behaviour in their own context watching and listening to the interaction, talking to people in the setting formally and informally, individually or in groups or both (Hammersley, 2006). A first-hand experience with the initial teacher training programme enabled a better understanding of the context and participants.

Qualitative case-study research relies on the researcher as key instrument in data collection. In this study, data was collected by the researcher using self-designed instruments for gathering trainees' views and perceptions, observing their behaviour, and capturing their feelings and thoughts through interviews.

Qualitative case-study research generates a thick description. A thick description only can be achievable through triangulation, collecting data from multiple sources. In this study, observations, questionnaire, interviews, and some artefacts (curriculum materials, policy documents etc) were used as sources for collecting data.

Qualitative case-study research allows opportunities for complex reasoning going between inductive and deductive approaches. In this study, data from multiple sources were analysed through inductive and deductive approaches and grouped in themes and categories.

The study focused on the participants' multiple and subjective meanings and views which were considered in analysis and interpretation of data.

Lastly, qualitative case-study research presents a holistic, complex picture. The participants' experiences in their training programme were presented in a holistic picture by capturing both positive and negative aspects of their experiences.

Apart from the above characteristics, the study used a conceptual framework based on a constructivist approach as a lens through which the participants' views and experiences were captured, analysed, and interpreted. The *Learning to Teach Framework* (LtTF) (see Chapter 5, Figure 12), developed and used in the first study, guided the design of the interview protocol enabling questions related to the components of the framework. The components were congruent with the first research question that sought to explore trainees' perceived learning opportunities that add to their knowledge, skills, and self-efficacy development. The framework was slightly modified by adding a new component to include trainees' affective characteristics in terms of perceived challenges and barriers to their learning. The *Triadic Framework for Learning to Teach* adapted from Bandura's Triadic Causation (see Chapter 5, Figure 14) also developed in the first study, was applied in this study to understand how trainee science teachers made sense of their experiences and how they added to their knowledge and skills development in the process of learning to teach. Teachers' experiences were interpreted through a triadic reciprocity between making sense of the knowledge, processing the knowledge, and enacting the knowledge within a socio-and cultural context for learning. More specifically, in the triadic causation, trainee teachers make sense of their teaching competences (in terms of knowledge, orientations, skills, understandings and self-efficacy) through a constructivist approach to learning within a learning context (coursework or school placement). The learning context influences trainees' competences that will be enacted through a cognitive and behaviour approaches (e.g., observational learning and teaching practices). The enactment of their teaching competences further improves their competences till they become proficient.

In short, the study aimed for a rich and in-depth description of trainee science teachers' views of their learning experiences within their training programme. Case Study research is appropriate for developing in-depth understanding of a group of people within a 'bounded system' (Creswell, 2013, p. 97). According to Creswell (2013), a Case-Study begins with the identification of a specific case which may be a concrete entity, such as an individual, a small group, an organization, or a partnership, community, a relationship, a decision process or a specific project. The case in this study is a single case study as the focus was on one single SCITT centre or programme to explore and understand how the programme can better foster trainees' development as practitioners (Creswell, 2013). A case study provided a better understanding of a single case in a real setting. The study used Creswell's definition of a case study as 'a methodology - a type of design in qualitative research' in which the case (the SCITT programme) is bounded in time (nine months) and place (one single centre) (p. 97).

A Case-Study is selected by the intent (Creswell, 2007). The study intent was to illustrate the uniqueness of the SCITT centre by describing the unique experiences of trainee science teachers that comprise the case ('intrinsic case'). Their unique experiences reside in their different personal characteristics (background, learning needs, prior knowledge, experiences, and beliefs). Also, the intent was to explore and understand what features of the programme were perceived to be effective in preparing science teachers and to use the case to explore these features and their impact on trainee teachers ('instrumental case') (Stake, 2003, p. 137). The decision to combine 'intrinsic' with 'instrumental' elements in the case study design was made on the rationale that the findings of the study may be transferable to other programmes and routes into teaching (Stake, 2003, p. 137). Therefore, the study had an external interest namely to ensure a degree of transferability of the findings among SCITT centres and other routes into teaching by providing sufficient description of the case so that readers could vicariously experience events and draw their own conclusions (Stake, 2003). Authors (Stake, 2003; Baxter and Jack, 2008) argued that an intrinsic case study places an emphasis on the case itself whilst an instrumental case, in addition, helps in pursuing other external interests.

The analysis comprised seven subunits within the case – six trainee science teachers and one educator as ‘embedded subcases’ (Yin, 1984 in Miles and Huberman, 1994, p. 26; Baxter and Jack, 2008). The context and trainees’ lived experiences during the duration of the study were described in detail. The study described each transcript as a subunit and then compared them in a whole. The themes were analysed across the seven transcripts and a complete description of both the case and themes was provided.

6.2.1 Setting and Participants

Setting. A School Centred Initial Teacher Training (SCITT) centre allocated to a local University has been chosen as a case and unit of analysis for a couple of reasons. First, it attracts candidates with different backgrounds (career changers) which makes the case interesting in exploring their different experiences to understand the provision offered by the programme from multiple perspectives. SCITTs are insufficiently explored in the literature.

School-Centred Initial Teacher Training (SCITT) programmes appeared in 1993 as a school led route into teaching (Whiting et al., 2018). SCITT programmes are run by a group of schools called teaching schools or other private bodies granted by the government to deliver their own training as ITT providers. Provider, Whiting et al. (2018) clarifies, is ‘the accredited entity that is accountable for the outcomes of trainees and recommends Qualified Teacher Status (QTS)' (p. 76). The SCITT providers need to work in collaboration with a university if they want to validate their Post-Graduate Certificate in Education (PGCE) (Whitty, 2017; Whiting et al., 2018). Trainee teachers in this study were based in accommodation located at a local validating university with the ITT provider being the Local Education Authority. Trainee teachers completed teaching practices at two different placement schools in the local area. The programme lasted for one academic year. To enter the programme the trainees were required to possess a degree and to have passed the professional skills tests in numeracy and literacy (Foster, 2019). The training programme in the study aims to prepare the candidates for teaching science across the 11-18 age range in maintained secondary schools in England (Foster, 2019).

Participants. Fourteen trainee teachers (six females and eight males) were enrolled in the programme during September 2019 and June 2020, and all agreed to be research participants. Their age ranged between 20-25 and over 40. All the participants possessed a bachelor's degree in a science specialism (seven in biology, three in chemistry and four in physics). The participants were recruited in two phases. In a first phase, the whole cohort of trainee teachers enrolled in the programme (all the population within the case) agreed to participate in a first and second phase of data collection (the questionnaire and observation phases). For the third phase (interviews), five 'rich information' participants with different experience and specialisms were purposefully identified by one of the teacher educators in the programme to act as a 'key person' in the research (Merriam and Tisdell, 2015, p. 127). During the first semester, one participant was deferred from the programme. To ensure a better representation within the case, another two trainees were recruited by email in a second phase on a voluntary basis. Each of the interview participants were a subunit of analysis. The case study design included seven subunits of analysis (six trainees and one educator) within a single case in the context of SCITT centre as a unit of analysis. All the six trainees (3 females and 3 males) were career changers.

6.2.2 Data Collection

Data collection took place over nine months of the programme between September 2019 and May 2020, mostly using qualitative sources, to gain an understanding of trainee teachers' views of their experiences in the training programme. Data was collected from questionnaires, observation sessions, and semi-structured interviews in three phases. The first phase took place between June and September 2019 involving the development of the questionnaire, piloting the questionnaire, and administrating the questionnaire in September. The second phase involved two observation sessions of the training activities during October and November 2019 at the designated local high schools. In the third phase, seven one-to-one semi-structured interviews were carried out at a convenient time and place for the participants between February and May 2020.

The design of the questionnaire was facilitated by The National Survey of Science and Mathematics Education 2012 (Fulkerson and Banilower, 2014) and Teaching and Learning International Survey (TALIS) questionnaires for teachers (OECD, 2014; OECD, 2018). The surveys provided validated questions about teacher backgrounds, their work environments, professional development and their beliefs and attitudes about teaching. I selected and adapted questions from the surveys to fit with the research questions following the guide for questionnaire construction provided by Cohen, Manion and Morrison (2007, p. 320). Three categories of questions were developed to gather information about the participants' background; their beliefs, and self-perceptions of their needs of development; and perceived level of preparedness (see Appendix F). To ensure the validity of the questionnaire, the questions were selected and adapted from questionnaires on the research topic already tested, using appropriate validated scales; the questionnaire was refined and improved through repeated checking for appropriate wording, language within the 'grasp of the participants', accuracy, and relevance to the sample being targeted and to the aim of the study (Cohen, Manion and Morrison, 2007, p. 322); the questionnaire was first piloted on a small sample of colleagues who had not seen the questions before: the questionnaire received approval from Ethics Committee. The responses to the questionnaire served as points for developing the observation and interview protocol.

The observation protocol was created following Lincoln and Guba's (1985 in Cohen, Manion and Morrison, 2007, p. 405) suggestions for conducting observations, taking into consideration the participants' responses to the questionnaire regarding their beliefs and perceived need of development. The observation protocol included: field notes during the teaching sessions about the physical setting, the activities taking place and how they stimulated the participants' learning, specific actions of the participants, their goals and feelings; logs of field experience (to be completed at short time after the teaching sessions); sketches and diagrams (to capture the physical context) and a reflective journal. The information gathered from the observation sessions alongside with the participants' responses to the questionnaire served for the development of the interview protocol.

The interview protocol was based on the research questions and theoretical framework of the study. The components of *Learning to Teach Framework*, developed in the first study, enabled questions that helped in answering the research questions. Open-ended questions were developed to reflect the participants' views and experiences in the programme regarding their change in beliefs, perceived developed knowledge, skills, confidence, and support received. The interview protocol included questions related to the above aspects to be covered with all the participants and flexible sub-questions as prompts to gather open ended answers from them (see the Interview Protocol in Appendix G). Merriam (2009) states that to generate quality data, is important to ask good questions. In devising the questions and sub-questions, attention has been given to the clarity and language in which they were formulated to avoid misinterpretations. Also, to increase the quality of data, questions with *yes* and *no* answers and leading and misleading questions were avoided (Cohen, Manion and Morrison, 2007).

Questionnaires

A structured questionnaire was applied to capture trainee teachers' views about teaching and learning science and their perceived level of preparedness at the beginning of the training programme. The questionnaire provided an understanding of how trainee teachers' prior experiences impacted on their learning by comparing their views at the beginning of the programme with the information gathered from the other sources. The questionnaire was completed by the whole cohort of trainee science teachers during the second week of their initial teacher training programme in September 2019. The questionnaire consisted of three sections (see Appendix F). The first section gathered demographic information regarding gender, previous experience in teaching science, degree, and speciality. The second and third sections included questions based on the *Learning to Teach Framework* components, a framework developed in the first study. The second section included questions that captured information about trainees' beliefs about teaching and learning science and their perceived level of knowledge, skills, and confidence for teaching science at secondary level. The third section included questions that gathered information about trainees' perceived need of support in terms of learning opportunities.

The type of the questions in the questionnaire were closed ended rather than open ended because the intent was to gain a snapshot of trainees' views and perceptions at the beginning of their training programme. Closed ended questions were quick to complete and clearer about the type of information required. Cohen, Manion and Morrison (2007) argue that open-ended questions may gather irrelevant information as through an open format the participants may be confused about the kind of information required from them. In addition, open-ended questions make the questionnaire appearing 'long and discouraging, leading to the participants not to answer' (Cohen, Manion and Morrison, 2007, p. 325).

The first section of the questionnaire combined dichotomous (yes/no) with multiple choice questions (as for qualifications) and one open ended question that enabled the participants to express their motivation for becoming science teachers. The second section included rating scales questions that enabled a degree of sensitivity and differentiation of responses (Cohen, Manion and Morrison, 2007). Example of rating scales: *Strongly disagree/disagree/ neither agree nor disagree/agree/strongly agree; Not at all/a little/to some extent/a lot/to a great extent; not at all/somewhat/fairly/very well.* The rating scales were useful for capturing trainees' attitudes, perceptions, and opinions. The third section included rank ordering questions on five ranks of priorities that enabled the participants to express their perceived priorities in terms of their needs of learning opportunities (the ranks used were from *not needed* to *very much needed*) (Cohen, Manion and Morrison, 2007). Because in closed questions the participants are limited in responses by choosing from a given choice, the questionnaire included a new open ended category *Others* for each section to enable the participants to reply in their own terms and provide their own opinions (Cohen, Manion and Morrison, 2007). The questionnaires were completed by the whole cohort of fourteen trainees (six females and eight males) during their lunch break in the presence of the researcher. Cohen, Manion and Morrison (2007) suggest that the presence of the researcher is helpful because it enables any queries or uncertainties to be addressed immediately.

Course Observations

Observation in natural settings is widely recognised as a powerful method for data collection in qualitative research as it allows first-hand experiences with a setting and people within the setting (Patton, 2001; Merriam, 2009). Patton (2001) argues that first-hand experience allows the researcher to be ‘open, discovery oriented and inductive’ (p. 265). This has the advantage of not relying on pre-conceptualisations of the setting from a second-hand source like documents or verbal accounts of the interviews. Because interview data are selective perceptions/distorted responses due to personal bias, observation provided a check of ‘perception-based data’ emerging from the interviews (Patton, 2001, p. 262). The interviews, on the other hand, allowed to go beyond the observed behaviour by exploring feelings and thoughts (Cohen, Manion and Morrison, 2007). Thus, the observation complemented the information gathered through interviews contributing to the credibility of the findings. Compared to an ethnographic study which enables long time immersion in the field allowing time for familiarization with settings and people in the settings, the observation, in this study, was shorter in duration limited to only two days of coursework activities running from 9 am to 5 pm. Given the limitations of short time observation, the study started form Patton’s (2001) assertion that it is impossible to observe everything, and observation must start from some selective features. The observation started with a structure of what needs to be observed based on the aims, research questions, and theoretical framework of the study (Merriam and Tisdell, 2016). The aim of the study was to identify how ITT programmes can more effectively prepare science teachers to teach science in secondary schools. To achieve the aim, an observation of how the initial teacher training programme was running in practice in different locations and in different science subjects was important to capture a general picture of the real learning context (Patton, 2001, p. 276). More specifically the focus was on the nature of the learning activities that comprised the programme and how trainee teachers reacted to them, rather than an evaluation of the programme or activities.

Patton's (2001) approach to participant observation as a 'continuum process' was adopted during the whole observation phase (p. 265). This approach involves a variation between being a participant and a spectator. The decision was made given the intense and individual character of the activities within the coursework which placed constraints on the observation of others. In this approach, whilst still participant, the researcher tries to stay sufficiently detached to observe and analyse the training activities offered (Merriam, 2009). Over two days of intense practical activities, as a science teacher herself who was learning about teaching outside specialism, the researcher needed to detach of the temptation of trying things out for own learning, resuming to observing and analysing the training activities by remaining in a 'marginal position' (Merriam, 2009, p.126; Merriam and Tisdell, 2015, p. 127). For instance, the participation in the training activities took place only when the participants' reactions could be observed such as group or whole class activities. Because most of the activities required individual practice, the observation was predominantly a spectator approach with the researcher circulating among trainees and observing their own reactions to their successes and struggles whilst trying out practical activities. Brief informal conversations took place during and between activities to provide insight into trainees' understandings of their learning. The observations were recorded in field notes in the form of descriptions and reflections during the study (Merriam and Tisdell, 2015). Details about the physical setting, events, activities, and participants' behaviours/reactions, were noted down shortly after each observation and interview (Merriam and Tisdell, 2015). Keeping a record of details followed by reflective personal comments was helpful to capture common patterns and differences in trainee teachers' learning experiences as reported in interviews and observed by the researcher (Patton, 2001).

Interviews

Interviews provide information and background on issues that cannot be observed or efficiently accessed such as feelings and thoughts (Patton, 2001). Patton (2001) declares:

> …the purpose of interviewing is to allow us to enter the other person's perspective. Qualitative interviewing begins with the assumption that the perspective of others is meaningful, knowable, and able to be made explicit. We interview to find out what is in and on someone else's mind, to gather their stories (Patton, 2001, p. 341).

Merriam and Tisdell (2015) state that, in conducting interviews, the focus is on the potential of each participant to contribute to the insight and understanding of the phenomenon studied rather than on the number of participants as in a survey. Semi-structered interviews allowed an understanding of multiple perspectives within the same programme. Compared to structured interviews that are more rigid not allowing access to participants' perspectives, semi-structured interviews assume that the participants define the world in unique ways (Merriam, 2009; Merriam and Tisdell, 2015). As Tracey (2019) stresses, less structured interviews stimulate discussion rather than dictate it. Such an approach encourages interviewers to listen, reflect and to adapt to ever-changing circumstances. The use of semi-structured interviews allows emergent understandings to develop and for the participants' viewpoints to be heard without the constraints of scripted questions. Furthermore, less structured interviews capture both content and emotional aspects. Compared to participant observation where first-hand knowledge of what people said and did is gathered in real learning context, in interviews, the interviewer relies extensively on verbal accounts of how people act and what they feel (Merriam and Tisdell, 2016).

The interviews were carried out over the period of February - May 2020 in two ways: face to face interviewing, and synchronously online interviewing using Zoom platform. In this study, six participants with unique experiences and one educator contributed to an understanding of the case. Only two participants and the educator were interviewed face to face in a place and time convenient to them and to the researcher, during February 2020, before Covid -19 lockdown to be imposed. The remaining four participants agreed to participate in online interviewing. All the interviews were recorded: four interviews (three face to face and one online) were audio-recorded, and three online videorecorded. The duration of the interviews was between 30 and 60 minutes. Merriam and Tisdell (2015) point to technology as 'always subject to breakdown' (p. 116). Although online interviews had the advantage of conducting a conversation from the comfort of home, it was indeed, subject of voice breakdown and minor issues with the recording.

The interviews were transcribed using NVivo 12 transcription software. The decision was made given that English was a second language for the researcher. The transcription software helped in increasing the reliability of the transcriptions. The interviews were relistened many times to make the necessary adjustments on the electronic transcripts. This was needed because the programme was not 100% accurate since it could not capture the participants' tone of voice, pauses, and other non-verbal cues (Merriam and Tisdell, 2015; 2016). These features were then annotated in and on the margin of the transcripts. The final number of pages of each transcript ranged from eight to fifteen. Each transcript was assigned a pseudonym. The participants were asked for a preferred pseudonym in advance. None of the participants had any preference.

6.2.3 Data Analysis

Merriam and Tisdell (2016) define data analysis as 'the process of making meaning of data to answer the research questions' (p. 2020); it is the process of breaking data down into segments of information and then assigning these segments to categories or classes which bring data together again, in a novel way (Bryman, 2015). This process is called coding and the approach to coding, common in qualitative research, is thematic analysis (Braun and Clarke, 2006; Merriam and Tisdell, 2016). In this study, thematic analysis was applied to each source of data. An exploratory data analysis approach was taken for the questionnaire using the method of combining the categories and calculating frequencies to get an overall picture of the perceptions of the participants enrolled in the programme. Due to a case embedded design, in which each subcase (transcript) was a subunit of analysis, the thematic approach was applied for each transcript separately. The transcripts were then brought together in a cross-case analysis within the context of the SCITT programme. Yin (2003) suggests that an analytic strategy is the best preparation for conducting a case study analysis. This study was guided by *Learning to Teach Framework* as analytical tool provided by the first study. The framework was slightly adapted to include a new component namely *Challenges and barriers* to capture the challenges that trainees encountered in their learning during their training programme. *Learning to Teach Framework*, developed from data analysis in the first study, was applied to data analysis of this second study because it provided the components which teachers, as participants in the review studies, were found to draw upon in their learning to teach during their education programmes. Therefore, the applicability of the framework is highly relevant to teacher training programmes because it gives insight into the components that trainee teachers need to develop during their training programmes. Data analysis started with an inductive approach through which the meanings (the codes) emerged from data of each transcript. In a second phase, *Learning to Teach Framework* was used as a coding framework or analytical strategy helping in categorising data according to common patterns in the components of the framework, namely *Knowledge, Orientations, Practice skills, Understandings, Efficacy,* and newly added component of *Challenges and barriers* (Table 17).

Table 17. Learning to Teach Framework (LtTF) – the Analytical Strategy

LtTF Components	**Description of each component**
Knowledge	Features of the programme as opportunities for trainees to expand their content knowledge (e.g., reading academic content). Features of the programme as opportunities for trainees to develop and expand their repertoire of instructional strategies (e.g., modelled activities). Features of the programme as opportunities for trainees to identify students' misconceptions (e.g., analyse students' work).
Orientations	Features of the programme as opportunities for teachers to challenge their views/beliefs/thinking about teaching and learning.
Practice	Features of the programme as opportunities for trainees to rehearse teacher role (e.g., teaching and planning).
Understandings	Features of the programme as opportunities for trainees to reason about content, to transform and transfer knowledge (sequencing), acknowledge and awareness (e.g., their own or other's limitations).
Efficacy	Features of the programme as opportunities for trainees to build up confidence (e.g., support and/or experiencing success).
Challenges/barriers	Features perceived to challenge/hinder trainees' development (e.g., lack of resources, inconsistent support, negative feedback).

The analytical strategy allowed a focus on the research questions that sought to explore learning opportunities that added to trainees' development and identify barriers and challenges they encountered during their training programme.

Data collection and analysis were processed simultaneously and were ongoing (Merriam and Tisdell, 2015; 2016). Given its useful application in the previous study, the coding process followed the steps for thematic analysis suggested by Braun and Clarke (2016; 2019). The steps are described in this section. Data analysis began with familiarization with data as it was collected. Codes were assigned to the text and grouped in common themes, deductively (for the questionnaire) and both inductively and deductively (for the observational data and interviews). *Learning to Teach Framework* provided six main themes in which all the subthemes were charted for each transcript separately. Single themes across the six transcripts from multiple sources were constantly compared in a cross-study analysis to ensure triangulation.

Analysis of the Questionnaires

Data resulted from the questionnaires provided a general picture of the participants enrolled in the programme on three levels: background, beliefs (student and teacher centred), and perceived need of learning opportunities and confidence. The statements from the second and third sections of the questionnaire were charted in *Learning to Teach Framework* components in a deductive way. To get an overall indication of the most needed learning opportunities, for each statement in the rating scale, the frequencies for the category 'a lot' were added with the frequencies of the category 'to a great extent' and compared them with the frequencies from the categories 'a little' added with those from 'to some extent'. The same procedure was followed for the ranking scales. This method of combining categories suited the purpose of the questionnaire in getting a general picture rather than a detailed one

(Cohen, Manion and Morrison, 2007). Any similarities and differences between males and females were explored. Because of the small number of participants, a statistical package was not needed.

Analysis of the Observational Data

The components and sub-subcomponents of *Learning to Teach Framework* were used as priori codes for the observation notes taken during the two days of coursework activities in biology and physics. Observational data was inductively coded, then categorized deductively in the five components of *Learning to Teach Framework* - the analytical tool. The observation categories were revised and permanently used as reference points for the participants' responses in the interviews (an example is provided in Table 19).

Analysis of the Interviews

Familiarisation. The interviews were the primary source of data. The interviews, transcribed with NVivo transcription software, were checked for accuracy by re-listening to the recordings, making corrections and inserting pauses where was necessary to make sense of data. The interviews were then uploaded in data analysis software NVivo 12. The software had the advantage to keep all data in the same place making it easily accessible (Merriam and Tisdell, 2016). Initially, the transcripts were coded using the computer software. Yet, using a computer programme for analysis was challenging. As Merriam and Tisdell (2016) observe, the software analysis is only useful in organising data whilst the analytic process is done by the researcher; thus 'the software no more does the analysis than the word processor' (p. 222). The computer programme proved to be daunting given the time taken to learn to run it properly. For instance, because of limited familiarisation with the programme and time restrictions, data for analysis was converted to manual analysis using the word processor. In word processor, each interview transcript was read repeatedly to gain a good familiarisation with the participants' accounts. First, important information within the text that related to the research questions was highlighted on the transcript to make sense of the meaning within each transcript as sub-units of analysis.

Generating codes. The coding process took place in two stages. During the first stage, an open coding was applied to each transcript. The codes that resulted from the words and phrases of the participants were written on the margin of the transcript. The process was repeated back and forth till the 'saturation' was reached (no other codes emerged) (Merriam and Tisdell 2016). From the open coding, the codes that resulted from the words and phrases of the participants, were identified for all the transcripts. In the second stage, similar codes were grouped together in common subthemes within each transcript. Each sub-theme was checked for relevance to the research questions and was annotated with excerpts from interviews to preserve the context (see Table 18 and 19).

Trainee teachers' experiences can only be understood in the context in which they learn. Bryman (2015) states that the process of making judgements and assumptions for interpretation is subjective. By annotating the interview data, the process was made visible allowing to see patterns and the context in which they arose. In this stage, data was 'brought together in a new way' (Bryman, 2015, p. 574). The sub-themes resulting through coding answered the research questions for each transcript separately. An average of twenty-eight subthemes per transcript resulted through the analysis.

Generating themes. To prepare each transcript for the analytical interpretation, the sub-themes were then deductively charted in the *Learning to Teach Framework* components for each transcript separately resulting six analytical frameworks (see Appendix H).

Table 18. A Coding Sequence

Excerpt from an interview	Codes	Sub-Themes
'I came into teaching with this idea that with practical work, you would do … kind of a lot of discovery learning in the idea that they would almost discover it completely for themselves. But I'm realizing actually, although you might do something which is exploratory, you also really need to make sure that you, kind of back it up with scientific knowledge to make sure that they're really understanding it and then maybe you go back to the practical work afterwards as well so they can really say that… then they can apply their knowledge as well. So, the practical work isn't just about discovering, but it's also about applying knowledge' (Sonya)	Initial beliefs about teaching and learning Acknowledging beliefs Change in beliefs	Challenging assumptions about teaching and learning (O)

The Learning to Teach Framework components were the main themes that captured the recurring patterns that cut across all data within all the transcripts (Merriam and Tisdell, 2016).

Reviewing and defining themes. In line with Braun and Clarke's (2006) steps in thematic analysis, the themes (*Learning to Teach Framework* components) were checked for coherence by comparing them with the codes in the context of each interview to ensure that the themes matched the trainees' accounts in an accurate way. Then, the themes were named as: ***-Features that add to knowledge; - Features that challenge orientations or change***

beliefs; -Features that develop practice; - Features that develop understandings; - Features that develop efficacy, - and Challenges and/or Barriers to Learning.

All the identified features/sub-themes within each theme were only trainees' perceived features to add to their knowledge, teaching skills and self-efficacy as well as perceived challenges to learning in the context of their training programme. In line with Clarke and Braun's (2006) suggestions, the themes were organised into a coherent and consistent account with accompanying narrative in relation to the research questions for each transcript separately (see Appendix H).

Cross-Case Analysis. All the transcripts **(**the subcases) were then brought together in a cross-case analysis. The cross-case analysis was made for each component/theme of *Learning to Teach Framework* at a time to enable the discovery of common patterns across the transcripts. The sub-themes within each theme were accompanied by excerpts from interviews as reference points to preserve the context in which they were made (Table 19).

The sub-themes within each theme across all the transcripts were re-coded and from the re-coding process resulted new common themes. For example, for the theme *Features that develop practice*, all the sub-themes from all the six transcripts were re-coded, and three new common themes were developed: Feedback and Support on Practice, Practice Rehearsal, and Teaching Experiences (Table 20). The same process was repeated for each theme of Learning to Teach Framework in the cross-case analysis. All the new resulting common themes across all the transcripts are presented in Table 24, Chapter 7. The new themes resulting from the cross-case analysis were grouped into four analytical categories for interpretation of the case in the context of the SCITT programme.

Table 19. A Cross-Case Analysis Sequence for the theme *Features that develop practice*

Trainee	**Sub-themes**	**Excerpts from interviews**
	Practical work and experiments	'I've learned practical skills...how to conduct
	Hands on activities	practical experiments... 'We had lots of hands -on
		activities… doing …required practical
Lisa	Application in practice	'…it is putting things I've learned into practice…'
	Reteaching lessons	'One of the things that benefited me most was
		reteaching a lesson'
	Feedback on practice	'…it would be good to get earlier feedback on
		documents…to know whether they are satisfactory
		and how they can be improved'.
	Application in practice	'Watching …and then trying what they did'
	Discussions and sharing	'…I think discussing how these applies and how
	experiences	other people are applying it to their practice'
Ryan	Trying out different strategies	'…I've used it in the class…and it really does
	Teaching experience	work… 'I have been in rooms on my own with my
		own classes responsible for their learning… for my
		own implementation of my teaching practice…
	Support on planning	'Support on paperwork … (planning, assignments)

Table 20. A Re-Coding Sequence for the theme *Features that develop practice*

Trainee	Sub-themes	New themes
Lisa	Doing practical work and experiments Hands on activities Applying in practice what has been learned Reteaching lessons Feedback on practice	Teaching experience Rehearsing practice Feedback and support on practice
Ryan	Applying in practice what has been learned Discussions and sharing experiences Trying out different strategies Teaching experience Support on planning	

The detailed cross-case analysis is found in Appendix I. The four analytical categories, resulting from the cross-case analysis, generated some implications for practice. The implications were used in the cross-study synthesis in Chapter 8 to identify matches, mismatches and gaps that inform and advance practice and research.

6.3 Trustworthiness of the Study

In alignment with a constructivist worldview on which the study is based, the trustworthiness of this study was evaluated on methodological rigor adopting the criteria proposed by Lincoln and Guba (1985): credibility, consistency (dependability), and transferability.

6.3.1 Credibility

Credibility is concerned with questions of 'how research findings match reality' (Merriam and Tisdell, 2016, p. 242). In line with the aim of the study and constructivist view, reality is seen from multiple perspectives. Trainees' experiences in their training programme are much influenced by their previous knowledge and beliefs. As such, the interpretation of the findings was based on trainees' own perceptions of their preparation as teachers. Internal validity from this perspective was ensured through an understanding of the participants' perspectives revealed by the findings. Three strategies to ensure credibility were used in this study: triangulation, peer review, and member checking.

Triangulation is the best strategy for ensuring that the interpretation of the findings match the participants' perspectives (Merriam and Tisdell, 2016). Triangulation made possible a comparison of data collected through the questionnaires, observations and interviews which added to the consistency of the findings. For example, the observations gathered information about the features that helped or hindered trainees' conceptual understanding and teaching skills. Also, through semi-structured interviews, trainees were asked to discuss about what has been more and less helpful for their development. The information gathered from the two methods was compared and the similarities confirmed the findings. An example of triangulation is provided in Table 21.

Table 21. An example of triangulation - *Knowledge and skills for teaching*

Notes from the field: the first day	Interview excerpts
…. trainees were performing practical work on diverse biology topics (practical work) …Trainers and trainees were having conversations covering misconceptions of the topic, practical rules, and tips for classroom management (discussions and sharing experiences). They explained how a demonstration can be effectively done to keep all the students focused and engaged (modelling). …Trainees looked enthusiastic and keen to try out practical, working in a relaxing atmosphere in which they could make mistakes and make fun of them (supportive environment). They looked interested to see and do things like extraction of DNA from strawberries (practical work). They helped each other and looked to each other's work making praises verbally or non -verbally for the best ones and being amused by new original creations like the cell model done from real pizza ingredients by one trainee (interactions with peers).	'We were able to demonstrate a lot of these experiments'(Nathan) 'We obviously had our subject knowledge straight in science where we were doing actually hands on… actually doing some of that required practical in the laboratory…' (Lisa). 'At subject knowledge days… usually it'd be practical… just go over different practical steps that show something really nice... concept really, really, nicely… so going over different practical and practice in those different practical... so I had a chance to do them myself (Laura). 'The biology training, again, has focused quite a bit on looking at common misconceptions and some of the practical rules, … … and so an important part in biology training was about giving us practical rules that are robust and should work without too many difficulties in schools. (Freddie)

The segment of triangulation shows some of the features that trainee teachers rated them as being valuable for their preparation. Such features were modelled activities, discussions, and opportunities to do practical works required in schools. Triangulation was complemented by peer examination and member checking. The findings and their relation to data were checked and refined constantly. Through member-checking, the interview transcriptions were checked with the participants to ensure the accuracy of what they have reported (Merriam and Tisdell, 2016). Copies of the transcriptions were sent to them via email. Five participants did not have any concerns or modifications to make, and one trainee only included one additional sentence for clarification.

6.3.2 Transferability

Transferability is concerned with the extent to which the findings of one study can be applied to other situations (Bryman, 2015). Bryman (2015) suggests that in qualitative investigations, the interviewed people are not representative of the whole population and the findings cannot be identical in other situations.

To ensure some degree of transferability, Lincoln, and Guba (1985) proposed the creation of ‘thick description’ so that readers can assess the similarity between the study and their own context (p.125). Thick description refers to a description of the setting and participants of the study as well as a detailed description of the findings with adequate evidence presented in the form of quotes from the participants’ interviews, field notes and other documents. Through thick description, readers can do their own interpretations and make informed judgements regarding the transfer of the findings to their own context.

In this study, detailed and appropriate descriptions of the context and the case with examples of raw data in the form of direct quotes from the participants were provided. These descriptions ensure a degree of transferability, giving the readers the opportunity to make their own interpretations and judgements on the applicability of the findings to their own contexts. For example, no matter the route, educators and trainees may adopt or adapt effective instructional methods or strategies from other contexts that fit with their own needs in a similar context.

From another perspective, transferability is seen from an analytical or theoretical view (Yin, 2003; Bryman, 2015). In this view, the findings are transferred to theory rather than to populations. In other words, the theory that emerges from one study can be applied and tested in another study. In this study, *Learning to Teach Framework* and *Triadic Framework* were developed from data analysis of the first study and applied and tested in the second study.

6.3.3 Confirmability and Dependability

Triangulation as a strategy for obtaining consistent and dependable data, as well as data most congruent with reality as understood by the participants, was complemented by an audit trail and reflexivity. Audit trail consists of an outline of the decisions made throughout the research process. Providing a rationale for the methods used and for interpretations and judgements of the findings, helps readers to discern how the decisions have been reached (Merriam and Tisdell, 2016).

In this study, the audit trail was achieved through making comprehensive notes to preserve the contextual background across the six transcripts. The selected themes were compared across the transcripts to verify their similarity and relatedness to the research questions. This trail can be identified in the sequence of cross-case analysis (Table 18) and in more detail in Appendix I. A rationale for the decisions made throughout the study was also provided.

6.3.4 Reflexivity

Merriam and Tisdell (2015; 2016) warn that, as the researcher is the main instrument in data collection, analysis and interpretation of data, his/her background and interest can impact on the study. These aspects must be acknowledged through a self-reflection on the researchers' own background and interests and consideration of how this will shape the collection, analysis, and interpretation of data. Thus, in alignment with a constructivist view, a self-reflective stance was necessary throughout the process to reduce a subjective view and to keep an 'empathetic understanding' when listened to trainees' narrations, analysed, and interpreted the text (Tracy, 2019, p. 51). A constructivist approach emphasises the importance of empathy and the examination of the world from the participants' points of view (Tracy, 2019). Tracy (2019) states that an empathetic researcher, 'sees the world as others see it', is 'non-judgmental', and 'understands another's feelings and communicate the understanding' (p. 51). Given my own background as a science teacher, this systematic reflexivity was important. There was the risk that the familiarity with what it means to be a science teacher from my own perspective could have made me assume that I already had a good understanding of others in similar contexts (Gilham, 2000). Therefore, it was important not to make assumptions of familiarity or similarity. Gilham's (2000) suggestion to consider that 'you are going to a foreign country and study a culture quite different from your own' resonated with my own position (p.18). Given that the preparation of teachers in the UK was different to what I experienced in my own preparation as a teacher abroad, I tried to keep an open mind and empathetic approach throughout.

During the research, I was aware that I needed to establish relationships with the participants so that they did not feel they were being watched (Patton, 2001). Patton (2001) warns that observations may affect participants' behaviour 'making them to behave in an atypical fashion' (p. 306). To reduce my intrusion, I carried out the observation of course activities at the beginning of the programme (Patton, 2001). Patton (2001) explains that 'such timing makes the observer one among a number of novices and substantially reduces the disparity between the observer 's knowledge and the knowledge of other participants' (p. 313).

Similarly, Gartland (2012) states that the easiest way to build relationships with people is to establish what you have in common with them. The research and the role of observation was explained to the educator and participants, highlighting the interest in activities from the perspective of a science teacher with limited experience in teaching outside of specialism. The limited experience in teaching outside subject specialism placed me on a position of equality with the participants most of them being career changers required to teach outside their specialism. The similarity with the participants may have made them to perceive me more like a colleague, making them more open and approachable.

To minimise the bias caused by an 'untrained observer' (Patton, 2001, p. 261), I took descriptive fieldnotes that detailed the physical setting, events, activities, and participants' behaviours/reactions shortly after each observation (Merriam and Tisdell, 2015; 2016). I attempted to preserve the details within the real setting. By keeping a record of details followed by reflective personal comments was helpful to capture a general picture of trainees' differences in their learning experiences as reported in interviews (Patton, 2001). Patton (2001) states that the observer's perceptions are also subjective and only by making the researchers' own perceptions part of the data allows for a more comprehensive view of the setting being studied.

Observational data was used to check the participants' accounts from the interviews avoiding thus a relying on second-hand data on the setting. For example, when asked about what knowledge has been learned about teaching in secondary school, an interviewee commented that she enjoyed doing practical work in all the three sciences feeling ‘like being at school’ (Sonya). The feeling of ‘like being at school’ was linked to the observational data describing the real setting of a science laboratory in a high school as perceived by the observer. In the real context of a science classroom, the interviewee could imagine herself being a student in a high school doing work that students usually do in a science lab. The science lab gave her the feeling of being a school student. This feeling helped her to empathise with the school students trying to understand the work from their own perspective which contributed to her improvement in how to approach teaching, as she narrated.

6.4 Ethical Considerations

Merriam and Tisdell (2016) draw the attention to the ethical way in which the study is conducted to ensure rigor in qualitative research. They argue that, to a large extent, the rigor of a study depends upon the ethics of the investigator. The study was guided by ethical principles based on respect for persons, justice, fidelity, and academic freedom (Farrimond, 2017; BERA, 2018). Whilst for the systematic review, an approval from Ethics Committee was not necessary, the case study only began after an approval from the Ethics Committee has been received and permission from the SCIIT centre, as a gatekeeper, has been granted. An application to the Ethics Committee, including all the documents sought for approval (such as the informed consent form, the questionnaire, and the interview schedule), has been submitted online on 12 August 2019 and approved on 14 August 2019 (see the approval letter in Appendix K). The first Covid 19 lockdown, coming into force in March 2020, disturbed the interwiew process leading to changes in the the way in which the interviews were conducted. Since face to face interviewing was no longer possible, a new application to the

Ethics Committee, submittted online on 21st April 2020, sought approval for conducting the remaining interviews on the online platform (see the second approval letter in Appendix K).

Since a case study involves research participants who disclose their personal views and experiences, data collection started only after the participants were informed about the purpose of the research and a written consent for their voluntary participation was obtained (Cohen, Manion and Morrison, 2007; Farrimond, 2017) (Appendix J). The participants' right to privacy was ensured by anonymity. Pseudonyms were used for all the participants in the interviews, and the questionnaires were collected unsigned.

The participants were also ensured of confidentiality. Data was accessed only by the researcher and supervisory team. In compliance with Data Protection Act (1998) and EU General Data Protection Regulation (GDPR), data consisting of audio and video recordings was securely stored on a personal computer with password protection. Other ethical principles like deception, right to withdraw and avoiding harm were adhered to throughout the study (Cohen, Manion and Morrison, 2007; Farrimond, 2017; BERA, 2018).

Chapter 7. Exploratory Case-Study. Findings and Discussion

The previous chapter described the methods used in conducting the Case Study research. This chapter presents and discusses the findings of the case study. The chapter is structured into five sections starting with a short introduction to the study. The second section presents the findings from the analysis of the questionnaires. The third section presents the findings from the analysis of the observations and interviews according to the research questions. The fourth section presents a discussion of the findings in relation with the literature. The chapter ends with conclusions of the findings.

7.1 Introduction

The aim of the Case-Study was to identify how ITT programmes can better prepare trainees to teach science to secondary students. Therefore, an exploration of trainee teachers' learning experiences in their training programme enabled an understanding of how they add to their knowledge, skills, and self-efficacy development and what challenges they face in learning. The questions addressed in this study were: What learning opportunities enhance trainee teachers' knowledge, skills, and self-efficacy development during their training programme? What challenges and barriers trainee teachers encounter during their training programme?

The questions were answered through a thematic approach to analysis guided by *Learning to Teach Framework* (LtTF) with its comprising components and subcomponents developed in the Systematic Review study (Table 22). The framework, that was developed from data analysis of the review studies, was relevant to this second study because it revealed five main components which teachers draw upon in their learning to teach during their education programmes. The framework was relevant to the research questions that sought to identify trainees' perceived learning opportunities that enhance their development as well as challenges they encounter during their training programme.

Table 22. Learning to Teach Framework (LtTF) developed in the first study

Knowledge of:	**Orientations:**	**Practice:**	**Understandings:**	**Efficacy:**
Content Instructional strategies Learners Curriculum Assessment	Beliefs Dispositions Views Perceptions Goals Ways of thinking	Action Behaviour Lesson planning Teaching	Awareness Acknowledgment Transformation Integration Interplay Transfer	Efficacy beliefs Self-efficacy Outcome expectancy

The components of *Learning to Teach Framework* were identified by drawing on the components of PCK frameworks applied in the studies included in the review. Learning to Teach Framework was used as analytical tool because it allowed for data to be categorised into themes provided by the framework. *Triadic Framework for Learning to Teach*, also developed in the Systematic Review study (Figure 15, Chapter 5), was used as theoretical lens for understanding trainee teachers' experiences from multiple perspectives.

7.2 Findings from the Analysis of the Questionnaires

7.2.1 Background Information

Based on the information gathered through the questionnaires administrated at the beginning of the training programme, eight males and six females with age ranging between 20 -25 to over 40 years old, were enrolled in the programme. Ten trainees gained diploma degree in a science area. Two of them gained a master's degree and another two gained a research degree. Eleven trainees did not have experience in teaching, two of them had less than one year experience and another one up to two years.

7.2.2 Perceived Learning Needs at the Beginning of the Programme

The analysis of the questionnaires revealed that at the start of their training programme, all fourteen participants would like to develop 'a lot' and 'to a great extent' knowledge and skills in the following aspects:

Knowledge bases: handling the classroom management (n=12), identifying students' misconceptions (n=11), assessing students' understanding of the topic) (n=11), learning from experienced teachers (n=11), learning knowledge about science curricula (n=10), seeing models of teaching (n=9), deepening their content knowledge (n=9), making links between science and other disciplines (n=6), motivating students' participation (n=6), providing experiences that relate to real world (n=4).

Practice: planning a differentiated lesson (n=12), understanding students' perspectives doing work that students do (n=11), rehearsing teacher role (n=8), selecting science materials, resources, and analysing students' work (n=6).

Orientations: 60% of the trainees 'agreed' and 'strongly agreed' with teacher-centred statements. 22.85 % neither 'agreed' or 'disagreed' and 18.57% 'disagreed'. However, they also agreed with student-centred statements in proportion of 66.07%, with 21.42% neither 'agreed' or 'disagreed' and 7.14 % 'disagreed'. This data clearly shows that trainee teachers' orientations, at the beginning of their training programme, were mixed. A reason for their mixed orientations may be the lack of ability to recognise them. Given that teachers' orientations inform their future learning, eliciting teachers' beliefs is an important aspect of their training programme.

Understandings: sharing and reflecting on experiences (n=8), analysing, and discussing resources (n=4).

Confidence. Eight participants felt 'somewhat confident' for teaching science and six participants felt 'fairly confident'. Asked about the support received, the participants rated the support from tutors as a first preference (n=11) and from peers as a second preference (n=10). The feedback from students was rated as a first preference only by three participants, and as second preference by four.

Challenges. Trainees perceived the following challenges to their learning: lack of classroom experience, stress, personal factors (family commitments), time management for paperwork, time pressure due to outside commitments (part-time student), behaviour management, hard to feel like a teacher, differentiation.

Looking across differences in gender, age, and qualification, there was a consistency in the voting by males and females in terms of the categories 'a lot' and 'to a great extent'. The overall pattern of voting by males and females was similar.

7.3 Findings from the Analysis of the Observations and Interviews

7.3.1 Background of the Participants

Three females and three males participated in the interviews (Table 23). Three trainees had a speciality in biology, two in physics, and one trainee in both physics and chemistry. Four trainees had a diploma degree, one had a master's degree, and two trainees had a research degree. Only one trainee had experience in teaching to secondary school students.

Table 23. Demographic information

Trainees' pseudonyms	Subject	The highest degree	Experience in teaching in secondary schools
Lisa	Biology	Diploma degree	Experience with younger students
Ryan	Chemistry/ Physics degree	Diploma degree	Experience with students in informal context
Laura	Biology	Diploma degree	No experience
Nathan	Physics	Master' degree	One year experience
Freddie	Biology	PhD	Teaching to adults
Sonya	Physics	PhD	No experience

7.3.2 A Snapshot of the Participants' Profile

Lisa had a biology degree and A level in chemistry and physics. After graduation, she worked with younger students to support their learning for many years. Because science subjects were almost absent from her job, she 'missed the science part of it' and thought to apply for teacher training to be a science teacher in a secondary school. Although she initially considered other routes into teaching, the SCITT route was chosen for several reasons. It was more convenient (close to home), she got a bursary, and it had been recommended 'by lots of people' in her previous job.

Additionally, as the route was said to be ‘practical based’, motivated her as she was interested to ‘get the school experience right from the start’. Although she was expecting there to be a lot of work, the course exceeded her expectations in intensity, and she thought that switching to part time would enable her to keep a good balance between personal and professional life as she stated: ‘I didn't think they'd be quite… it would be quite intense as it has been. And I did switch to part time as result of that. I was finding it, absolutely…. it was taking over my life completely’.

Lisa entered the training programme with no experience in teaching secondary school students. She considered that her science knowledge at secondary level was very limited given the long time since she graduated. At the beginning, she found the training activities overwhelming. She came to acknowledge the complexity of teaching in secondary schools learning triple science subject knowledge with general pedagogy in terms of how to manage students’ behaviour, knowledge about learners, methods of instructions as well as about assessment.

The main feature of her preparation that she considered it benefited her most was applying in the classroom the strategies she learned during the coursework or from observing teaching. Equally, she felt she could improve her teaching by reteaching lessons and reflecting on what worked and what did not, and to adapting the lesson accordingly. Lisa valued the activities that helped her to develop teaching skills with respect to conducting practical works, timing lessons, and the way in which to approach students.

Ryan, another career changer, entered the teacher training with a degree in physics and some experience from working with students in an informal context during his previous job, other than teaching. Before embarking on SCITT route, he had experienced a different route, yet due to health problems, he needed to stop his training. Between his programmes, he benefited from some school experience in a support position. His motivation towards teaching came mainly from his desire and the pleasure he took from working with students during his previous work. In addition, he had a passion for science especially for physics and wished to take the opportunity to pass this on to students. Because of family commitments, Ryan chose the route near to his home. His expectations from the course were based on his previous experiences before becoming ill. He stated: ‘So much better because you get fully integrated into the schools when you're there. You really are literally a member of the team’. He declared himself satisfied with the layout of the programme and the diversity of the activities and people leading them. He appreciated the time spent in school and the feeling of being part of the school community.

Laura was the youngest participant in the study. She entered the programme with a degree in biology and initially intended to enter straight into teaching at the end of her undergraduate studies. During the final year of her study, she took the opportunity within the University to try out teaching to high school students. Laura realised that she was too close in age to the students and decided to gain some ‘life experience’ before embarking onto teaching. She worked in a different domain for a couple of years before she entered the training programme to follow her dream – to become a science teacher.

During her quest in finding the best training programme for herself, she decided that a school-based programme would better equip her with ‘how to teach’ skills than an HEI based programme. Her expectations from the programme had been much exceeded regarding the amount of work she was expecting to do. At the start of the programme, she found herself ‘all over the place’ and enveloped in a sheer amount of paperwork and assignments, as she stated: ‘...the only thing that really shocked me is how much paperwork there is each week that has to be submitted.’

Freddie entered the teacher training programme with a passion for science being especially interested in biology. With a degree in biology and research, he enjoyed a science career in the context of higher education. He was mainly inspired by his teachers when he was a teenager and, like Laura, he couldn't imagine being a teacher in secondary school in his early 20's. He narrated how a few years back, he had volunteered for a refugee camp where there were schools set up for refugee teenagers to help them with their education. He was impressed by the number and dedication of many teachers around the countries who had spent their weekends trying to educate those teenagers in the refugee camps. His experience in the refugee camp guided 'the spark in his mind' wishing to go into teaching and 'change people's life and inspire them'.

Freddie initially applied for a different route into teaching which seemed 'ideal' to his needs, but he was advised to apply for the SCITT route because of 'their experience in preparing career changer people'. His expectations from the course were 'idealistic and naive' based on his initial information that the programme 'was all about getting people into schools as soon as possible'. He was surprised by the intensity and demands of the training programme recognising that he was not aware of many of the details and found it difficult to prioritise things. Like other colleagues, he appreciated the 'gentle introduction' in the programme to the things they needed to know 'right from the start'. For Freddie basic skills for teaching were paramount to changing his style of teaching to match the new context. Thus, he valued the experience of being in front of classes and learning to teach 'by doing'. The modelled activities within the training programme equipped him with teaching skills such as timing a lesson, handling practical activities, and doing demonstrations.

Nathan completed a master's degree in a physics related domain. Before enrolling on the teacher training programme, he was asked to work in school as a physics instructor. After one year of working in school, he decided that he would like to be a science teacher, so his decision to be a science teacher appeared more ‘from accident’. He didn’t come in with ‘lots of expectations’ because his purpose was to gain a qualification ‘to be able to teach’. He knew from the beginning what route to take into teaching, ‘deliberately’ choosing a school-centred route for being able to continue working and further gaining experience in school. At the time of his interview, the schools had been closed because of the pandemic caused by Covid-19 which led to the first national lockdown. School closure was disturbing for all the trainees enrolled in the programme because as Nathan commented: ‘that’s affected the course slightly for me because it's now no longer a school centred simply because it is closed’.

Sonya was specialised in physics at a master’s level and had a research degree in computer science. She conducted a research project in education and technology in school from where she got her motivation for being a science teacher. During her studies, she commuted between towns and felt that was spending much time away from her family and was not sure if it was ‘worthwhile’. She decided to go into teaching to make meaning to her life and a difference in children’s lives. She was going to choose the route specially created for getting researchers in schools but was more attracted by the SCITT route for two reasons: it was more local, closer to her family, and more based in school which was more favourable as she did not have much experience in teaching and wanted to ‘maximise’ her time spent in school. Apart from expecting to spend much time in school, she did not know what else to expect from the course. Therefore, she was, like others, surprised by the intensity of the activities which were sometimes ‘overwhelming’ and made it difficult for her to know what needs to be prioritised. Acknowledging that feeling ‘busy’ may be sometimes ‘normal’, she focused on her ‘motivation’ that helped her to go on and enjoy the overall experiences.

The analysis of the participants’ interviews resulted in the identification of some common features as perceived learning opportunities that enhance trainees’ development as well as perceived challenges in learning during their training programme (Table 24).

Table 24. Identified Common Features for Development & Challenges in Learning

Learning to Teach Framework (LtTF) components	Common features
Knowledge	Observing teaching/Modelled activities
Orientations	Challenging assumptions/Cognitive dissonance/Teaching style similarity
Practice skills	Teaching experience/Rehearsing practice/Feedback and support on practice
Understandings	Acknowledging teaching alternatives /Transforming knowledge/Reasoning/Reflection/Discussions/Sharing experiences
Efficacy building	Positive experiences/Support and guidance/Experience in teaching/Subject knowledge/Familiarity with the context
Challenges in learning	Lack of consistent support/Lack of reasoning on teaching /Sheer number of paperwork/ The models' tacit knowledge/Lack of alignment between theory and practice/Intensity and complexity of activities/Behaviour management/Lack of collective work/Consistent collaboration with colleagues

7.3.3 Research Question 1. Perceived Effective Learning Opportunities

The common features, as perceived learning opportunities that enhance trainees' development in the components of *Learning to Teach Framework*, addressed the first question of the study: What learning opportunities enhance trainees' knowledge, skills, and self-efficacy development during their training programme? The common features for development resulting from the cross-case analysis were grouped based on similarity into four analytical themes and discussed in detail next. The four themes were: - *Creating dissonance and unexpected events; - Learning from Relevant Models; - Teaching and Rehearsing Practice; - and Consistent Cognitive Support.*

Creating Dissonance and Unexpected Events

This theme addresses trainee teachers' perceived features especially for changing the orientation component of *Learning to Teach Framework.* As revealed by the responses to the questionnaires, the participants' orientations towards teaching and learning science, at the beginning of their training programme, were mixed. A reason for their mixed orientations may be the lack of ability to recognise them. This raises issues of eliciting teachers' beliefs at the start of the programme to inform their future learning. The analysis of the interviews showed that five out of six trainee teachers entered the training programme with traditional orientations towards teaching and learning science. Their initial views about teaching and learning were based on their previous experiences as students or experiences in previous jobs. As career changers, many came into teaching a long time after they graduated not knowing what is expected of them in terms of teaching secondary students. Lisa explained that 'I haven't done science for a long time'. Based on his past experiences, Ryan believed that teaching is transmission of information with little interaction with students, as he commented:

> When I started …I very, I taught the way I was taught. You know, I was… when I went to school, the teachers stood at the front. They told you a load of facts and information, you wrote them down or didn't… that's sort of my perception of teaching …we stand at the front and lecture.

Similarly, Sonya had the same image of teaching at the start of the programme, as she commented:

> I guess initially you imagine teaching, standing at the front and talking or, or doing a practical.

Previous experiences influenced the way of viewing teaching as passive for Freddie, as he admitted:

> I was probably a little bit idealistic and naive …My recent experience has all been with postgraduates…. people who have degrees in science, they understand.…already… …when I was at school since the age of eleven, I never was in classes with low ability students. And so, I never had that experience since primary school of how low ability students are taught.

Laura's views and beliefs about science teaching had been much based on her science teachers who made science easy and accessible which contributed to her perceptions about the kind of teacher she 'wanted to be'. Over the programme, the participants' views about science teaching and learning shifted more towards student centred approach. Lisa's initial beliefs and expectations were challenged when she was placed in a position to acknowledge the difference between younger and older students in terms of teaching requirements. Thus, she realised that she needed to incorporate in her teaching methods and strategies that she never applied and thought of before. Ryan's beliefs about teaching and learning were challenged by discussions and reflections on preconceived ideas. He commented:

> …I like to add to my knowledge, constantly updating and changing it…you know, and stuff does constantly change. And an idea that you had from 20 years ago just is not valid anymore. But unless you go back to them, you never know. This has been really,

really fantastic… in taking you back to preconceived ideas and being like, oh, no, that's not the way I interpreted it when I learned that skill.

When confronted with the reality of teaching in the classroom, Laura came to fully acknowledge the complexity of teaching and she developed ‘even more appreciation of experienced teachers’ who ‘can just go into any biology, chemistry, or physics at the drop of a hat and teach a lesson’. Similarly, Freddie came to acknowledge his ‘ingrained habits of standing in front of people and interacting with them’ as he commented:

> I can still remember the first lesson that I took charge of back in September and realizing how much I was not seeing that I was standing and looking at the class of students… I just was not conscious of.

Sonya came to acknowledge different ways of communicating information to students. By being exposed to different approaches to teaching, she realised the importance of having a focus on students’ understandings. She explained:

> I came into teaching with this idea that with practical work, you would do a lot of kind of a lot of discovery learning, in the idea that they would almost discover it completely for themselves. But I'm realizing actually, although you might do something which is exploratory, you also really need to make sure that you, kind of back it up with scientific knowledge to make sure that they're really understanding it…and then maybe you go back to the practical work afterwards as well, so they can apply their knowledge as well. So, the practical work isn't just about discovering, but it's also about applying knowledge.

In contrast, for Nathan, the school experience before teacher training was helpful in developing realistic expectations. Thus, the training activities did not significantly change his perceptions about teaching and learning, rather contributed to expanding his repertoire of teaching.

From the participants’ comments resulted that they were likely to change their beliefs when they had opportunities to observe effective and alternative models of teaching and their impact on students’ outcomes. The most positive features of the programme perceived to be helpful in developing new ways of thinking were opportunities that took them back to ‘preconceived ideas.’ Such opportunities were discussions and reflections, peer sharing of their experiences in the classroom as well as opportunities to observe experienced teachers’ teaching and discover by themselves best ways of approaching teaching by ‘doing’.

Learning from Relevant Models

Observation of others’ teaching was a dominant feature that helped trainee teachers to improve in all the *Learning to Teach Framework* components. Trainee teachers added to their knowledge and understandings, changed their orientations, developed practice skills, and increased their self-efficacy by observing relevant models. The participants’ level of experience in teaching to secondary students and their views on teaching and learning science, influenced the way they experienced learning during their training programme. As career changers, they felt that knowledge outside of their specialism would benefit them most. As revealed by their responses in the interviews, they more ‘switched focus’ on the subject area outside their specialism as they commented:

> …in terms of my subject knowledge, biology really is where I've learned… For me, this course mainly is providing me with a lot of biology knowledge…which is fascinating. (Ryan)

> I am biology specialist…it's been knowledge with chemistry and physics as well. My knowledge needs to be brought up to what it just like gone over… (Laura)

> I would say that the physics training for me has been the most helpful because... physics is my weakest subject. (Freddie)

> I kind of expected to be given a bit more knowledge in biology and chemistry because they're the subjects in science that aren't my specialism. (Nathan)

> I've really enjoyed the biology ones because I didn't do A level biology, so it's the one that I do know least about. (Sonya)

Trainee teachers' responses in the interviews indicated that they accumulated much knowledge and teaching skills by observing experienced teachers' teaching. Teachers' expertise in schools was a powerful source for showing them 'how to teach' and what means to 'act and think like a teacher'. They gained valuable insights in teaching and were 'impressed' with some of the teaching styles observed during their teaching practice in schools. By applying in practice some of the observed strategies, they could expand their repertoire of learning strategies, learn about how to differentiate students, how to manage their behaviour, and how to approach teaching from many perspectives. In addition, the resources they have been offered or recommended, such as books and videos, contributed to their understandings especially about how to effectively manage the classroom behaviour, a most concerning aspect for all trainees. The insights gained from observations of teaching are best understood from trainee teachers' statements below. From her teaching observations, Lisa gained valuable insight in 'what worked and what didn't' in teaching. Observing teaching was helpful in grasping strategies that engage and manage students' behaviour and thus, improving her own practice:

> …A lot about behaviour management. I think that’s been one of the major things I’ve learned. From my observations, I’ve learned very different strategies that you need for managing the children…a lot of the pedagogy, about what’s required in terms of assessment and differentiation …about what works and what doesn't work. And I learned a lot about the type of things that engage the students.

Similarly, Freddie focused his attention on ‘basic pedagogy’ such as explaining certain scientific topics and addressing misconceptions that helped him to ‘relearn many ways of communicating things’ that were not clear to him before.

> I think the most important things I've learnt, have been some of the most basic things about teaching.’ ‘…having seen ways to communicate … that it’s going to help me pass that to students, but also, having intuitive ways to explain things.

A multi-perspective on teaching was also beneficial to Freddie who commented:

> ...I have seen some teachers teaching the same kind of topics to high and low ability classes and seeing the different ways they do that... those are the kinds of practical things which I think are the most helpful... so most of the observations have insights because it makes sense to me...and seeing probably seven or eight or even eight or nine different teachers in different teaching styles within science and three different sciences… has all been very, very useful.

Witnessing different ways of teaching was also found valuable by Sonya and Nathan as per their comments:

> I observed a teacher teaching a unit …and that teaching was really, really effective… and it really gives you those ideas, you get to see different teaching methods, different ways of getting students to work…put notes in their books when writing on the board. (Sonya).

> I'm thinking about just watching my mentor from my second placement school… So, this was quite a unique way that I've never really considered before. I think the most valuable thing I'll take away from my science teaching this year at home is using historical stories to actually teach about discovery. (Nathan)

Differentiation for teaching and learning was a feature much emphasised in trainees' narration. The observation of teaching gave them insight in how to differentiate students to maximise their learning. Nathan remembered:

> I used to observe… (a teacher) teaching and his form of differentiating worksheets was phenomenally effective. And being in his classrooms was incredibly…is exactly what you want the lesson to be like.

A main concern among the participants and thus a great focus was on handling classroom management, especially in practical situations. Therefore, trainees were interested to observe how teachers across departments dealt with such issues. For Ryan, a good management of behaviour was a central point in gaining confidence for teaching. His interview indicated that confidence and behaviour management are key factors for successful teaching. He started teaching with low confidence which originated in his prior negative experiences with managing behaviour as a cover teacher. Thus, for him, good behaviour management skills give him the feeling of 'control of the classroom'.

> I would have said that behavioural management is the biggest thing. For the simple reason that it doesn't matter how good a teacher you are if nobody listens to you. I think that's been one of the biggest steps that I've made. So though it's not necessarily about my science knowledge or my delivery of science, I think, I think in some ways that's so secondary, you need control of the room, you need to be in charge, and you need to have the kids in a position where they can learn. (Ryan)

His interest in keeping the classroom ‘under control’ motivated him to further improve his behaviour management skills by reading and watching videos about behaviour management techniques modelled by experienced teachers:

> I've bought five books on behavioural management, and I've read those cover to cover...it's about understanding the psychology behind why kids do what they do…He (the teacher) had a brilliant story with his, ‚*maybe*’. He uses the word ‚*maybe’* as a behavioural management technique. And he said it's just a magic word. And it really is. Those kinds of strategies are simple things that you can remember and then just apply…

Observation of models handling behaviour had a similar impact on Nathan and Freddie:

> The most effective form of getting the kids to be quiet came from the most experienced teachers in the science department…, …I even went outside of science, and I did a few (observations) in technology. I chose to do that because they're in a similar situation in the sense that they've got a practical lesson… So, it was interesting to see how that culture was also managed… (Nathan)

> But having to see, you know, behaviour management in the food technology lesson, is really important. It's just seeing the techniques that people use …..and seeing how best teachers are teaching now, which is different from how methods were taught when I was in school. Having been taught that, it's all very helpful …(Freddie).

Laura was interested to see and focused on how to manage students with special needs in practical conditions.

> Science is very practical...So if you have a student with ADHD like I did, I wanted to see how he would behave in that space because he can't get up and walk around. So what does he do and how does the teacher manage that? And that was really, really

> useful just to see..some of the techniques that he's come up with like students that don't have English as their first language or students with other disabilities…some of the techniques that he came up with to help engage them or just help them access the information, has been really, really useful as well.

Unlike others, Nathan felt that he ‘came in’ with some ‘cultural experience’ which gave him a head start in the programme, further making progress by expanding his repertoire of instructional strategies. He stated that ‘being able to pick up on those behaviour management strategies, especially in a science classroom, were really important’. Another line of interest was to see and grasp an understanding of how ‘the culture’ in a lab is managed by experienced teachers. With science being a very practical subject, seeing how others in similar conditions manage to conduct practical works whilst using dangerous objects or substances was ‘very useful’.

Observation of different ways of teaching was the main feature in the programme that impacted on trainee teachers’ orientations. By seeing models of teaching, different to models from within their own experience, and observing the effect on students’ outcomes, their initial beliefs were challenged considerably. Trainee teachers entered the programme with enthusiasm and were open to new ideas, as revealed from the observation notes and the educator’s comments in the interview. The exposure to alternative ways of teaching effected change in trainee teachers’ initial perceptions about teaching. From their responses, it was clear that trainee teachers became aware of the more student-centred approaches to teaching and learning. They became aware of the complexity of teaching and of the multiple goals they need to achieve in teaching and learning science. The most reported student-centred approaches they learned were hands on or practical work, strategies to engage students in the process of learning, inquiry teaching, learning through stories, and addressing misconceptions. Ryan explained:

> I've discovered … it's doing the learning for kids. You don't learn when you just sit there passive, and the result, they don't absorb. So, they need to actually be doing stuff, so, learning is an active process, and I think that's, that's the biggest message that I've had this year, is that they need to actually do things to learn things.

Apart from learning from experienced teachers in their school placements, equally valuable were the activities modelled by their trainers during the coursework of the programme. Trainee teachers learned practical skills in topics linked to school curricula, skills that could then be applied in the classroom. Applying in the classroom what they have learned during the coursework was a feature that appeared across all the participants' accounts. The emphasis was on the transformation of the content for teaching to make it understandable to students. For Laura, learning how to sequence the content was a 'useful learning experience'. She narrated about an instructor who demonstrated how to break down a difficult concept in chemistry for students to understand.

She stated:

> XXX (the trainer) who took the session… was talking about how you break down moles in chemistry so that the students understand such is a really… difficult concept to understand. And he said, 'I do it like this' and then he taught us as if we were his class and he broke it down just using whiteboard pens…and he was like -if you can break it down to something they can see in front of them, then they can understand it better. So, he uses whiteboard pens and … is just a little kind of technique. (Laura)

The same emphasis was found in Freddie's narration. Freddie felt that he could develop a good understanding of what means to be a science teacher in secondary school by learning how to convey information especially difficult concepts to students in all the three science subjects. He was 'impressed' by the 'effective ways' trainers managed to demonstrate and explain difficult concepts so that students can understand. He became aware of things that he 'didn't even thought about, before'. For him, having effective ways to convey information to students was 'more important than a deep understanding of the content':

> So, I think that different trainers have different styles. So they're trying to communicate different things in different ways….XXX ...I think it's just given us a lot of thought… very effective ways of making difficult concepts in physics....perfectly accessible for students, typically with most official demonstrations... Chemistry training, I think, has been fairly similar with more of a focus on practical...was very good at providing ways of explaining difficult concepts...The biology training, again, has focused quite a bit on looking at common misconceptions and some of the practical rules, which I suppose it is often quite different because biology is messy… it's a practical course for doing things or…preparation for living things which don't always work very well in school settings… and so an important part in biology training was about giving us practical rules that are robust and should work without too many difficulties in schools. And that was I hope that was an experience very……very helpful too. (Freddie)

Trainee teachers' responses in the interviews appeared to be consistent with the responses in the questionnaires. Looking at the learning opportunities they wished to have during their training, it appeared that their expectations had been met to a great extent. In terms of knowledge acquisition, the biggest interest was in learning how to handle classroom management (n=12), identifying students' misconceptions (n=11), assessing students' understandings of the topic (n=11), and learning from experienced teachers (n=11).

Teaching and Rehearsing Practice

Learning to Teach Framework components further develop with opportunities to teach and rehearse practice. Trainee teachers reported that when they had opportunities to practice and apply the skills and strategies learned from their observations, modelled activities, and discussions with peers, they could gain more experience and confidence in their ability to teach science. The participants narrated on positive experiences which boosted their confidence and motivation. Their positive experiences were due to opportunities to experience different ways of teaching in the classroom, practicing and rehearsing experiments, demonstrations, and explanations before lessons. Their experiences with the application of knowledge in practice were captured from their comments.

Nathan 'modelled' his 'teaching on…this maths teacher…because his form of differentiation and its cultural management' were 'incredibly effective'. Similarly, Sonya successfully tried in practice some of the methods she observed, such as questioning methods, ways of explaining, and demonstrations, as she remembered:

> The things like no hands up methods, that with the questioning… that was one thing that I have tried in the classroom, and it does work…
>
> I taught the same unit (as the teacher did) with this way of, explaining demonstrating frequency and wavelength using videos of waves…. and that teaching was really, really effective.

Another effective feature for Sonya was rehearsing teaching and practice, as she further commented:

> …being able to repeat, first to observe and then to get it and then repeat it and get to be better than I was before… that was a really good learning experience.

Rehearsing teaching and practice benefited Lisa as well:

> One of the things that benefited me most was reteaching a lesson that hadn't engaged the pupils the first time I taught it. By teaching it again in a different way I could see how changes in my teaching methods could have a big impact in the classroom.... I had to think of a different way to do the lesson, to make it more engaging. And it went really well so it was …I could see I could compare what works and what doesn't work well (Lisa)

This feature was also highlighted by Ryan:

> I think the more you explain stuff, the better you get… if your explanation is not simple, you don't really understand it.

One feature that was found the most valuable in gaining confidence for teaching, yet the most challenging of the programme, as rated by trainees, was the opportunity to lead their own classes. Asked if they felt prepared to teach science at secondary level, Ryan commented:

> I have been in rooms on my own with my own classes responsible for their learning, I am responsible for my own implementation of my teaching practice, I think that I am very prepared for it…'it's a constant feedback process' …'it's reflecting on what did work, what didn't work, how is this group dynamically different from another group?'…really understanding the psychology of the groups and then being able to adjust that.

Similarly, Freddie valued being in front of classes and learning from 'doing'.

So, being having the chance to work with children of that level (low ability) and learn from my own experience about good ways of teaching children has been a really positive part of the programme.

The same perspective is found to Laura who felt that through teaching experiences she ‘learned how to teach’:

I've been in school, and I've been in front of classes and that's been really, really good. …so, I feel like I can differentiate the work, which I didn't even know what that was before I saw teaching. I've been able to take on my own classes and build relationships with those classes...I feel like…my behaviour management is quite good. But I think you just have to be firm but fair. And they (children) really respond to that (Laura).

Sonya stated: ‘the more I taught the more confident I got’, and Ryan stated: ‘the more times you can do it, and in the more diverse ways that you do it, the more confident you get’. Given his prior experiences with adults, Freddie entered the programme ‘overconfident about what it was going to be like in the classroom’. Over the course, he realised that he had to learn a lot, especially to change his habits. He felt confident in his subject knowledge, and his confidence further increased over the course due to a ‘refresh’ in subject knowledge and positive experiences:

I started out in September’s study overconfident about what it was going to be like in the classroom… and then over the course of the first term, first couple of months, realized how much I need to learn, how much I need to unlearn some habits. I think since January I felt like I've been making good progress and gaining some kind of confidence… this really looks like a word...but gaining some more kind of positivity, actually able to do things reasonably well and …constantly improving… and then by the end of this year, reasonably competent in teaching science.

Nathan, on the other hand, felt confident in teaching science from the beginning. He boosted his confidence when he was given the opportunity to lead A level classes. Teaching in his own specialism to 'elite' classes and being given full responsibility in handling miss-behaviour further increased his confidence, as he narrated:

> I was pretty confident … when I started teaching, I was quite excited to be able to share my passion for physics. I was putting originally at A level teaching….so they wanted me to take the elite physics classes… they were quite happy to put me in front of the 30 worst year 10 students who misbehave, and they'd be quite confident in my ability to sort of manage that classroom. I guess my confidence has grown with the accumulation of all these teaching strategies, but I think from the beginning I was quite confident.

Whereas teaching experiences were perceived the most valuable in gaining confidence in teaching science, opportunities to practice strategies for teaching in a supportive environment during the coursework alongside discussions and sharing experiences helped trainees to develop skills and understandings before real teaching in their classrooms. The participants valued those opportunities, as revealed by their comments:

> I'm thinking of XXX's (the trainer's) physics day when we were playing with the ones that make the sound…We could make the big loop train of people and then the lights were turning back…. So, I went and bought one of those things and I have it here in my room…That was incredibly engaging. We were able to demonstrate a lot of these experiments and not just in physics, but in biology and chemistry, really. (Nathan)

Opportunities such as practicing demonstrations and explanations with peers in a supportive environment helped Sonya to get insight in students' learning difficulties:

> And so, doing things like dissections, which I've never done before and some of the other practical work…things like extracting DNA from the strawberries and amylase and…I think, for me, it's like I get to learn all I would get which was really exciting… It's like being at school and that's really nice…and then, also, it's quite nice because we all were students together, then practicing explaining it to people who have… like a biology specialism, that is helpful because it gives you…. seeing the things that other people find difficult, so that, you know that will be difficult for your students as well…

Freddie became aware of the importance of practicing the activities beforehand to make teaching more engaging for students:

> … it's good always to practice your demonstrations or your practical if you haven't done them before... so as a new trainee, you have to practice quite a bit...

Ryan discovered that getting to know how others approach the same topic contributes to a better understanding of how to effectively transform the knowledge for teaching the topic. Discussions and sharing experiences with peers were one important way in which he felt he could enrich his repertoire of alternative approaches on the same topic. A good understanding and reasoning on practice was much emphasised in Ryan' narration. In Ryan's view, a way through which he can develop teaching skills are opportunities to build explanations and analogies, and to practice them:

> I think having, having, like discussions….and I think pair share. You know, I think that's really, really useful where you could talk to other people who are doing the

same thing you are… sharing ideas is almost as important as …when they present us with new material because we need to absorb it. And I think discussing how these applies and how other people are applying it to their practice'… it's finding these new and more varied ways of explaining the same thing …I think the more you explain stuff, the better you get… if your explanation is not simple, you don't really understand it.

Similarly, for Sonya, participation in small groups discussions and reflections on aspects of teaching were valuable features of her training. Doing work that students usually do in school was considered the most needed learning opportunity as rated by eleven trainees at the beginning of their training programme.

Consistent Cognitive Support

Trainee teachers indicated in the interviews that when they were adequately supported their learning was more effective because they knew what, where, and how to improve. The support came from vary sources within the network of the SCITT programme: tutors, trainers, school mentors, fellow teachers in school placements and peers. In general, trainee teachers described the support received as being 'fantastic', 'incredibly helpful', 'really good' or 'very supportive'. The support came in many forms. Access to resources was rated helpful especially for lesson planning. Such resources consisted of 'lesson materials', 'tips and tricks' strategies, 'explanations', and 'misconceptions' that trainees needed to be aware of when planning for teaching. Feedback in the form of guidance and advice on teaching and lesson plans before or after teaching was another helpful feature that gave trainees insight into how to approach different aspects of teaching. Open discussions and reflections followed by comments /feedback on challenging aspects of teaching and learning science were much valued.

Some of the comments on the support received during their training are presented below:

> I've been given strategies before lessons. This I can see it's help in terms of lesson planning and… and pedagogy and explanations and misconceptions before lessons from subject knowledge trainers, from… from the professional, from the subject tutor, as well as my mentors. And… lots of I mean, general advice about how to approach things from my SCITT tutors. I also had some support from my fellow trainees… so all of the science trainees share materials... And also, just that at the training days there is… you know…, we talk to each other and we … we share experiences and we can learn about how we're getting on by talking and seeing how other people are getting on and comparing their experiences. (Freddie)

> There's an incredible amount of feedback. I mean, there's loads of verbal communication, e-mails never go unanswered, so that was really good…'In both placement schools that I was at, any time you would throw a question to the room, there'll always be 1 million answers. (Nathan)

> I just pop my head round one of their doors and the head of biology especially, she shares everything with me. She shares resources like little tips and tricks...If I'm doing a practical, methods, she'll share absolutely everything with me. (Laura)

The feedback received from students following their teaching had some weight in improving their confidence. At the beginning, Laura was 'scared' of not being able to answer students' questions. She 'improved the confidence a little bit' when she received positive feedback from her students. She felt that she could manage to build positive relationships with them. The feeling of having confidence in managing students' behaviour, in controlling the classroom and enabling a proper learning environment for students, contributed to an increase in trainees' self-efficacy. For Ryan, the support with behaviour management meant to be 'put back in the power position.' The support also came in the form of encouragement, reassurance, and offering alternative solutions in difficult moments (such as emotional aspects of personal life, distress, difficulty in keeping up with the intensity of the activities or less successful classroom teaching experiences). Sonya narrated:

> In my last observation when my lesson didn't go very well …I was just completely gutted. I was in tears afterwards. But XXX (the tutor) was very lovely. Everybody has been very good. They see you as a human being. (Sonya)

Cognitive support was also mentioned in relation to their participation in the school life. Open discussions and sharing experiences with veteran teachers, from a position of equality, teachers' openness and their availability/approachability were mentioned as features that boosted their confidence, feeling that they were being treated as members of the team. Nathan commented:

> My mentor from my second placement was a physicist himself and he was head of department, so we were able to communicate quite a lot on the physics side of things and we were able to help each other out and give each other suggestions. That's actually quite nice…the fact that he'd asked me for ideas about how to teach something, even though he's been teaching for longer than I've been alive!

Similarly, Ryan stated:

> I had a lot of interactions with the SEND department and the computer department, and then with the scientists as well within the department. They were fantastic in offering advice and resources and things like that… In some ways I offered them quite a lot of stuff as well. (Ryan)

Sonya talked about personal motivation as an important factor in building confidence. With a proper support and feedback in a friendly environment, what is left depends only on own practice, and as an ‘independent person’, she is ‘good at asking for help’ when needed. The same intrinsic motivation was found to Ryan who stated:

> …and I certainly know how to resolve problems and find answers myself. And obviously, I've, you know…, created a huge, huge group of colleagues who I can ask, who I can rely on, and I think …that's, also really valuable.

7.3.4 Research Question 2. Perceived Challenges and Barriers

This section addresses the *Challenge* component of Learning to Teach Analytical Framework and answers the second question of this study: What challenges trainee teachers encounter during their training programme?

Trainees’ experiences in the training programme were not without challenges. The challenges trainee teachers encountered during their training programme were multifaced. For Lisa, the biggest challenge was to keep up with the speed and intensity of the activities within the programme. She perceived the information from the course as ‘overwhelming’ and ‘hard to recall’ with ‘no time to consolidate that knowledge when it's given’. Apart from this, ‘the structure of curriculum’ in Lisa’s school placement did not enable her to apply the knowledge she learned during the coursework. She noticed that in her school, students were taught at a higher level (GCSE content at Key Stage Three) and the content was ‘knowledge heavy’. Additionally, teaching was more based on ‘facts’ than on opportunities ‘to do more exploration’. She also felt that the information she needed to teach did not match with the information presented on the course. Although useful and valuable for ‘later on’, she wished to be equipped with relevant knowledge that she needed for immediate application. More specifically, she was assigned upper classes in her school placement while at that time, she received on the course more knowledge on lower classes. Moreover, Lisa felt that she would have benefited more from differentiation strategies and more resources to help her with planning effective lessons. She wished ‘to get earlier feedback on the documents uploaded to know whether they are satisfactory and how they could be improved’. She felt that ‘discussions on how to improve’ were missing, and the access to resources was limited, ‘particularly at the start’:

> I think it would be good to get earlier feedback on documents uploaded to know whether they are satisfactory and how they could be improved; it might have been helpful for me, particularly at the start, to be given more resources, which are now coming through a lot more.

Another barrier, Lisa felt she had, was the quantity and quality of mentoring support she received in her placement school. The busy life within the school placement left too little room for personalised guidance from mentors. At times, the observation of teaching did not help her to see ‘what works well on differentiation’ either:

> …I don't feel I've had that much support or guide on lesson planning and what works well on differentiation, particularly, doesn't seem to be used as far as I can see in my observations. Yet we're expected to do that, so I'm getting no guidance from the school as to what sort of differentiation would work.

The limitations of observations of teaching in schools were also acknowledged by other trainees. Trainees admitted that not everything they observed could be applied easily and immediately in practice. Many aspects of teaching and learning science could not be grasped for several reasons: tacit nature of knowledge for teaching; lack of reasoning behind the activities, and therefore a lack of understanding of the principles of those activities; or a mismatch with their teaching style. Some of their experiences are included below:

> So, finding examples of that (effective teaching) might be a bit of a challenge. (Nathan)

> Watching other teachers and seeing how they teach, trying to think why their lessons go really well, but also, when you teach there's a lot, you learn a lot because it's like, you don't know… because it's a skill, it's not… you can know the theory of how to teach, but you also need to learn how to put it into practice. And that's, that's a really hard bit because you have to go wrong in order to get it right. (Sonya)

> He (the teacher) just had an amazing way with the kids, and they hung off his every word and it was hard to see how he did that. It really was….and I think in some ways, you know, the answers are all there and observations of teachers doesn't necessarily show you the surface…you can't see what's going on underneath. You can see the result. We can't necessarily see how they got to that result, which is it's really interesting. (Ryan)

> So many of the ways that some really talented teachers engage their students... I know I'm never going to do because…. you have some amazingly kind of extroverted and warm and humanistic kind of teachers who connect so well with students… and I'm more of an introvert and more of a bookish kind of person. I'm never going to be that kind of student teacher. So, again, that's…. that's something I can appreciate as a trainee, but I'm not so likely to put into practice. (Freddie)

Besides, Freddie acknowledged that learning from experienced teachers is sometimes 'the most difficult to pick up.' Freddie, like many others, felt, at times, overwhelmed by the intensity and complexity of the activities in the programme. He wished for more focus on ‘basics’ to help him grasp more effectively what is ‘absolute’ necessity for teaching science before building complexity, as he explained. The amount of paperwork he needed to fill in for every lesson took up time which he ‘could use more profitably just thinking …. and preparing the teaching material…a bit better’.

Not all trainee teachers felt that they always had access to adequate support throughout the programme. Some found the support and feedback mixed in the sense that sometimes the support from their school mentors was inconsistent, unsatisfactory, and ‘confusing’. The access to resources had been found difficult in the first part of the training, and the feedback on lesson plans or teaching was not considered constructive or it was ‘minimal’. Lisa did not have the chance to go to her second placement at the time of the interview. Being a part timer early in the training, and due to national lockdown, she was confused ‘whether it is the school or different mentors that offer different kind of formal and informal support’. She did not feel she had enough support as she narrated:

> I have one hour with my mentor every two weeks, to cover everything. So, it is really, not enough time to go into all the lessons…but I have had feedback after the lessons as required by the course. But not a great deal of tuition from my school mentor. I would say that’s been minimal.

Freddie reported similar experiences with the support in his school placement. In his first school placement, he experienced less support and feedback. Because his school mentor ‘was going through difficult times’, he relied on the other schoolteachers for support. He quickly realised that the schoolteachers had other ‘priorities’ rather than to guide trainee teachers. Therefore, he started in confusion not knowing what to prioritise:

> The school as a whole in my first placement was not very supportive. And so, I didn't get very much feedback from my, from my fellows, from my colleagues in my first placement school… I wasn't aware of what to begin with about how little progress I was making and how little feedback, useful feedback I was getting…. and so probably over the course of that first term, it became clear to everyone that I wasn't doing very well because I wasn't being given the feedback that I needed to improve my practice.

In a similar way, Laura's experiences in the programme were mixed with lots of challenging steps, especially at the beginning. As a newcomer to teaching, in her view, the support and feedback weighted greatly in increasing her knowledge and confidence development. Unluckily, she felt that she did not receive the right support from the mentors that were 'supposed to guide' her:

> …experiences with me, was with support…. So, you have your personal tutor who is meant to be there for you in... like a pastoral way… and…although we really get on...sometimes one of some of the things she says isn't particularly supportive… I think she's unnecessarily harsh sometimes…. so, for example, the first time she ever came to watch me, she called my lesson futile… which… that was the first observation I ever had by anyone. And the lesson got called futile, which really upset me actually for quite a long time ….

The inconsistence of feedback on teaching was something that Laura felt hindered her improvement of teaching by leading her into confusion about what was right and not in teaching a lesson. She also felt that it was difficult to find openness for discussions due to the 'busy' time her mentors had.

> Whenever my lessons are observed, they say… okay, these are the two things you need to improve on… so… differentiation and assessment for learning. No one actually, gives me any techniques on how to do that… so they just expect me to know how to do it … so I tried to differentiate a whole lesson the other day and I thought I'd done it really, really well. And then my feedback was – don't differentiate. So, it's really, really confusing… I just find it so confusing, and it makes it really unclear what is actually expected of you.

She encountered a similar confusion with respect to her lesson plans. She felt that she did not have proper feedback on her lesson plans and sometimes the feedback was misguided or totally lacked. She recognised that planning took a lot of time at the beginning, but through experience 'she became better and quicker at it'. She was much affected when the class teacher whose class she was going to teach, 'didn't have time to read properly' through her lesson plan so that she could prepare an effective lesson.

> I send my lesson plans to the teacher of the class that I was going to be teaching. …sometimes they don't even e-mail back to say that they've received it, or sometimes they'll email back saying, okay, looks good. But then afterwards, when I get my feedback, they'll say, oh, well, why didn't you do this, this and this? And I say, well, why didn't you tell me that before, so I could have done it before when I went through the lesson plan and then they say, oh, well, I didn't actually have time to read it properly.

It was clear from Laura's narration that she developed in more depth understandings when she had opportunities to observe good quality teaching and to develop awareness of how different strategies apply in teaching. She valued the modelled activities that enabled her to see how experienced teachers transform the knowledge for teaching and how they differentiate the work for students. Yet, the activities were not always made explicit, and Laura felt that she ‘didn’t enhanced her knowledge’. She narrated from an episode outside her specialism:

> I do enjoy the practical work, but I think there definitely does need to be a consolidation and an explanation afterwards …even if it's just a couple of bullet points, I'd prefer that, so, there's something to look back over because you can't write a practical down. And when you come to look back over it, to remind yourself of what you did, there's nothing there. So, I do prefer that, but I like an explanation as well.

Overall, Laura enjoyed the experiences in the programme and felt adequately prepared for teaching science. In her view, teaching experience does matter most and ‘getting used with everything in her school, becoming a permanent, a fully member of the department’ was taken as a challenge to reach in the first year of teaching.

In contrast, Nathan’s journey through his training programme was not marked by big challenges. He felt adequately prepared for teaching science at secondary level, especially in the school where he had experienced already teaching and was familiar to him before starting teacher training. The only challenges, he reported, were related to ‘writing coursework for assignments’, and changes brought by Covid 19 to the ‘dynamic of the classroom’ when he will need to adapt some strategies for teaching. For example, before the pandemic, students gathered around the teacher’s desk to observe demonstrations in physics lessons. During his training, before school closure, he couldn’t observe alternative ways to frontal demonstrations.

Lastly, the ‘real biggest challenge’ for Sonya was how to manage students’ behaviour. She recognised that the ‘kind of authority’ and the ‘feeling to be in charge’ depends on the ‘kind of confidence and familiarity with the situation’. A feature that she thought it would have benefited her was a more constant and closer collaboration with her colleagues and opportunities for sharing experiences:

> I think it would be nice to see people on a more regular basis…to be out of school one day a week on a regular basis because… sometimes, you want to learn something and be able to apply it the next day… and sometimes… you want to be able to see the other trainees and talk to them on a regular basis. I think you could build up more close relationships with other students if you saw them on a regular basis rather than seeing them intensely for a week and then not seeing them for a long time.

During their training, trainee teachers experienced mixed support and feedback. Yet, they acknowledged that they should not rely only on the guidance and support from tutors and mentors. They recognised the need to be 'creative' in the process of teaching and learning- the need to be independent and confident learners:

> Even if I don't know all of the answers, I certainly would be able to give a good approximation to what I think the answer should be…I think most of teaching is about confidence. Very little else is very much important… So, I think in a lot of ways, being confident and knowing what you're doing is really what carries you through teaching. (Ryan)

> I can go back and reuse a PowerPoint presentation, but I want to make sure that they (children) really understand what I've explained revisiting it so I would create a new set of tasks for them. (Freddie)

> I have shown the shared folder, and I would use things from that, but I generally plan over lessons myself. I make some of my own resources. (Sonya)

When Sonya moved to the second school placement where ‘the school environment was different and more challenging in terms of behaviour management’, her confidence decreased. She needed to change the approaches to match the new requirements. It took her time to get used to the new environment, but her previous positive experiences motivated her to keep up and rise to the new challenges:

> I'm not going to leave the confidence that I built up, but I did at least know that I can get back because, I got back the first time, and I know I can get back again’… I just need to practice more, I think…I don't know if there's anything else…. it's that finding a happy medium and that will take you forward.

7.4 Discussion

The aim of the study was to identify how ITT programmes can more effectively prepare science teachers to teach science in secondary schools. Trainee science teachers’ experiences during a SCITT programme in England were explored to understand how their training can be enhanced. The *Learning to Teach Framework* applied to the analysis provided insight into effective approaches to preparing trainee science teachers. The *Learning to Teach Framework* highlighted the components which trainees draw upon in their learning to teach during their training programme. In their learning to teach, trainee teachers acquire: - *knowledge of the topic to be taught* (knowledge of the content, of the curriculum, of the learners, of the assessment and of the instructional strategies); - *student-centred orientations*; *practice skills* (how to plan lessons, how to sequence lessons, how to convey information to students); - *understandings* (how to reason through the content, how to transform the content for teaching, how to transfer concepts from one topic to another); - and *efficacy* (self-efficacy in teaching a given topic). The study provides evidence of multifaceted experiences among trainee teachers highlighting the importance of personalised learning to improve the quality of their training. The findings resulting from the cross-case analysis identified four effective approaches that contribute to trainees' development in the above *Learning to Teach Framework* components and subcomponents. The findings are discussed according to the four main categories of effective approaches to preparing trainee teachers to highlight trainees' perceived learning experiences within each approach: *Creating dissonance and unexpected events; - Learning from Relevant Models; - Teaching and Rehearsing Practice; - and Consistent Cognitive Support*

The first category of findings ***- Creating Dissonance and Unexpected Events -*** addresses trainee science teachers' orientations for teaching and learning, more specifically, perceived effective features that help trainee teachers to change their orientations towards more student-centred approach during their training programme. At the beginning of their training programme, the participants in this study showed mixed orientations towards teaching and learning science as revealed by their responses to the questionnaires. Five participants in the interview reported that they used to imagine teaching from a teacher-centred perspective. This finding supports the findings of the review studies reporting on teachers' traditional orientations at the beginning of their education programme (Brown, Friedrichsen and Abell, 2013; Adadan and Oner, 2014; Aydin et al., 2015; Barnett and Friedrichsen, 2015; Mavhunga and Rollnick, 2016; Grospietsch and Mayer, 2018). The finding is also consistent with those from the wider literature (Feimen-Nemser, 2001; Gess-Newsome, 2015; Kind, 2015). Consistent with the findings from the systematic review, trainees' orientations for science teaching were based on previous experiences with their schooling or jobs. The evidence for this statement comes from their narration in the interview conversations. Given that trainee teachers' orientations influence their future learning, it is important that trainee science teachers must recognise them. Feimen-Nemser (2001) identified five tasks that are central in the early phase of teaching career. The first task is to 'examine beliefs critically in relation to vision of good teaching' (p. 1050). The author argues that to analyse critically their 'taken for granted beliefs', teachers need to acknowledge their existing ones so that they can be amended and developed (p. 1017). The examination of beliefs should be coupled with the formation of new 'visions of what is possible and desirable in teaching to inspire and guide their professional learning and practice' (p. 1017). Thus, it is important for trainee teachers to have opportunities to examine their perceptions of teaching. In this study, the participants had opportunities to acknowledge and develop a good vision of teaching by observing more experienced teachers' classroom practice in their school placements. Additionally, through discussions and sharing experiences with peers, trainee science teachers expanded their views about teaching and learning science. Scholars (Feimen-Nemser, 2001; Osborne and Dillon, 2010) noticed that when teachers observe and experience new ways of teaching, their thinking about teaching and learning science is challenged. In this study, trainee teachers, all of them career changers, had opportunities to learn about teaching and learning in a way never seen and considered before. They were placed in a position in which their views were challenged through what Osborne and Dillon (2010) called cognitive dissonance or disequilibrium in thinking. Osborne and Dillon (2010) explained that cognitive dissonance happens when an individual holds two beliefs that are in conflict with each other. Cognitive dissonance occurred through 'persuasive communication' when trainee teachers were exposed to effective alternative ways of teaching (Osborne and Dillon, 2010).

The change in orientation due to cognitive dissonance was experienced by all the trainees in this study. For Ryan who entered the programme with traditional orientation to teaching and learning science, 'the biggest message' that he 'took from the programme' was that 'children need to actually do things to learn things.' He 'discovered' that 'it's doing the learning for kids' rather than a passive transmission of information. A powerful cognitive conflict was obvious in his narration about a discussion held on molecular biology and genetics. The discussion challenged his previous beliefs up to the point in which he was determined to make his own research by reading and talking to specialists to gather more credible evidence on the topic of the discussion. He came to acknowledge the rapid changes in science discoveries and was 'amazed' by things which he did not consider or did not give importance to before. Similarly, Freddie acknowledged that he was not conscious of his 'ingrained habits' of standing in front of children and needed to 'relearn' how to teach to secondary students. Like Freddie, Sonya also talked about different ways of communicating information to students. An impactful cognitive conflict could also be identified in Lisa's comments when she was trying to adapt her teaching methods to a new vision of teaching in secondary school. Placed in a position to change her teaching approach, she could see 'how changes in her teaching methods could have a big impact in the classroom.'

Research shows that teachers' orientations act as filter for new learning (Gess-Newsome, 2015; Feimen-Nemser, 2001) and sometimes are resistant to change (Pajares, 1993; Kagan, 1992b). The findings of this study show that the participants were open to new ideas and their orientations were prone to change when the context was favourable. Evidence for this statement comes from the participants' comments, field observations, and the educator's comments about trainees' personal characteristics such as 'enthusiasm for learning and openness to new ideas.'

The findings of this study suggest that trainee teachers' orientations were developed through new learning contexts others than they experienced previously (e.g., discussions, and sharing experiences, observations of alternative ways of teaching). New learning contexts created a social supportive environment in which trainee teachers were vicariously persuaded of the effectiveness of some strategies for teaching that they did not consider or were conscious of before (Bandura, 1971). For example, classroom observations created a new social and cultural context in which trainees could see first-hand the impact of some learning strategies on students' outcomes. They were, thus, vicariously convinced of the effectiveness of the strategies which led trainees to develop positive outcome expectancy (Bandura, 1971). Positive outcome expectancy acted as a motivator for applying the observed strategies in their own practice. By experiencing success with the strategies, their confidence in teaching increased which changed their thinking towards more constructivist way of teaching. This interpretation is based on the view that new learning contexts act as 'catalyst of change' in developing new views on teaching science (Scharfenberg and Bogner, 2016; 2019). A significant number of review studies support the impact of the alternative learning contexts on changing orientations (Van Driel, Jong and Verloop, 2002; Bektas et al., 2013; Adadan and Oner, 2014; Aydeniz and Kirbulut, 2014; Scharfenberg and Bogner, 2016; Tolsdorf and Markic, 2017; Wheeldon, 2017; Scharfenberg and Bogner, 2019; Ekiz-Kiran, Boz and Oztay, 2021). Therefore, it is important for trainee teachers to observe effective teaching methods and experience positive teaching events during their training programme if they are to develop more student-centred orientations.

The second category of findings ***- Learning from Relevant Models -*** addresses similarities and differences in trainee science teachers' learning experiences when learning from models. The findings from the interviews suggest that much of trainees' learning come from vicarious experiences (Bandura, 1999). Through vicarious experiences, trainee teachers learn by observing others. It is useful to remember that trainee teachers perceived the information given in the coursework of the programme as 'overwhelming' and with 'no time to consolidate it and apply everything in practice'. The intensity of the activities in the programme was recognised even by the educator during the interview. Trainee teachers in this study found it difficult to know how to prioritise things. In line with Bandura's view of observational learning, trainee teachers were forced to develop an awareness of what was and what was not worthy learning and applying in practice by anticipating or predicting what strategies would maximize their chances for successful teaching. Salkind (2004) states that the observation of a model can encourage or discourage an individual's motivation to retain a strategy. Bandura (1999) also states that people are frequently in situations in which they choose not to imitate models because the anticipated outcomes are not worth the effort or hold no value to them. This anticipatory behaviour provides the motivation for learning or applying a specific behaviour. These views help in understanding why trainee teachers in this study chose or rejected or could not apply in practice some of the teaching aspects they observed. For example, Freddie commented on introverted and extroverted style of teaching, choosing not to apply in practice some of the observed teaching strategies because of a mismatch with his introverted 'bookish kind of person'. The findings suggest that the choices trainee teachers made about what to apply in practice depended to a great extent on their perception of the relevance and usefulness of the activities modelled and/or on the extent to which they developed an understanding of the principles behind them. It was clear from Ryan's responses that he only learns something if he is 'interested in' and 'can see a use for it' in practice and 'get some positive result back from that'. The same thinking was found to Sonya in her comment 'I'm trying to find the knowledge to do something with it'. Here, Stuckey's et al. (2013) model of relevance can be useful in helping trainee teachers to acknowledge and observe how the three dimensions of relevance for students' learning are applied by experienced teachers in the classroom.

In contrast with Lortie's model of apprenticeship of observation according to the observers imitate the models without thinking, Bandura's theory of observational learning gives another perspective on learning from models. In Bandura's view imitation is more complex and an intentional process (Bandura, 1993). According to this view, trainee teachers imitate intentionally only aspects of teaching they perceive relevant and useful to their practice. In this study, trainee teachers tried to make sense of the activities by attending to the models' thinking. They tried to understand what makes a particular strategy effective and 'why their lessons go really well' as Sonya stated. This was sometimes 'difficult to pick up' due to models' 'tacit knowledge' as indicated by Ryan and Freddie. In Bandura's view, the thinking behind teaching is called abstract modelling. Through abstract modelling, the model (the educator) explains the rules or reasoning behind a particular strategy or practical work so that trainees to understand what and why happens (Shulman, 1986; Bandura, 1999). When reasoning behind the activities is not made visible and accessible, learning does not take place. The above interpretation helps in explaining an episode experienced by Laura when she could not grasp an understanding of the value of a practical work because she could not access the model's thinking. As an activity outside her specialism, she needed more understanding and some 'useful points to come back to,' on a later date when needed. As a result, she felt that she 'did not enhance her knowledge'. This feeling appears quite natural in the light of Bandura's (1971) four interrelated processes for learning from models: attention, retention, rehearsing, and motor reproduction. Without one of these processes, in Bandura's view, learning cannot take place (1971). If the activity modelled is understood well and does make sense, or it is found relevant to their practice, trainee teachers are motivated to memorise and rehearse it. In the case of Laura, the activity lacked relevance, because she 'had no clue why happened what happened'. As a result, she missed out an opportunity to learn an activity. This raises issues of making models' thinking more visible by reasoning on teaching and modelled activities to create what Osborne and Dillon (2010) named a 'window in thinking' (p. 21).

From another perspective, learning from models can lead to innovative teaching. Bandura (1999) argues that vicarious learning conveys rules for generative and innovative teaching. In other words, the information learned previously can be used in a novel way and in different contexts. This generative learning can be obvious in Nathan' s narration on observing a new approach to teaching. When Nathan observed a lesson on infrared radiation taught through a historical story, he felt that he learned a new way of teaching and thinking 'never considered before - using historical stories to teach about discovery'. Certainly, this way of teaching is innovative as it requires novel adaptations to fit with a specific topic. According to Bandura (1999), Nathan extracted from his observation a rule that will help him to generate a new way of thinking and teaching that goes beyond of what he observed. Vicarious learning provides trainee teachers with a range of strategies to enrich their knowledge repertoire, without necessarily with immediate application.

The effectiveness of learning from models, when reasoning on action is visible, finds much support in the previous literature (Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Mavhunga and Rollnick, 2013; Karal and Alev, 2016; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga et al., 2016; Tolsdorf and Markic, 2017; Grospietsch and Mayer, 2018; Mavhunga, 2018; Ekiz-Kiran, Boz and Oztay, 2021). Thus, it is important for trainee teachers to be exposed to alternative effective ways of teaching which, in the present study, was a 'challenge' to find (see Nathan's perspective). In the context of ITT in England, the finding is not surprising. Although, trainees' access to expertise in schools has been central in school-based teacher training programmes, Carter (2015) identifies deficits in subject knowledge and pedagogy in many training programmes in England. The review calls for strong partnerships to form a 'critical mass of subject expertise' to ensure that trainees have access to the expertise they need (Mutton, Burn and Menter, 2017, p. 20).

The third category of findings – ***Teaching and Rehearsing Practice*** **-** addresses trainees' learning experiences with teaching and practical work. It is often assumed that 'experience is the best teacher' (Goodlad in Schmidt, 2010, p.131). Although previous research shows that experience alone does not guarantee good results (Berliner, 2001; Hagger et al., 2008), it was rated by trainee teachers in this study the most valuable feature of the programme for developing teaching skills. This finding supports previous literature on trainees' views on their preparation. Hobson (2003) found that school-based experiences were most valued by trainees because they tended to provide them with more practical advice and feedback which could be immediately applied to their teaching. In a small-scale survey, Hobson (2003) reports that 91% of respondents valued learning from trial and error in the classroom. Often, classroom experience is associated with readiness to teach. Giannakaki, Hobson and Malderez (2011) found that trainees enrolled on a school-based programme reported more preparedness than trainees on postgraduate courses, because of more time spent in school which enhanced trainees' confidence in their readiness to teach. Similarly, Kind (2009) indicates that classroom experience among possession of good subject matter knowledge, self-confidence, and supportive working environment appear to contribute to the growth of PCK in early career teachers. Numerous previous studies show that teaching experience has the most powerful impact on teachers' PCK development (Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021). Based on this research evidence, the practical element of training has been placed at the centre of initial teacher training reforms in England (DfE, 2016; 2019). The focus on practice aims to equip trainees with 'key teaching skills' (Marshall, 2014, p. 276), although concerns about gaps between theory and practice continue to be raised (Marshall, 2014; Mutton, Burn and Menter, 2017; Whitty, 2017).

From a vicarious learning perspective, trainees develop teaching skills and confidence through experience if they have opportunities to rehearse practice (Bandura, 1999). Rehearsal or repeating a particular strategy or teaching skill till it matches the original model in terms of effectiveness, was a frequent reference in trainees' comments. For Lisa, 'reteaching a lesson that hadn't engaged the pupils the first time' was the most beneficial. For Sonya, being able to 'repeat it and get to be better' than she 'was before' was a good learning experience.

Bandura's theory contends that teachers take complex steps in matching the teaching they observe. In time, they become increasingly aware of what 'works' and does not and why. This view can be identified in trainees' comments. For example, Lisa experienced teaching episodes in which she became more aware of what and why worked in terms of engaging strategies. Similarly, Sonya became aware that 'in order to get it right you get to be wrong'. Freddie became aware of his improvement when started to get 'five times more feedback'. As beginners, trainee teachers need to practice a lot during their training, both in terms of lesson planning and conducting practical work and demonstrations, as recognised by Freddie. However, a significant finding is that lesson planning was not a feature that trainee teachers valued during their training programme. This may be because of the 'minimal' support with it. Alongside behaviour management, planning was one of the biggest challenges trainees encountered, as resulted from their comments and educator's.

In Bandura's view, positive experiences are crucial in building self-efficacy beliefs. The many references in trainees' comments like 'I gave it a go myself and worked' (Nathan), or I've used it in the class ...and it really does work' (Ryan), showed satisfaction with the observed strategies because they worked in practice. Therefore, the successful experiences increased their confidence in teaching. Bandura (1999) states that mastery experiences are achieved by 'tackling problems in successive attainable steps' (p. 46). This view is based on the apprenticeship model when trainee teachers learn how to break down ‘the complex task of teaching’ so that they could develop one set of skills at a time. This way of learning, which in accord with Shulman’s (1986, p. 9) ‘transformation of content in accessible forms for students to understand’ is the way through which trainee teachers learn ‘the role of the teacher’. Bandura states that mastery experiences and the feelings associated with those experiences are the most influential on peoples’ self-perception of their capability. This helps in understanding trainee teachers’ positive and negative teaching experiences in relation to their self-efficacy. Through their teaching experiences, trainee teachers could assess their teaching capability. When Sonya perceived she failed to conduct an effective teaching, she was ‘gutted’ and ‘in tears’. In her actual teaching situation, in line with Bandura’s view, Sonya could assess her capability by reflecting on how her teaching skills were enacted in the classroom. The perception that her teaching had been a failure lowered her efficacy beliefs. The decrease in her efficacy beliefs may be attributed to a more focus on self than on students’ learning. From Bandura’s social learning perspective, self-efficacy beliefs are developed by placing more emphasis on effort and persistence, on controllable variables, rather than on self and thoughts when encounter problems in practice (Tschannen-Moran, Hoy and Hoy, 1998). Such focus on self can be identified from both trainees’ and educator’s accounts. Ryan was concerned with having ‘control of the room’ and being ‘in charge’, a critical factor for ensuring a proper learning environment, in his view. Laura, on the other hand, was worried not to ‘set a bad example for the kids’ by admitting that she does not know something. Freddie thought that teaching style similarity with the usual class teacher made things ‘to go quite well’. The instructor commented on this aspect, highlighting the difficulty for trainee teachers to shift from the focus on themselves to effective strategies for students’ learning. She remarked:

> That's another aspect they (trainees) find very difficult, because when the trainees…go into class …all they think about is me, me, me, me, me. How can I get from A to B? Can I do the lesson according to my plan? They don't actually think about how effective those strategies are or if the children are learning… By the end of the programme…they actually seem to be more on - all right, whatever I'm doing, what effect I've got on the learning of the pupils? (Instructor)

These findings resonate with the findings from previous studies. Previous studies found that teachers rarely think about students' learning when planning and teaching lessons (Smit et al., 2017; Smit, Rietz and Kreis, 2018). When teachers have opportunities for reflections and to be confronted with realities of teaching, they become increasingly aware of how their teaching impacts on students' learning. Trainee teachers in this study recognised the need to practice more and in more diverse ways whilst building positive relationships with students. Sonya commented: 'what I need is to practice more.' Ryan was aware that 'the more times you can do it and in more diverse ways that you do it, the more confident you get'. For Lisa, it was relationship building, and Laura thought that 'a lot of it is experience'.

The fourth and the last category of findings – ***Consistent Cognitive Support*** – reports on the learning support trainee teachers experienced during their training programme. The findings suggest that the support trainee teachers received influenced to a great extent the nature of their learning experiences in the programme. These findings are in line with previous literature that highlights the vital role of support in trainee teachers' development (Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015). The support trainee teachers needed fell in some main categories: support with lesson planning, advice and guidance on teaching, support with resources, and feedback on teaching for improvement. Much of the support was expected from school mentors in their school placements where trainee teachers needed more immediate practical knowledge and guidance through the daily teaching tasks. At the beginning of their training programme, eleven out of fourteen trainees placed the feedback from mentors and tutors on the top of their preferences. However, the support and feedback were not found consistent among trainees. Previous research found similar findings (Hobson, 2002). Hobson (2002) found that trainee teachers considered mentoring to be the key aspect of the programme. The author claimed that 81% of trainees valued the feedback on teaching from mentors. Yet, school mentors, the author noticed, were not always successful in creating conditions for effective teacher learning. Similarly, Hobson and Malderez (2013) find mentoring practice in England to be highly variable, with many mentors failing to create good relationships with their trainees.

Clearly, the quality of mentoring in ITT has not improved too much in the last decade. In the context of this study, although trainee teachers generally rated the support 'really helpful', the findings suggest that the support and feedback were inconsistent and not always adequate and aligned to their own needs. An inconsistent support may be attributed to the variation in quality and availability of professional tutors in schools, aspect remarked by their teacher educator of the course, and supported by the vast literature on ITT (Hobson and Malderez, 2013; Carter, 2015; Lofthouse, 2018; Jerome and Brook, 2019). Hobson and Malderez (2013), drawing on data from interviews with beginner teachers and mentors in both primary and secondary schools, identify causes of the failure of school-based mentoring on three levels: mentoring relationship, the school, and the national policy context. The authors found three major causes for poor mentoring: week mentor selection leading to mentors 'who lack appropriate knowledge, skills and characteristics required for the role' (p. 2); lack of consistent high-quality training for mentors; and lack of provision of sufficient time for mentoring. The variation in the quality of mentoring was also noticed by Carter (2015) in his review on ITT. His recommendations led to the publication of National

Standards for school-based initial teacher training (ITT) mentors (DfE, 2016d). The mentoring standards set out the expectations of mentors on four levels: personal qualities, teaching, professionalism, self-development and working in partnership (DfE, 2016d). However, what the standards mean in practice is unclear (Murtagh and Dawes, 2020). Murtagh and Dawes (2020) notice that standards do not reflect the complexities of mentoring. Furthermore, the authors argue, the reciprocal learning relationship between mentor and mentee and the collaborative dimension of dialogic mentoring are absent from the National Standards. Murtagh and Dawes (2020) find that the absence of a standard model of effective mentoring coupled with the lack of time provision led to variability in trainees' experiences during their school-based placements. This resonates with the findings of this study.

In the context of this study, trainees wished to have more time for collaboration and reflection with peers and mentors. Freddie commented on the limited support and feedback he received in his first school placement which impacted on his capacity to improve. Lisa expressed her dissatisfaction with the lack of resources and 'minimal support' on guided lesson planning, not knowing whether it was the 'norm' or 'the school'. Similarly, Laura experienced feelings of injustice and imbalance of 'power relationships' when she received criticism on her first teaching, and her lesson planning did not receive feedback for improvement (Lave and Wenger, 1991, p. 29). These feelings of frustration, tension, and uncertainty impact on trainees' self-perception of teaching capability.

Bandura states that in developing self-efficacy, the chance plays an important role, yet the individuals can choose what to do with their chances. In the context of this study the chances can be perceived as access to quality mentoring support. Trainee teachers experienced different levels of support, which in other words means that their chances to support were unequally distributed. Some trainee teachers valued the open dialogue with their colleague veteran teachers managing to develop collaborative relationships in the school environment. From Lave and Wenger's (1991) perspective of legitimate peripheral participation, trainee teachers felt that they moved from the periphery to becoming a member of the team. This feeling is apparent in Ryan and Nathan's comments. They felt an increase in confidence due to their collaboration with veteran teachers from an equal power position by sharing ideas on teaching. Not all the trainees were lucky to benefit of this kind of support. Though, learning to teach as a social process was acknowledged by other trainees who commented on the importance of developing relationships both with students and school staff. Sonya became aware of learning to teach in a 'proper medium' in which to feel familiar with the context. Also, Laura felt that she would get the experience needed when she does 'get stuck' in a school as a full member. Trainee teachers recognised the importance of the community of practice (the community of teachers) within which collaboration is vital for an effective teaching and learning (Lave and Wenger, 1991). The above findings suggest that trainee teachers gain confidence in their teaching abilities as they become more familiar with the context (the school). New challenges, however, such as having to teach in a new setting (new school), generate a re-evaluation of their efficacy. When Sonya needed to change the school placement, she encountered new challenges and self-doubted her capabilities once again. She was aware that she needed to try harder to 'get used with another way to do it'.

The feedback and support from educators are great sources for self-efficacy development. In line with Bandura's (1993) view of social persuasion, trainees are influenced by the credibility, trustworthiness, and the expertise of teacher educators. Educators provided trainees with useful guidance and advice through weekly written reflections, emails, and verbal conversations. Sharing resources and experiences with their peers was also rated a valuable source of support. Discussions and sharing experiences with peers acted as a persuasive cognitive and emotional support which allowed trainees to empathise with each other. Through social comparison, trainees could gather information about their own teaching performance (Bandura, 1993). The findings are consistent with those from previous research indicating that PCK improves significantly when teachers have opportunities for collaboration with peers and mentors (Schechter and Michalsky, 2014; Günther et al., 2019). In this study, opportunities for collaboration with peers and school mentors were perceived insufficient, as indicated by Sonya's interview.)

On the other hand, social persuasion can negatively influence trainees' self-efficacy. In the case of Laura, the negative feedback she received on her first teaching and planning decreased her self-perception about her teaching competence and impacted her emotionally for 'a long time'. The effect of social persuasion was powerful for her because the persuader was a credible role model as mentor in school. In other situations, the feedback received from credible sources encouraged trainees to persist in their effort. In contrast to Laura, after an unsuccessful teaching, Sonya received encouragement. She felt that she was treated like 'a human being' and she was directed to focus on successful events which kept her self-efficacy beliefs balanced. Such focus on successful events gave her the motivation to persist in effort.

7.5 Conclusion

The aim of this study was to identify how ITT programmes can more effectively prepare science teachers to teach science to secondary students. The aim was achieved through an exploration of trainee science teachers' learning experiences in their training programme to better understand how they add to their knowledge, skills and self-efficacy development and what challenges they face in learning. The present study is limited by sample size and one single centre. However, it highlights trainees' perceptions about effective features of their training programme that help them to develop as practitioners, as well as the challenges they must overcome. A thematic and initial inductive approach to analysis was undertaken to extract codes from the transcripts. The subsequent analysis followed a deductive approach using *Learning to Teach Framework* as analytical strategy that provided five themes for the categorisation of data. *Learning to Teach Framework* developed during the Systematic Review study revealed five components that trainee teachers need to develop during their training programme. *Triadic Framework for Learning to Teach* also developed during the Systematic Review study, provided an understanding of the way trainee teachers learn and develop during their training programme. The two frameworks have relevance to teacher training programmes as they provide educators with useful tools for helping teachers to develop their foundation for teaching before entering the classroom.

Overall, the findings of this study suggest that trainee teachers mainly develop their expertise when they are exposed to alternative ways of teaching, have relevant and good models of teaching, experience direct teaching, and are consistently and adequately supported. The findings also suggest that the challenges trainee teachers encounter during their training programme often relate to the gap between theory and practice. To better align theory with practice, some authors suggest an introduction of explanatory frameworks for guiding observations in schools or conceptual tools during the guided practice such as planning (Mena, Hennissenm and Loughran, 2017). Such suggestions are reflected in the findings of the cross-study synthesis, in this paper, that combines the findings of the Systematic Review with those of the Exploratory Case-Study. The cross-study synthesis outlined in the next chapter reveals useful strategies with potential to increase and accelerate trainee teachers' knowledge and teaching skills during their training programme.

Chapter 8. Cross-Study Synthesis

This chapter reports on the cross-study synthesis that combined the findings from the two studies (Systematic Review and Case-Study). The aim of the cross-study synthesis was to compare the findings from the review study with those from trainee teachers' views to identify matches, mismatches, and gaps that can inform and advance practice in ITT programmes. First, the chapter presents a summary of the findings from the Systematic Review and Case-Study. Next, using a thematic framework, the findings are combined, compared, presented, and discussed.

8.1 Summary of the Findings from the Systematic Review

The aim of the Systematic Review was to gather the available international evidence on effective PCK approaches to preparing science teachers. The main research question that guided the review was: What PCK approaches are effective in preparing science teachers? The systematic review selected, appraised, analysed, and synthesised the literature on PCK approaches used to enhance secondary science teachers' development during their education programmes.

Through the thematic analysis of the thirty-seven primary studies included in the review, a framework namely *Learning to Teach Framework* (LtTF) was developed. *Learning to Teach Framework* consists of five components which teachers were found to draw upon in their learning to teach during their education programmes. The five components of the newly developed framework are: knowledge bases for teaching, orientations for teaching and learning science, practice skills, understandings, and efficacy for teaching. Each component includes several subcomponents (Chapter 5, Figure 13 and Chapter 7, Table 22).

Learning to Teach Framework guided the subsequent cross-studies synthesis in the review study. From the cross-studies synthesis, four main categories of effective PCK approaches to preparing science teachers were developed: - Teaching experiences; - Collaborative Planning, Teaching, and Reflection in Cycles; - Integration and Transformation; - and Consistent Cognitive Support. The four approaches with their key features and contributing studies are summarised in Table 25.

Table 25. Summary of the findings from the review study

Effective PCK approaches	**Key features**	**Studies**
Teaching experiences	Direct teaching in classroom	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013;Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021.
	Observing mentors and peers' teaching	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021.
	Reflections on teaching	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Ekiz-Kiran, Boz and Oztay, 2021.
	Readings/Discussions	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021.

Table 25. (Continued)

Collaborative Planning, Teaching and Reflection in Cycles	Collaboration in Planning /Discussions/ Reflections with peers and mentors	Hume and Berry, 2011; 2013; Schechter and Michalsky, 2014; Milner-Bolotin, Egersdorfer and Vinayagam, 2016; Wheeldon, 2017; Rutt and Mumba, 2019.
	Collectively reflecting on both problems and successes	Schechter and Michalsky, 2014; Günther et al., 2019
	Using pedagogical tools to guide focus and discussions (CoRe, PCK, prompts, questions)	Hume and Berry, 2011; 2013; Adadan and Oner, 2014; Aydeniz and Kirbulut, 2014; Donnelly and Hume, 2015; Juhler 2016; Wheeldon, 2017; 2018; Rutt and Mumba, 2019.
	Repeating learning for mastery	Scharfenberg and Bogner 2016; Juhler 2016; Juhler, 2018; Scharfenberg and Bogner 2019; Jufri et al., 2019.
Integration and Transformation	Explicit reflection on NOS and NOS content - embedded	Demirdöğen et al., 2016; Demirdögen and Uzuntiryaki-Kondakçi, 2016; Demirdöğen, 2016; Grospietsch and Mayer, 2018.
	Conceptual change texts for changing orientations	Demirdögen and Uzuntiryaki-Kondakçi, 2016; Grospietsch and Mayer, 2018

Table 25 (Continued)

	Strengthening content knowledge	Demirdöğen, 2016
	Modelling activities and relating them to practice	Grospietsch and Mayer, 2018
	Explicit explanations and demonstrations of transformation of content /Focus group reflection/ Collaborative planning	Mavhunga and Rollnick, 2013; Demirdöğen, 2016; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga et al., 2016; Mavhunga, 2018.
Consistent Cognitive Support	Educative mentoring framework	Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015.

Some implications for practice were drawn from each category of findings (see Chapter 5). The implications were compared with those from the second study. The comparison revealed a set of evidence-based practices for preparing science teachers.

8.2 Summary of the Findings from the Case-Study

A qualitative Case-Study aimed to explore trainees' views of their learning experiences to understand how the ITT programmes can better prepare them to teach science to secondary students. Two questions guided the design of this study: What learning opportunities enhance trainee teachers' knowledge, skills, and self-efficacy development during their training programme? What challenges and barriers trainee science teachers encounter during their training programme? The *Learning to Teach Framework* (LtTF), developed in the review study, was the guiding and analytical tool of this second study. The analysis followed an inductive-deductive approach.

The findings of this study found that, at the beginning of the programme, most of the participants expressed mixed orientations to teaching and learning science. Among the participants in the interviews, five out of six expressed traditional views of teaching. The findings suggest that teachers' orientations were based on their previous experiences with schooling or jobs. During the training programme, all the participants became aware of their traditional orientations. The participants' perceived effective ways for development were opportunities to: - observe alternative perspectives on teaching and learning; - learn from effective and relevant models; - experience direct teaching and rehearsing practice; - receive constructive and consistent feedback and support from educators.

The challenges trainee teachers encountered during their training programme were diverse. The participants were impacted by: - lack of alignment between content taught during coursework and content taught in school; - intensity of the activities within the programme; - models' tacit knowledge; - inadequate or lack of support with lesson planning; - less opportunities for discussions and feedback for improvement; - and behaviour management.

8.2.1 Practical Implications Resulting from the Findings of the Case-Study

The findings of the Case-Study were grouped into four main categories for the interpretation of the case. From the findings of the Case-Study, six implications for practice were drawn: - Creating opportunities for changing orientations (challenging situations and opportunities to observe alternative effective ways of teaching and their impact on students' outcomes); - Promoting learning from effective modelling of teaching and practical activities/strategies (mentors' teaching quality, reasoning on action, accessibility for understanding); - Promoting opportunities for practice rehearsal to master knowledge and skills; - Promoting direct teaching for successful experiences; - Promoting collaboration and discussions for enriching perspectives on teaching; - and Creating conditions for improvement through consistent feedback before and after teaching (support and feedback on lesson plans, support on different aspects of teaching before teaching, feedback and reflection after teaching).

8.3 A Cross-Study Synthesis

The cross-study synthesis drew on Thomas's et al. (2003) concept of thematic synthesis. The authors used thematic synthesis to combine quantitative with qualitative studies in healthcare with the aim to promote children's healthy eating. They compared two types of reviews: reviews on children's views and reviews on evaluation studies. In this study, a thematic synthesis was used to combine one integrated (mixed) review with one single primary qualitative study. Compared to Thomas's et al. study, the purpose of this study was not to evaluate the effectiveness of the intervention activities carried out by authors of the review studies, but to gather a set of evidence-based approaches to preparing science teachers.

The cross-study synthesis compared the findings of the Systematic Review to the six implications resulting from the findings of the Case-Study through a thematic framework. The purpose was to identify to what extent the practical implications resulting from the findings of the Case-Study were addressed in the review studies and what was their effectiveness in practice, and in which ways the review studies (through the lessons learned – implications for practice drawn from the systematic review) may inform further ways of support for trainee teachers' development. The synthesis is presented in Table 26 and discussed in detail in this chapter.

Table 26. Cross-Study Synthesis

Practical implications drawn from the Case-Study	Intervention studies that matched the implication	Other studies with features that addressed the implication
Creating opportunities for cognitive dissonance	Demirdögen and Uzuntiryaki-Kondakçi, 2016; Mavhunga and Rollnick, 2016; Scharfenberg and Bogner, 2016; 2019; Demirdöğen, 2016; Wheeldon, 2017; Grospietsch and Mayer, 2018.	Bektas et.al., 2013; Aydin et al., 2013; Brown, Friedrichsen and Abell, 2013; Adadan and Oner, 2014; Barnett and Friedrichsen, 2015
Promoting learning from effective models (Observations of teaching and modelled activities)	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Adadan and Oner, 2014; Karal and Alev, 2016; Demirdöğen, 2016; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga et al., 2016; Tolsdorf and Markic, 2017; Mavhunga, 2018; Ekiz Kıran, Boz and Öztay, 2021.	Aydin et al., 2013; Scharfenberg and Bogner, 2016; Aydin et al., 2015; Barnett and Friedrichsen, 2015
Promoting opportunities for practice rehearsal	Scharfenberg and Bogner, 2016; 2019; Juhler, 2016; 2018; Jufri et al., 2019	Hume and Berry, 2011; 2013

Table 26 (Continued)

Implications for practice	**Intervention studies that matched the implication**	**Other studies with features that addressed the implication**
Promoting opportunities for direct teaching	Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz Kıran, Boz and Öztay, 2021.	Aydin et al., 2013; Schechter and Michalsky, 2014; Aydin et al., 2015; Barnett and Friedrichsen, 2015 Scharfenberg and Bogner, 2016; Juhler, 2016; Juhler, 2018.
Creating opportunities for discussions and sharing experiences	Milner-Bolotin, Egersdorfer and Vinayagam, 2016; Rutt and Mumba, 2019	Ekiz-Kiran, Boz and Oztay, 2021
Creating conditions for consistent feedback and guided learning (planning)	Hume and Berry, 2011; 2013; Aydin et al., 2013; Schechter and Michalsky, 2014; Aydin et al., 2015; Barnett and Friedrichsen, 2015; Günther et al., 2019.	Demirdöğen, 2016; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Scharfenberg and Bogner, 2016; Juhler, 2018.

8.3.1 Findings from the Cross-Study Synthesis

Table 26 shows the six implications for practice drawn from the Case-Study and the interventions studies that addressed the implications. Other studies that did not focus directly on the implication but had features that addressed the implication to some extent, were also presented and discussed. From the cross-study synthesis resulted matches, mismatches, and gaps. Matches relate to common features found in the review studies and perceived to be effective by trainee teachers in the Case-Study. Mismatches highlight features that were mainly found in the review study and were shown to be effective in preparing science teachers. These features are the ‘lessons learned’ from the review study which are advanced as a set of evidence-based practices that can be used to advance practice. Gaps are highlighted and used for further recommendations (see Chapter 9). The matches and mismatches are described separately for each implication presented in the above table as follows:

Implication 1. Creating opportunities for changing orientations

The interview data from the Case-Study indicated that trainee science teachers changed their orientations towards more student-centred approaches due to opportunities to witness different ways of teaching and the impact on students’ learning. Through discussions and sharing experiences, trainees enlarged their views on different aspects of teaching. The studies matching this implication reported positive results in changing science teachers’ orientations when orientation was explicitly addressed (Demirdöğen, 2016). The studies showed that when teachers were exposed to new learning contexts, their initial beliefs were challenged. New contexts for learning included inquiry, argumentation, history of science, different views of students’ learning difficulties, and content embedded NOS. Adadan and Oner (2014) challenged the participants’ ideas about diverse topics in chemistry by engaging them in conflicting situations. Science teachers further developed understandings and transformed their views by reading research literature on students’ conceptions and misconceptions in different science topics and critically reflecting on their experiences.

Furthermore, the review studies provided evidence for the effectiveness of other features such as explicit reflection on orientations (using, for example, conceptual change texts) rather than implicit reflection (reflection tasks, reflection on own's learning). Meaningful and explicit experiences related to practice were also effective in changing teachers' orientations in other studies (Demirdöğen, 2016; Demirdöğen et al., 2016). In a study conducted by Scharfenberg and Bogner (2016), teachers' orientations were addressed by placing them both in the role of a teacher and of a student so that they can develop different views of student learning difficulties. Similarly, Grospietsch and Mayer (2018) created opportunities for teachers to explicitly reflect on individual misconceptions, and the content was taught with reference to teachers' later roles as science teachers. In addressing teachers' orientations, Barnett and Friedrichsen (2015) used comparisons between teacher and student-centred approaches. Mixed or negative results were reported in studies in which teachers' beliefs were not directly related to the purposes of teaching science or their orientations were not explicitly addressed (Demirdöğen, 2016; Ekiz- Kıran, Boz and Öztay, 2021).

Implication 2. Promoting learning from effective modelling

From trainees' s views of their own learning experiences resulted that much of their learning came from observations of experienced teachers' teaching and doing practical works as in the classroom. Trainee teachers commented on positive teaching experiences due to application in the classroom of the teaching strategies they observed. At other times, learning from experienced teachers was found to be difficult or challenging. Several reasons behind those challenges were mentioned: experienced teachers' tacit knowledge, perceived lack of relevance to trainees' own practice, or differences in teaching style. These findings are supported by the review studies that match this implication. The review studies showed that it is difficult for teachers to observe experienced teachers' teaching without pedagogical tools to focus their attention. For example, Ekiz Kıran, Boz and Öztay (2021) reported on teachers complaining about 'observing their mentors without any clear focus and writing reports on activities that were not effective for their professional development and were a waste of time' (p. 7). To fill this gap, the authors redesigned the school experience around a PCK framework using a set of pedagogical tools including reflection tool, Content Representation (CoRe) template for planning and observation form. The observation form allowed teachers to observe each component of PCK that experienced teachers considered in their teaching. Teachers' teaching observations were critically evaluated during the coursework of the programme.

The importance of observing experienced teachers' teaching followed by discussions with them was also highlighted in other studies (Van Driel, Jong and Verloop, 2002; Tolsdorf and Markic, 2017). Yet, as mentioned above, observations of experienced teachers are not straightforward or guaranteed to be effective (Ekiz Kıran, Boz and Öztay, 2021). According to Lortie (1975), due to their prior experiences as students in school, trainee teachers may not have the ability to correctly interpret the experienced teachers' decisions about teaching in the classroom. Thus, using tools that focus the attention on key aspects of teaching during observations coupled with discussions and reflections on those observations are more helpful.

A valuable feature of the training programme, as perceived by trainees, was learning to conduct practical works and demonstrations and how to sequence a lesson for teaching. The effectiveness of step-by-step learning was highlighted by the studies matching this implication. Many studies showed that teachers improve their skills when there are explicit demonstrations of how to break down the topic for teaching (Mavhunga and Rollnick, 2013; Mavhunga, 2016; Mavhunga et al., 2016; Mavhunga and Rollnick, 2016; Mavhunga, 2018). In these studies, the knowledge components were discussed one at a time in relation to their application in practice. Reasoning through content was a key feature that helped teachers to transform the content by integrating all the teaching components in their lesson plans. The use of CoRe tool was helpful in focusing their attention on what was essential for teaching.

Implication 3. Promoting opportunities for practice rehearsal to master knowledge and skills

Rehearsing teaching and practical works benefited trainees during their training programme. Trainees felt that they could improve their skills when they had opportunities to repeat the same topic and practice demonstrations and explanations before lessons. This feature was also emphasised in the review studies. In Adadan and Oner's (2014) study, teachers' progress was due to first-hand experiences with inquiry strategies and reflecting on those experiences after being modelled by educator. Similarly, Mavhunga (2016) and Mavhunga and Rollnick (2016) first modelled the activities which were then practised by teachers under guidance, and any challenges were solved through collective discussions. This implication was especially addressed by Scharfenberg and Bogner (2016; 2019) in a role change approach. The approach enabled teachers to experience hands and minds on activities through repeated learning sequences.

Teachers also improved their lesson planning skills through a lesson study approach applied by Juhler (2016; 2018). The lesson study involves group discussions followed by a refinment and repetition of the lessons. The cyclical nature of the lesson study and the use of CoRe enabled teachers to focus on the content knowledge being taught and guided their thinking and planning towards students' perspectives. Similar results were reported by Jufri et al. (2019), yet, the study did not use the CoRe for planning as in the previous studies. Previous studies (Juhler, 2016; 2018) suggested that without CoRe for planning to focus attention many important teaching aspects are missed.

Implication 4. Promoting direct teaching for successful experiences

The findings from the Case-Study revealed that teaching experiences were rated by trainees as the most valuable feature for learning ‘how to teach’ and ‘think like a teacher’ (Lave and Wenger, 1991, p.105). Trainee teachers felt that they could develop teaching skills through ‘trial and error’ by applying in the classroom what they have learned from their observations and coursework. Many studies matching this implication provided evidence of the importance of classroom experience in developing expertise in teaching (Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz Kıran, Boz and Öztay, 2021). However, Burn, Mutton and Hagger (2017) warn that pure imitation of others’ practice is less likely to lead to the expertise that teachers need. Contrary to pure imitation of what works, trainee teachers in this study tried to understand why what worked was effective. Trainees acknowledged that, to develop teaching expertise, they ‘need to get it wrong in order to get it right’.

Certainly, critical reflection on teaching is crucial in developing expertise. The review studies reported positive results when teaching experiences were followed by discussions and reflections on those experiences. For example, in the study conducted by Schechter and Michalsky (2014), teachers focused and reflected on both positive and problematic events from the lessons taught. After each lesson taught in physics, teachers were required to complete a five-step reflection format to focus on the following aspects: a problematic or successful event, actions that led to the outcome, critical turning points, principles of action, and unresolved action for further inquiry. Similarly, Tolsdorf and Markic (2017) found that teaching experiences and discussions with mentors influenced student teachers’ diagnostic competence on ‘high level’. Van Driel, Jong and Verloop (2002) found that participation in reflections on teaching experiences developed teachers’ understanding of students’ learning difficulties. Discussions with mentors also contributed to their awareness of instructional strategies, students' learning difficulties, and use of language. Students' posed questions and responses to tests and assignments had a significant role in science teachers' increase in representations. An important feature of learning from experience was discussions with mentors before teaching. Evidence for the effectiveness of this feature was provided by Hume and Berry (2013). The authors observed that discussions before teaching improved science teachers' planning skills. In the context of the SCITT programme, these features would have particularly benefited trainee teachers with a perceived need of receiving feedback on their lesson plan before rather than after teaching. Also, somebody available 'to discuss with' both before and after teaching was a perceived need and an important feature for improvement (see trainees' comments in Chapter 7).

Implication 5. Promoting collaboration and discussions for enriching the content and perspectives on teaching.

Other valuable features indicated by trainees' experiences within the SCITT programme were discussions and peer sharing. Trainee teachers learned multiple perspectives on teaching through discussions with peers, experienced teachers, and educators. Seeing how other peers apply in practice the same topic was a feature perceived to be valuable in enriching their repertoire of teaching. Although discussions and sharing experiences within the SCITT programme allowed trainees to develop a multi-perspective on teaching, the structure of the programme did not provide regular opportunities for trainees to develop relationships with peers (as revealed from Sonya's interview). The review studies provide both evidence for the effectiveness of collaborative learning and suggestions for practice. Although trainee teachers could share resources and diverse information virtually, the online communication was informal and not supported by a learning task guided by educators. The review studies showed that learning can be effective even online when it is guided and scaffolded by educators. Unguided peer learning did not bring positive results in some studies due to peers' limited knowledge and lack of experience in reflection processes (Donnely and Hume, 2015; Weitzel and Blank, 2019). Yet, when the online learning was guided by a more knowledgeable person or prompts, teachers were found to improve their knowledge and skills. For example, Milner-Bolotin, Egersdorfer and Vinayagam (2016) found the online discussions on designing multiple choice questions to be constructive. Teachers improved their questioning strategies as well as content knowledge through discussions with peers. The discussions were continued in the class where teachers had the opportunity to reason on their choices. Similarly, Rutt and Mumba (2019) stimulated teachers' thinking and readings with prompts which led to a developed conceptual understanding.

The studies showed an increase in the components of PCK when collaboration and discussions were facilitated by educators, not only online but also during coursework. Collaboration on planning was not referenced in trainee' reported experiences. Planning alongside behaviour management were challenging aspects for trainee teachers as indicated by the educator's interview. In the context of the training programme, the findings suggest that there was a lack of a collaborative approach to planning and a limited school mentors' availability for constructive feedback on it. Lederman and Niess (2000) claim that planning and having objectives is critical, and writing a plan increases teachers' effectiveness because it forces them to think on the topic to be taught. However, with limited or no teaching experience, trainee teachers in this study were not initially aware of what they needed to develop as practitioners. Therefore, they did not know what to include in their lesson plans to make teaching more effective. As the rationale for planning is to develop 'the thinking not the writing' (Lederman and Niess, 2000, p. 59), it is crucial to create windows in trainee teachers' thinking. This is achievable only through a collaborative planning with peers and school mentors.

A significant number of the review studies provided evidence of the effectiveness of collaborative planning in developing knowledge and teaching skills. In Adadan and Oner's (2014) study, teachers designed lesson plans in collaboration with peers using CoRe planning template. The design of CoRe lessons was more effective when planning was facilitated by educators. In Hume and Berry's (2011; 2013) study, teachers worked in collaboration with their school mentors in designing lesson plans. Guided lesson planning, also an effective feature in a study conducted by Demirdöğen (2016), stimulated teachers' PCK development and the translation of their PCK into planning.

Implication 6. Creating conditions for improvement through consistent support and feedback before and after teaching.

Although trainee teachers on the SCITT programme benefited from mentoring support during different stages of their training, the support was not always perceived as adequate and consistent. As trainee teachers indicated, the support was at times a big issue (see trainees' comments). A few studies acknowledged this problematic aspect and advanced a mentoring framework based on a set of research-based practices. These practices included CoRe design, explicit PCK instruction, microteaching, reflection, and educative mentoring throughout the school practice. The authors concluded that educative mentoring practices based on CoRe have the potential to be a 'lifesaver' for teachers who have insufficient PCK for teaching science (Aydin et al., 2013; 2015). CoRe enabled the participants to articulate their PCK and facilitated the integration of all the components in planning. Through educative mentoring, teachers are supported on all the aspects of teaching in a consistent way during their teaching practice in schools. In studies conducted by Aydin et al. (2013) and

Aydin et al. (2015), due to mentoring structure, teachers moved from a fragmented PCK, which was more based on pedagogical knowledge, to more integrated knowledge. Barnett and Friedrichsen (2015) used guided learning and collaborative planning with peers and mentors. The mentor provided the teacher with strategies both for immediate application and for long term development by modelling critical reflection on instructional choices.

The above comparison of the findings of the Systematic Review to the implications for practice arisen from the Case Study revealed a set of evidence-based approaches to preparing science teachers. These approaches can be borrowed and/or adapted to strengthen the preparation of trainee science teachers within the SCITT and other programmes. These evidence-based practices are the lessons learned from the review study which complement or corroborate those from trainee teachers' views on effective learning opportunities during their SCITT programme. These lessons are summarised in the following section.

8.4 Lessons Learned from the Cross-Study Synthesis

The cross-study synthesis used a thematic framework to compare the findings of the Systematic Review to the six implications for practice resulting from the Case-Study. The findings from the cross-study synthesis revealed that the review study covered all the features perceived to be effective by trainee teachers within the SCITT programme. This may be because trainee teachers' views of their learning experiences were gathered from both coursework and teaching practice in school placements. The review study also covered a range of education programmes, ranging from two hours to two years, including coursework, teaching practice in schools, or both.

The comparison of the findings of the Systematic Review to those from trainees' views revealed a set of nine evidence-based practices for preparing science teachers, briefly described in this section. The resulted set of nine evidence-based practices helps to inform and advance practice in teacher training programmes (Table 27).

Table 27. A set of evidence-based practices resulting from the cross-study synthesis

Evidence-based practices	Contributing studies
Deepening content knowledge and conceptual understanding before teaching	Bektas et al., 2013; Karal and Alev, 2016; Mavhunga et al., 2016; Milner-Bolotin, Egersdorfer and Vinayagam, 2016; Rutt and Mumba, 2019.
Promoting explicit rather than implicit reflection on teaching	Adadan and Oner, 2014; Tolsdorf and Markic, 2017; Grospietsch and Mayer, 2018.
Promoting authentic and meaningful experiences that relate to practice	Scharfenberg and Bogner, 2016; Günther et al., 2019.
Using pedagogical tools to guide focus (observation checklist, CoRes, PCK framework, prompts, questions, instruments)	Hume and Berry, 2011; 2013; Aydin et al., 2013; Aydeniz and Kirbulut, 2014; Aydin et al., 2015; Juhler, 2016; Mavhunga, 2016; Juhler, 2018; Mavhunga, 2018; Rutt and Mumba, 2019; Ekiz-Kiran, Boz and Oztay, 2021.
Creating opportunities for guided collective dual reflection (both on problematic and successful teaching events)	Schechter and Michalsky, 2014; Adadan and Oner, 2014; Günther et al., 2019.
Collaborative planning with mentors	Hume and Berry, 2011; 2013; Mavhunga and Rollnick, 2013; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga, 2018.

Table 27 (Continued)

Evidence-based practices	Contributing studies
Promoting opportunities for rehearsal to master learning	Scharfenberg and Bogner, 2016; Juhler 2016; Juhler, 2018; Scharfenberg and Bogner, 2019; Jufri et al., 2019.
Creating opportunities for abstract modelling	Adadan and Oner, 2014; Barnett and Friedrichsen, 2015; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga et al., 2016; Mavhunga, 2018.
Ensuring consistent support and feedback	Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015.

8.4.1 Short Description of the Set of Evidence-Based Practices

Deepening content knowledge and conceptual understanding before teaching. Often, unsuccessful teaching is attributed to deficiencies in content knowledge and conceptual understanding (Bektas et al., 2013; Karal and Alev, 2016). Unsuccessful teaching impacts negatively on trainee teachers' self-efficacy. Deepening content knowledge and conceptual understanding before teaching ensures that trainee teachers experience successful teaching events. Successful experiences, in turn, increase their self-efficacy. It is thus important for trainee teachers to have opportunities to consolidate and master the content of the topic to be taught before entering the real classroom context. In the context of ITT in England, initiatives have been put in place to increase participants' content knowledge, such as Subject Matter Enhancement courses (DfE, 2014b; 2022). However, although teachers' subject knowledge was found to make a difference, the subject matter preparation has often been found inadequate and insufficient (Kind, 2009b; Mutton, Burn and Menter, 2017). Mutton, Burn and Menter (2017) express concerns regarding the focus on covering the content rather than on the processes by which knowledge comes to influence practice. Kind (2009b) observes that trainees showed inability to transform subject matter knowledge to PCK and, mostly, they used subject knowledge sources from their teaching practice schools rather than university-based materials or ideas. This, clearly, shows that subject matter courses, although helpful in acquiring substantive knowledge, are not as effective as in conjunction with a conceptual understanding of the topic to be taught.

Promoting explicit rather than implicit reflection on teaching. A long-lasting issue in education programmes relates to teachers' orientations often found to be difficult to change. Trainees' ability to develop their understanding of the subject matter for teaching depends on their orientations towards the subject. Promoting explicit rather than implicit reflection on teaching was found to be more effective in changing orientations and developing conceptual understanding. Reforms in ITT have had an increased focus on improving trainees' skills needed to become reflective practitioners (Gillies, 2017). However, in initial teacher training, trainees mostly use reflexion as an evaluation tool of own teaching (Menter, Peters and Cowie, 2017). Evidence from research shows that explicit reflection (e.g., conceptual change text) is more effective that written reflections or reflections on own's learning (implicit reflection) (Adadan and Oner, 2014, Tolsdorf and Markic, 2017; Grospietsch and Mayer, 2018).

Promoting authentic and meaningful experiences that relate to practice. Promoting authentic and meaningful experiences that relate to teachers' practice are more likely to change teachers' orientations. In some studies, authentic experiences, such as role change approach and learning case method, were more likely to help teachers to see the relevance of the activities to their practice and to their role as teachers (Günther et al., 2019; and Scharfenberg and Bogner, 2016).

Using pedagogical tools to guide focus. Using pedagogical tools to guide focus (observation checklist, CoRes, PCK framework, prompts, questions, instruments) is not only 'lifesaver' (Aydin et al., 2013) but also, timesaver. Pedagogical tools were found to have multiple advantages in learning to teach: - increase the focus on essential aspects for teaching; - more effectively link theory with practice; - increase the focus on students' understanding of the topic; - ensure a common discourse or shared language; - ensure a development in all the components of PCK and integration between them; - and help in organisation of the knowledge for teaching (Hume and Berry, 2011, 2013; Aydin et al., 2013, 2015; Aydeniz and Kirbulut, 2014; Juhler, 2016; Mavhunga, 2016; Juhler, 2018; Mavhunga, 2018; Rutt and Mumba, 2019; Ekiz-Kiran, Boz and Oztay, 2021).

Creating opportunities for guided collective dual reflection. Another strategy for learning is to create opportunities for guided collective dual reflection (both on problematic and successful teaching events). Collective reflection would be more beneficial in learning from each other's problems and successful teaching events. A collective reflection guided by educators was found to have more lasting impact, challenge trainees' thinking and develop their ability to articulate their reasoning (e.g., Schechter and Michalsky, 2014; Adadan and Oner, 2014; Günther et al., 2019).

Collaborative planning with mentors. Equally important, collaborative planning with mentors and peers outweight individual planning in effectiveness. A collaboration with mentors in planning, using pedagogical tools (e.g., CoRe template for planning), ensures that trainees have access to the educators' expertise in planning, a condition for successful teaching (Hume and Berry, 2011; 2013; Mavhunga and Rollnick, 2013; Mavhunga, 2016;

Mavhunga and Rollnick, 2016; Mavhunga, 2018). Lofthouse (2018) refers to an effective collaboration between mentors and trainees as a 'transformative space' where both mentors and trainees develop professional identities (p.14). A collaborative approach to planning involves positive and trusting relationships in which trainees feel that their ideas are valued. In the light of variation in quality of mentoring and issues with mentoring relationships, as revealed by the literature (Lofthouse, 2018; Jerome and Brook, 2019), it becomes imperative that an effective model of mentoring based on fruitful collaboration between mentors and trainees should be a priority in ITT.

Promoting opportunities for rehearsal to master learning. Mastery experiences are the most effective source for developing self-efficacy. When trainee teachers have opportunities to rehearse practice, they are more likely to increase their confidence, understandings, and skills, by subsequently incorporating new more effective strategies in their planning and teaching (Juhler, 2016, 2018; Scharfenberg and Bogner, 2016, 2019; Jufri et al., 2019).

Creating opportunities for abstract modelling. To further develop trainees' ability to reason on practice, it is important to create opportunities for abstract modelling. It is important for trainees to grasp the reasoning behind teaching and activities. Educators must ensure that trainees understand what and why learning happens, so that they do not imitate teachers' practices without thinking (Adadan and Oner, 2014; Barnett and Friedrichsen, 2015; Mavhunga, 2016; Mavhunga and Rollnick, 2016; Mavhunga et al., 2016; Mavhunga, 2018).

Ensuring consistent support and feedback. At the beginning of their career, science teachers were found to have limited PCK. Therefore, their need for consistent guidance and support is understandable. Consistent support and feedback in the context of the SCITT programme is something that ‘can be improved’ as some of the trainee teachers suggested. For many trainees, the feedback was perceived inconsistent. Issues with consistency of feedback, also, have been highlighetd in the literature. Scholars find that feedback in ITT is more monological than dialogical (Jones, Tones and Foulkes, 2018; Murtagh and Dawes, 2020). Monological feedback takes the form of annotations on trainees’ lesson plans; it is more formal criterion-based approach to feedback. Jones, Tones and Foulkes (2018) find that dialogical feedback is more effective as it is personalised; it focuses on trainees’ actual teaching rather than on achieving the teaching standards. Jones, Tones and Foulkes (2018) found informal discussions after and before lessons as the most common form of dialogic feedback. This kind of feedback was perceived a need by some of the participants in this study. Consistent feedback gives trainees reassurance when they doubt their teaching capabilities. This may be the reason why the lack of feedback becomes a source of frustration for trainees who put effort into their lesson planning and teaching. The review studies show that a CoRes-based mentoring-enriched practicum ensures a consistent support and feedback during trainees’ teaching practice in schools (Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015).

In summary, in this chapter, the cross-study synthesis combined the findings from the Systematic Review with those from the Case Study using a thematic framework. The findings and the implications drawn from the Systematic Review were compared to the six implications for practice drawn from the Case-Study. The findings of the cross-synthesis revealed a set of nine evidence-based practices that can be drawn upon to strengthen the preparation of trainee science teachers during the SCITT programmes and other routes into teaching. The study’s limitations and further recommendations are addressed in the next chapter.

Chapter 9. Enhancing ITT to Teach Science in Secondary Schools. General Discussion, Limitations and Conclusion

This chapter provides a summary of the whole thesis highlighting the main findings and their practical and theoretical implications. The contribution of the study to the body of knowledge and a critical reflection on the strengths and limitations of the study are also outlined. The chapter ends with a conclusion and recommendations for future research.

9.1 Introduction

The current thesis consists of two studies with the overarching aim to enhance ITT for trainee science teachers. In achieving the aim, first, evidence of effective learning strategies for preparing science teachers were gathered from science education programmes around the world using a systematic review methodology. The research synthesis sought to identify effective PCK approaches to preparing science teachers from different contexts. Second, a Case-Study of a SCITT science programme was used to explore trainee teachers' own perceptions of their learning opportunities. A framework developed during the first study alongside a thematic approach were used to analyse and synthesise the findings from the two studies. The findings from the two studies were combined in a cross-study synthesis using a thematic approach. This dual approach to research provided rich insight into effective strategies for preparing science teachers.

The study is based on Pedagogical Content Knowledge (PCK) as theoretical underpinning. PCK has been widely used in preparing teachers as it is regarded as the specific professional knowledge for teaching. Although a range of studies support the link between PCK and teachers' development (see the review studies), how the components are best integrated and how they relate to teachers' practice has been always unclear (Berry et al., 2008; Neumann, Kind and Harms, 2018). This lack of clarity may be primarily due to the inconsistent way in which PCK has been conceptualised and measured in research to date (Smith and Banilower, 2015). Given these ambiguities, previous literature reports a lot of limitations in capturing and assessing teachers' knowledge. In addition, as research on PCK did not distinguish between knowledge, practice skills, and understandings, the relationship between PCK and practice has often been found to be inconsistent. Previous studies observed that PCK does not always relate to what teachers know and do. These findings support the wider literature on inconsistences between beliefs and practice (Kagan, 1992b; Mansour, 2009; 2013). For this reason, PCK has been found to be idiosyncratic (see the review studies) being seen as an 'amalgam' (Neumann, Kind and Harms, 2018; Kind and Chan, 2019, p.1). Neumann, Kind and Harms (2018) comment that this amalgam generates multiple interpretations, and therefore, different understandings of what PCK is. A more coherent form of knowledge for teaching would be beneficial for trainee teachers at the beginning of their teaching career.

This study addresses calls for research on how PCK relates to teachers' practice by developing and testing a PCK based framework which serves as a pedagogical tool to enhance trainee teachers' development. The PCK based framework, namely *Learning to Teach Framework* (LtTF), was developed through data analysis of the Systematic Review. The framework consists of five components which teachers, as participants in the studies included in the review, simultaneously drew upon in their learning to teach during their education programmes. The five components are *Knowledge, Orientations, Practice, Understandings,* and *Efficacy*. Each component of the framework consists of several subcomponents which teachers were found to develop in the process of their learning to teach. The *Learning to Teach Framework* components and subcomponents for teaching a specific topic are presented in Chapter 5, Figure 13.

The application of the framework in practice was validated by the findings of the review study. The review study provided evidence of how the components of the newly developed framework were used in learning to teach in an integrative way. The framework was used to guide the Case-Study exploring trainee teachers' perceptions about their own preparation (Chapter 6 and 7). The findings of the Case-Study again validated the value of *Learning to Teach Framework*. Trainees were found to enact all the components of the framework in their learning to teach during the ITT programme. Collectively, the findings provide direct support for the components of *Learning to Teach Framework* as five pillars upon which trainee teachers draw in their learning to teach.

The second newly developed framework in the first study - the *Triadic Framework for Learning to Teach*, provides a theoretical account of how trainee science teachers accumulate knowledge, skills, understandings, change orientations, and develop high self-efficacy during their training programmes. This study advances the two frameworks as a model for enhancing trainee science teachers' development during their training programmes. The tools have considerable implications for practice helping educators to prepare trainee teachers more effectively by identifying gaps in *Learning to Teach Framework* components and targeting learning opportunities to address them.

In this final chapter, the key findings of the study and their implications are summarised and discussed in relation to the developed frameworks as tools for facilitating trainee science teachers' development during their training programmes. The findings' implications for practice, research, and policy are also highlighted and suggestions are presented for future research.

9.2 Enhancing ITT to Teach Science in Secondary Schools

The findings from the thirty-seven studies included in the Systematic Review revealed considerable evidence for the effectiveness of PCK approaches to preparing science teachers. Data analysis indicated that teachers develop PCK more effectively when they are offered diverse learning opportunities. In addition, PCK development is more successful when all the components of *Learning to Teach Framework* are addressed in relation to each other and to the topic to be taught. There were studies that showed that even in a workshop of two hours teachers may learn content knowledge and change their orientations (e.g., Wheeldon, 2017). This finding is in accordance with other research (Gartland, 2012) showing that even small changes in practice can have a positive impact on trainee teachers' development. The conclusion is that, effectively designed training activities, even short in duration, may help teachers to develop expertise during ITT programmes.

Expertise in the current study is seen through the lens of *Learning to Teach Framework*. More specifically, to develop expertise, a teacher must: - acknowledge the knowledge bases for teaching and develop good knowledge in the topic to be taught; - develop student-centred orientations; - develop good skills for planning and teaching the topic; - develop good conceptual understanding of the topic; - and develop strong efficacy beliefs for teaching the topic. The framework does view its components as developing simultaneously for a given topic. Also, the orientation component is viewed as being topic and context specific (for example, orientations towards nature of science or orientations towards teaching about evolution).

Because of inconsistent conceptualisation and issues with articulation of PCK, previous studies acknowledged some limitations with respect to their own findings. Issues with articulation of PCK were also found in the Case-Study. The Case-Study revealed, among others, challenges trainee teachers face in grasping some aspects of teaching and learning because of models' tacit knowledge (Chapter 7). Using the newly developed frameworks alongside the set of strategies identified in this study (see the evidence-based practices in Chapter 8), it is hoped that at least part of the limitations and challenges can be avoided.

9.2.1 The Main Findings of the Study

The main findings of the study are summarised and discussed around six key messages that educators should consider in designing learning opportunities for trainee science teachers.

Developing trainee teachers' components for teaching through a holistic approach

A significant finding of this study is that trainee teachers, all career changers, perceived a continued need to develop knowledge for teaching and learning science, especially from outside their specialism. Entering the programme with varying science backgrounds, their knowledge outside their specialism was perceived to be limited. This finding is consistent with those from the review study and wider literature indicating that teachers enter the training programme with limited knowledge and skills for teaching (Van Driel, Jong and Verloop, 2002; Abel, 2007; Kind and Kind, 2011; 2014; Bektas et al., 2013; Karal and Alev, 2016). The findings of the review study (Chapter 5) showed that insufficient knowledge for teaching impacts on teachers' subsequent developments in different ways. In other words, the knowledge bases impact on the other components of *Learning to Teach Framework*. Beyond addressing the knowledge alone or separate components, however, the findings of this thesis highlight the importance of addressing the knowledge bases in relation with the other components of teaching (*Learning to Teach Framework* components).

Collectively, the findings are consistent with those from the wider literature indicating that neither knowledge nor experience alone is sufficient for teaching (Shulman, 1986; 1987; Hagger et al., 2008; Kind and Kind, 2011). Scholars agree that simply possessing the knowledge does not automatically translate into practice (Mansour, 2008; 2013). The inconsistences between 'knowing and doing' may appear because of several reasons (Morine-Dershimer and Kent, 1999, p. 39). First, teachers cannot teach what they do not understand (Gess-Newsome, 1922) or they may not be aware of their orientations (Mansour, 2013). In addition, teachers' self efficacy influences their teaching. It is widely agreed that teachers with low self-efficacy tend to avoid teaching challenging content such as nature of science (Demirdöğen et al., 2016; Bektas et al., 2013; Tolsdorf and Markic, 2017) or socio-scientific issues (Osborne and Dillon, 2010). It becomes obvious that teaching is a complex process in which teachers need to simultaneously draw upon all the Learning to Teach components when making decisions in and about teaching. Therefore, a holistic approach to preparing science teachers is imperative.

Eliciting teachers' orientations

Another significant finding of this study draws the focus on the importance for educators to help teachers become aware of their own orientations towards teaching and learning science. As in previous research, trainee teachers, as research participants in the Case-Study, entered the programme with different images about teaching and learning science based on their previous experiences (as detailed in Chapter 7 and 8). As mentioned previously, teachers' orientations are in part impacted by deficiencies in knowledge. In this study, trainee teachers' orientations were shown to be prone to change when they were exposed to alternatives ways of teaching. As a component of *Learning to Teach Framework*, *orientation* indicates teachers' changes of thoughts, views, goals, and beliefs about teaching and learning science. Previous research found that teachers have multiple purposes and goals for teaching and learning science (Demirdöğen, 2016; Demirdögen and Uzuntiryaki-Kondakçi, 2016.) In the review study, teachers' orientations were not consistently translated in planning and teaching. As mentioned earlier, the reason behind the inconsistences between orientations and practice may be attributed to trainee teachers' lack of awareness of their orientations to teaching and learning science (Ekiz-Kiran, Boz and Oztay, 2021). A lack of awareness of orientations impacts negatively on future learning. Thus, it is important, first, for trainee teachers to acknowledge or explicitly reflect on their orientations for teaching and learning science.

Ensuring equal access to a good vision of teaching

A further finding of this study is concerned with trainee teachers' need to learn from effective models of teaching. The review study provided evidence for the importance of learning from experts in developing expertise in teaching. By observing relevant and good models, trainee teachers learn about the knowledge bases for teaching, develop a better conceptual understanding, and expand their repertoire of instructional strategies and perspectives on teaching.

However, some challenges associated with learning from models, such as scarce opportunities for observing effective models of teaching and lack of reasoning behind teaching, impact on trainees' conceptual understanding (see Chapter 7). Without a good conceptual understanding, trainee teachers' initial orientations for teaching and learning may remain unchanged. Initial orientations coupled with low efficacy determine teachers to avoid innovative teaching methods, adopting thus teacher-centred strategies.

Maintaining a good balance between theory and practice

Further, it is not a surprising finding that trainee teachers most valued the opportunities to apply their knowledge and skills in the classroom. In the Case Study, the practical aspect of the training programme was the main reason why trainee teachers chose a SCITT route into teaching. This finding fully supports previous studies that found teaching experiences as the most valuable way of learning to teach. The review study provided evidence that PCK mainly develops through teaching experiences (Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Bektas et al., 2013; Karal and Alev, 2016; Tolsdorf and Markic, 2017; Ekiz-Kiran, Boz and Oztay, 2021).

However, the review study also showed limitations of ‘learning from teaching experiences.’ Deficiencies in knowledge and conceptual understandings were the most cited factors that impact on teachers’ teaching experiences (Bektas et al., 2013; Karal and Alev, 2016). Studies found that deficiencies in knowledge may result from lack of alignment of the content taught during coursework with the content taught in the classroom. These findings are supported by trainees’ views. For example, one trainee stated that she was assigned to teach key stage four content in the classroom whilst she was learning key stage three content during the coursework of the programme (Chapter 7). Such incongruences may confuse and place additional demands on trainee teachers who already struggle with the content to be taught. On the other hand, an emphasis on school content may be limited, yet a combination of school and academic content contributes to a better conceptual understanding and ultimately to more effective transformation of the content for teaching regardless the level (Karal and Alev, 2016).

In the context of the SCITT programme, some challenges that appeared from direct teaching experiences placed trainees’ creativity at risk. For example, scarce collaboration with school mentors and inconsistent support with planning may hinder trainee teachers' own ideas about teaching. As one trainee narrated, her own ideas about differentiation were rejected by the school mentor without providing a reason (see Chapter 7). Negative feedback affects trainee teachers' self-efficacy which is vital in the early years of their career (Tschannen-Moran and Hoy, 2001). To increase the quality of teaching experiences, the study findings support a balance between teaching experiences and explicit reflections on those experiences (Van Driel, Jong and Verloop, 2002; Jong, Van Driel and Verloop, 2005; Karal and Alev, 2016; Tolsdorf and Markic, 2017).

In line with the *Triadic Framework for Learning to Teach*, originally created in this study (Figure 15, Chapter 5), trainee teachers need a balance between making sense of their learning (knowing what and understanding why) and doing (knowing how), building continually on previous experiences till they develop proficiency and adaptive expertise. An effective learning context is crucial for maintaining this balance. An effective learning context should involve trainee teachers in social interactions, in school learning communities, and ensure that they are effectively supported and scaffolded. Reflection is an important aspect of learning from experiences. Dewey (1933) highlights the importance of a balance between experience and reflection arguing that 'an emphasis on experience without meaning making, nothing takes root in the mind' (in Schmidt, 2010 p. 142).

Towards a more collaborative approach to learning to teach

Trainee teachers' opportunities for collaboration and discussions is another relevant finding for science teacher training programmes. A significant number of studies included in the review provided evidence for the effectiveness of this feature. Eighteen studies approached their intervention from a collaborative approach (see Chapter 5 and 8). The studies showed that teachers develop the components for teaching when they have opportunities to work in collaboration with both peers and educators and to repeat what they learn. In the context of the SCITT programme in this study, opportunities for collaboration with peers and school mentors were perceived to be valuable by trainees. Trainee teachers made frequent references to their perceived need to 'see how others apply in practice the same topic' or 'how other people are getting on'. Therefore, designing activities that give trainee teachers more access to collaborative learning would be more beneficial.

Ensuring equal access to quality training

Perhaps, a standout finding of this study is the unequal and inconsistent support and feedback trainee teachers perceived throughout their training. The support and feedback were not always consistent and adequate (see Chapter 7). Feedback on practice is crucial for making progress. Often, trainee teachers are not aware of their own limitations and alternatives on practice, as revealed by the findings of the Case-Study. It is important for trainee teachers to acknowledge their limitations if they are to improve practice. As one trainee teacher remembered he had not made any progress because he had not been told what and how to improve. Therefore, feedback before and after teaching is vital in learning to teach.

What is equally important, according to the interviews with trainee teachers, is that the support and feedback from school mentors is one of the greatest sources for developing self-efficacy. Given that teachers with strong self-efficacy are more likely to develop resilience in face of challenges, trainee teachers need access to quality mentoring support during their training programmes. Only a few previous studies focused on intensive mentoring support during teacher education programmes (Aydin et al., 2013; Aydin et al., 2015; Barnett and Friedrichsen, 2015). These studies promote a cognitive apprenticeship approach with a focus on procedural knowledge (knowing how to teach) in which trainee teachers are encouraged to come with ideas and to be innovative. Modelling activities and consistent guidance were found the most effective in learning procedural knowledge.

Clearly, the above findings indicate that trainees more effectively learn how to teach if they are offered opportunities to develop the components and subcomponents of *Learning to Teach Framework* through a multiple approach. A multiple approach to learning how to teach allows the components and subcomponents of the framework to develop simultaneously in relation to each other. This is important because any deficiency in one component affects the others. The findings have implications for practice, policy, and research, discussed next.

9.2.2 Implications for Practice, Policy, and Research

Implications for Practice

The findings of this study provide developed pedagogical tools (*Learning to Teach Framework and Triadic Framework for Learning to Teach*) and a set of evidence-based practices to help providers and educators in their efforts to prepare effective science teachers. The developed tools may help providers and educators to support trainee teachers in achieving the Teachers' Standards, the measures against teachers are assessed. In England, Teachers' Standards do not currently differentiate between experienced and inexperienced teachers. Scholars have found that Teachers' Standards for initial teachers are difficult to achieve (Stuckey et al., 2013). Although, the Core Content Framework (2019) gives details about how each standard can be achieved, the details are in terms of general statements for all the subjects and age ranges. Therefore, 'it remains for individual providers to design curricula appropriate for the subject, phase and age range that the trainees will be teaching' (DfE, 2021b, p. 4). Providers and educators are advised to 'carefully craft the experiences and activities detailed in the ITT Core Content Framework into a coherent sequence that supports trainees to succeed in the classroom' (DfE, 2019, p. 4). The two frameworks developed in this study alongside the set of evidence-based practices may facilitate a better understanding of how Teachers' Standards apply to initial teachers. *Learning to Teach Framework* provides the components for teaching which teachers need to develop during their training programmes. The *Triadic Framework* alongside the set of evidence-based practices provide insight into how teachers can develop the components for teaching. By using these tools, educators more effectively can address the knowledge bases for teaching in relation to the other components which trainee teachers draw upon in their learning to teach. Educators can better predict trainee teachers' learning needs, and thus, better can address issues of individualised learning.

First, educators should aim to elicit teachers' orientations so that they can design appropriate training activities that are more likely to develop trainee teachers' student-centred orientations. The findings from the review study validated by the findings from the case-study give educators a set of evidence-based approaches to draw upon in designing activities that address trainee teachers' orientations both during coursework and teaching practice in school placements, face to face and online (see for example the lessons 2 and 5 in Chapter 8).

Acknowledging that trainee teachers develop critical skills by observing different ways of teaching and reflecting on their observations is important. Whilst it is ideal that trainee teachers can observe effective models of teaching, the findings of this study reveal that trainee teachers can also learn from critical reflections on less successful teaching (theirs and/or others'). The findings of this study provide educators with examples of strategies that work for critical reflections on teaching (see for example the lessons 2, 5, 8 and 9 in Chapter 8 with more details in Chapter 5).

Equally important, the developed tools assist educators in ensuring that trainee teachers experience a good balance between making sense of the knowledge for teaching, processing the knowledge, and enactment (applying the knowledge and skills). Educators can draw on the factors highlighted in the *Triadic Framework for Learning to Teach* (Chapter 5, Figure 15) to design subsequent opportunities for developing trainee teachers' components for teaching. Other tools and conceptual frameworks identified in the review study (e.g., CoRe) also can assist educators in developing trainee teachers' lifelong learning skills that depart them from the view of learning today and applying tomorrow (Mena, Hennissenm and Loughran, 2017).

The findings of this study indicate that a collaborative approach to learning to teach is more effective and it would benefit trainee teachers in the context of the SCITT programme. Certainly, well prepared school mentors are needed to adequately guide trainee teachers during their teaching practice in school placements. Though, school mentors may find it difficult to find proper resources and strategies for guiding trainees. The study provides useful suggestions for school mentors to engage trainee teachers in collaborative learning. The tools and suggestions for practice can also be transferred to the coursework of the programme (see Chapter 5 and, for example, the lessons 6, 8 and 9 in Chapter 8). A collaborative approach to learning is supported by a great number of review studies. This finding highlights the importance of collective discussions and reflections in developing trainee teachers' critical understandings of teaching. The findings from trainee' views revealed that opportunities for discussions and reflections with school mentors are rare. This unequal balance between theory and practice calls for policy makers' attention.

Implications for Policy

It is well documented in the literature that in the context of the ITT programmes in England, with the increased move towards school-led and school-based training, the balance between theory and practice has been much affected (see Chapter 2). The governments' rhetoric that trainee teachers learn best as apprentices in schools has led to a great emphasis on practical skills and less on developing theoretical understandings for teaching. This vision places a great pressure on educators who make efforts to cover the prescribed content (DfE, 2019) in a limited time (for example only two days of subject knowledge courses for each Key Stage content). The focus on covering the content within a limited time may explain the intensity of the programme that made trainee teachers in this study 'get confused' and feel 'overwhelmed' (as revealed in Chapter 7).

On the other hand, trainee teachers often perceived the support and feedback on practice as inconsistent and insufficient. This issue leads to the question of whether school mentors are adequately prepared themselves to effectively guide trainee teachers during their programme. Though, the pressure on educators to help trainee teachers in developing teaching skills should not be underestimated. In the context of the SCITT programme in this study, it appears evident that educators themselves are in a difficult position to maintain the balance between theory and practice without government support. Educators need more space and time for reflections with trainees, before and after teaching sessions. A firm response is needed from policy makers to remove the barriers that block trainee teachers' access to quality training. Policy makers should ensure that school mentors are more equipped with tools, space, and time for reflections, by setting a more consistent mentoring framework throughout the training programmes. This way, policy makers will ensure that trainee teachers have equal opportunities and access to effective mentoring support, promoting thus, social justice that recognises equal access to quality training.

The findings of this study find support in a recent review of the ITT market in England published by the government (DfE, 2021b) at the time of writing the findings of this thesis. The review, drawing on previous efforts to improve ITT (e.g., Carter Review, 2015 and the Core Content Framework, 2019), aimed to identify how ITT programmes can provide high quality evidence-based initial training. The review addresses aspects discussed in this study. For example, the review recognises the need for a consistent and targeted feedback for trainee teachers. The importance of the alignment between theory and practice specifically between what teachers learn during coursework and what they teach in placement schools was also highlighted in the review. An emphasis has been placed on intensive experiences for trainees so that they can develop understandings and confidence for teaching. The review recognises the importance of effective mentoring in ensuring high-quality training suggesting a better preparation of school mentors. Alongside several recommendations, the review set up a set of quality requirements for ITT providers to ensure high quality in the design of the training curriculum. Hopefully, the pedagogical tools developed in this study may be valuable in supporting teacher training providers in their response to the review. In the design of the curriculum for trainees, providers may consider the components for teaching and the factors within which the components develop from the two frameworks advanced by this study.

Implications for Research

The findings of this study have implications for research. For a long time, educators and scholars have been preoccupied with developing and measuring teachers' PCK knowledge. The current PCK models often create confusion both in the comprising components and measurement (Loughran, Mulhall and Berry, 2006). This study provides new insights into PCK conceptualisations. Research can draw on these new insights to further check the applicability and utility of the new developed *Learning to Teach Framework*, both in enhancing teachers' development and measuring their knowledge and understandings. Because the developed tools place a great emphasis on understanding and reasoning, the study goes beyond the procedural knowledge and challenges the notion of 'conceptual and procedural understanding' in learning to teach science (Star, 2000, p. 5). The focus on conceptual and procedural knowledge aligns better with the current vision of initial teacher training in which trainee teachers learn what and how to teach as apprentices observing masters in schools (Childs and Menter, 2013). This way of learning is widely criticised for being based on superficial and rote learning (Mc Donough, 2012). As reforms require teachers to develop critical thinking about teaching, the notion of procedural understanding appears to more usefully be aligned with learning about what to teach, how to teach and why (Star, 2000). By taking this perspective, research may bring more clarity to ways of capturing and measuring both teachers' knowledge and understandings.

Having highlighted the main findings of the thesis and their implications for practice, policy, and research, it is important to underline the contribution of this study to the body of knowledge.

9.3 Contribution to the Body of Knowledge

This study, aiming to enhance ITT programmes for science teachers, makes some contributions to the body of knowledge:

This study is unique (to my knowledge in science area) in the methodological approach that combined data from secondary and primary research to reveal a set of evidence-based practices with potential to inform and advance practice in ITT programmes.

The uniqueness of this study resides in a combination of the findings from a review study with those from trainee teachers' views of their own learning experiences within their training programme. This methodological approach provides a holistic picture of how trainee science teachers can more effectively be prepared during their training programmes.

Another uniqueness of the study is that the Systematic Review study addressed PCK approaches exclusively at secondary-level science which is different as complexity from primary level or other areas. The review study aiming to enhance secondary science teachers' PCK development provided evidence of effective approaches to preparing science teachers (see Chapter 5). The review study also identified what PCK components are more successful and why and where are the gaps that need further consideration. The Systematic Review study answered calls for identifying what works in other contexts in preparing science teachers so that educators can borrow and adapt approaches to strengthen the preparation of science teachers in their setting.

The Exploratory Case-Study (Chapter 6 and 7) contributes to the literature on teachers' views of their preparation. The Case-Study revealed several challenges that trainee teachers face during their training programme. Teachers' views are an important source of information in designing training activities in a way to overcome the challenges.

Through the Cross-Study Synthesis (Chapter 8), the study provides a set of evidence-based practices that can be used by educators to address the gaps in trainee teachers' knowledge, orientations, skills, understandings, and efficacy. The evidence-base practices show promising value in trainee teachers' development during their training programmes, though, the educators might need to make some adaptations to the strategies to overcome the limitations identified in this study.

The study makes an original contribution to the body of knowledge by developing and providing novel tools that can be used to facilitate trainee teachers' development. The *Learning to Teach Framework* and the *Triadic Framework for Learning to Teach,* alongside the principles of application in practice (the set of evidence-based practices) may have potential value for providers and educators in enhancing trainee teachers' development throughout their training programmes, and for research to enhance and capture trainee teachers' progress. The tools are originally created to better understand how trainee teachers develop as practitioners during their training programmes. This way, the study answers call for more focus on how trainee teachers 'accumulate knowledge and teaching skills from their educators as a main source of learning' (Burn, Mutton and Hagger, 2017, p.105). The *Triadic Framework for Learning to Teach* is a framework originally created based on *Learning to Teach Framework* components, Woolfolk-Hoy, Davis, and Anderman's (2013) four pillars for teaching, and Bandura's triadic causation model. The framework helps in understanding of how trainee teachers learn to teach within three factors that influence each other bidirectionally. Both the developed frameworks help educators and trainees to acknowledge more clearly what they need to know and do to be more effective.

Through the developed tools, the study contributes to the literature on PCK advancing a new perspective on PCK conceptualisation especially for teacher training programmes. A new perspective on PCK may expand the understanding of PCK, the conceptualisation of which has been widely debated and its usefulness often questioned (Abel, 2008; Kind, 2015). PCK components have been always unclear (Neumann, Kind and Harms, 2018) and often used for capturing and measuring teachers' knowledge rather than in supporting their development. The frameworks advanced in this study may answer call for more clarification of how the components develop, interact and 'play out in teaching' during the initial teacher training programmes (Kind, 2009; Neumann, Kind and Harms, 2018, p.10). The study gives a new insight into the components (*Learning to Teach Framework* components) which trainee teachers draw upon in learning to teach within the contextual learning factors that influence their learning (factors from the *Triadic Framework for Learning to Teach*) during their training programmes. These new insights in PCK conceptualisation have implications for educators enabling them to target learning opportunities to address trainee teachers' gaps in the *Learning to Teach Framework* components. Also, the insights have implications for research that can further check the tools for their applicability and effectiveness in preparing science teachers.

Lastly, the study makes recommendations for future research based on the identified gaps. Also, the insights from the findings of this study give direction to my future areas of research. The recommendations and insights are stated in the conclusion section in this chapter.

9.4 Strengths and Limitations of the Study. A Critical Reflection

The study has strengths as well as limitations. Undoubtedly, carrying out a review synthesis to inform a primary study is challenging. Synthesising multiple studies generates a large amount of data which is challenging and time consuming. The review study consisted of thirty-seven articles yielded through an extensive electronic and manual searching. The review aimed to identify effective PCK strategies in preparing science teachers. To identify effective PCK strategies, codes were assigned to statements in the findings and discussion sections of each individual study. This approach to analysis generated a long list of codes. However, previous PCK research offered an initial analytical framework that facilitated both the analysis and synthesis. The framework included priori codes that covered most of the evidence that answered the first research sub-question of the review study.

Combining a secondary synthesis of multiple studies with a primary study on trainee teachers' views of their experiences within a training programme is a strength of this study. This methodological approach has some advantages. One advantage is that the findings portray a complete picture of the issue under investigation (identified what works best and why in preparing science teachers in different contexts and what can be applied to fill the gaps in the local context). Through a synthesis of multiple studies with different designs, the review gave insight in the current science education programmes across the world. Moreover, the findings revealed through this methodological approach are more reliable (generalisable) than those from single studies or homogenous synthesis. The evidence is more generalisable because it is based on data gathered from multiple studies. The findings from multiple interventions combining different learning strategies (e.g., teaching experiences with discussions, reflections, collaboration, or modelling) are more likely to be applicable in supporting improvements in teachers' knowledge, skills, and self-efficacy than the findings from single interventions studies. Furthermore, matching the findings with those from trainee teachers' perceptions about their preparation allowed for a further validation of the effectiveness of the strategies.

Generalisation is a weakness of single studies. The present review is relatively broad because it includes studies from many countries within different contexts. Because of common challenges the countries face in science education programmes, the studies generated similar findings which enables some degree of transferability across different education programmes and countries based on similarity with the context.

Though, a gap of this review is that it is limited to intervention studies using PCK approaches and only conducted in teacher education programmes. Other studies with different focus and settings were left out because of time and space limits. Therefore, the evidence of effective strategies in preparing science teachers was drawn only from the above category. Other intervention or non-intervention studies using PCK or non PCK approaches might have yielded other useful strategies for developing trainee science teachers' components for teaching. For example, McNeill and Knight (2013) found a professional development workshop series, grounded in authentic practice, to be successful in teachers' development of PCK for scientific argumentation. Jolliffe and Snaith (2017) gave useful insight into collaborative learning in initial teacher education. Colclough, Lock and Soares (2011) explored trainee teachers' subject knowledge and attitudes towards abstract topics in Physics in initial teacher training. Schumacher and Reiners (2013) focused on authentic learning environments to challenge teachers' pre-conceptions about chemistry practice. More recently, Kind (2017) developed and used pedagogical content knowledge (PCK) rubrics, potentially applicable to a range of science topics and levels of teacher experience, especially as support for out-of-field teachers. Clearly, different approaches to preparing science teachers may be a useful area for future research that can make an update of this review.

The inclusion criteria may further add to the limitations of the review study. Due to an inclusive search, some relevant literature might have been missed. The search of the literature was limited by language and peer review. There was not a search of the grey literature. However, the findings from the included studies appeared to generate similar findings which suggests that other intervention studies on PCK may not have significantly changed the results.

Another limitation points to the quality of the studies in the review. The measurements used by the primary research are open to debate since PCK is complex and difficult to measure (Kind, 2009; Park and Kyung Suh, 2015). Although the authors of the primary studies used validation tools to ensure the rigor of their results (see Chapter 5) there is a lack of consensus on PCK measurements (Smith and Banilower, 2015). These inconsistences in measurements may have generated differences in results across studies and inaccurate representations of teachers' PCK development.

Furthermore, data was collected from different types of education programmes. The intervention activities carried out in a postgraduate education programme compared with an undergraduate programme may have generated more positive results due to more accumulated knowledge and practice by the research participants. However, the purpose of the review was not to evaluate the quality of the intervention studies. Merely, the aim was to answer the research questions that sought to gather perceived effective features of a training programme that can help in advancing practice.

The voice in the review is only of the researcher's, authors', and the studies' participants. The voice of the stakeholders is missing from this review. The review was undertaken as part of a doctoral thesis (Boland, Cherry and Dickson, 2017). Andrew (2005) states that research students are not necessarily expected to undertake a systematic review as it requires more than one researcher working independently from each other. Usually, a systematic review is a team project involving expertise in systematic review methods (Petticrew and Roberts, 2005). Also, it is recommended to be done in consultation with powerful stakeholders' views which is, according to Petticrew and Roberts (2005), 'time-consuming exercise' (p.31). The author of this paper was a beginner to the research area and was limited to a manageable volume of work within a time and word limit. However, given that the research was undertaken under academic supervision with team members with expertise in conducting systematic reviews, the systematic review has yet many strengths making the review trustworthy and credible.

This study also has limitations posed by the Case-Study. Data from trainee teachers' views is drawn from a small, selected sample of trainees enrolled in one single SCITT centre and from one single route into teaching. Therefore, generalisation to other centres and routes into teaching is not the strength of this study. Yet, given the common challenges trainee teachers face during their training programme coupled with a rich description and deep analysis specific to a case study approach, it is hoped that a degree of transferability across centres and routes into teaching can be possible based on vicarious similarity with the context.

Some challenges encountered in conducting the Case-Study further add to limitations. The questionnaire given at the beginning of the training programme was sought to be followed by another questionnaire at the end of the programme for comparison. This plan was postponed because of the introduction of the national lockdown which led to school closure and online training. A comparison of trainees' perceptions between the beginning and end of year may have brought more consistence to data as well as a comparison between different cohorts from different centres or routes into teaching. Furthermore, the questionnaire generated a small amount of quantitative data that is based exclusively on trainee teachers' self-perceptions. The observations were limited to only two days of subject knowledge courses whilst following trainee teachers in their school placements could have contributed to a more in-depth understanding of their learning experiences. However, the study used triangulation that helped in validating the research findings (see Chapter 6).

9.5 Conclusion

The aim of this study was to identify how ITT programmes can better prepare trainee teachers for teaching science in secondary schools. The aim was achieved through a methodological approach that brought together findings from a Systematic Review of interventions studies with findings from a Case-Study. The findings from the thirty-seven studies included in the review revealed considerable evidence for the effectiveness of PCK approaches to preparing science teachers. From a thematic analysis resulted that the interventions that promote an explicit and multiple approach to developing trainees' PCK are more effective. A Case-Study design was used to generate rich description of trainee teachers' learning experiences in a SCITT programme. A cross study synthesis revealed matches and mismatches between the findings from the intervention studies and those from trainee teachers' views. The effective learning opportunities as perceived by trainee teachers matched those from the review studies. Mismatches were the features that are the lessons learned from the review study which complemented and /or corroborated those from the Case-Study to provide a set of nine evidence-based practices with value in informing and advancing practice.

By conducting this study two gaps in the literature are covered. First, the Systematic Review gives insight into effective teaching approaches to preparing science teachers in different contexts. Second, the Case-Study elicits trainee teachers' voice on their own preparation. Collectively, the findings of this study contribute to advancing practice in ITT programmes by providing a comprehensive model for preparing science teachers and reveal several gaps that can guide further lines of research, which are addressed next.

9.5.1 Recommendations for Future Research

This study notices that previous research conducting training activities during coursework of the programme reported limitations due to teachers' lack of teaching experiences. On the other hand, previous research conducting training activities during teaching practice in school placements, reported limitations due to teachers' deficiencies in knowledge. Research that covered both coursework and teaching practice in schools aimed to ensure a balance between teaching experiences and reflection on experiences. In the context of this study, only a few studies covered both coursework and teaching practice in schools (n=5). It is, thus, important for future research to investigate coherence and synchronisation issues between coursework and teaching practice in school placements and the impact on teachers' development.

The voice of trainee teachers in the design of the training activities is crucial (McIntyre, Youens and Stevenson, 2019). McIntyre, Youens and Stevenson (2019) claims that trainee teachers' views and learning experiences are a potential source of information for the design of the activities within a training programme. Activities built on trainee teachers' views and prior knowledge are found to be more effective. Aligning the learning strategies to trainee teachers' own learning needs and preferences more likely increase their motivation and the activities are perceived more relevant to their practice, as the findings of this study indicated. For example, in the studies carried out by Smit (2017; 2018) on peer coaching, teachers lacked critical skills in their role of coach because they were not prepared in advance for this learning approach. Therefore, teachers could not maintain a constructive dialogue with their peer. Apart from this, the approach may not work for some of trainee teachers who do not like role playing as revealed by the Case-Study. In the context of this study, teachers' beliefs and prior knowledge were not always considered in the design of the intervention and training activities. An interesting area for future research would be to combine a review of intervention studies with a review of exploratory studies (for example, a review on trainee teachers' views across programmes). Future research can aim to use trainees' views to inform the design of intervention activities for trainee teachers. Future research may build on trainee teachers' learning needs and preferences to maximise the impact on and relevance to their practice.

As trainee teachers enter the programme with limited knowledge and prior beliefs about teaching and learning, more consistent support and feedback on practice is crucial in building the components for teaching science (*Learning to Teach Framework* components). In the context of this study, only three studies had a greater focus on intensive mentoring support throughout their interventions. The support and feedback trainee teachers received was frequently rated as being inadequate and insufficient. Future research should explore in more depth issues with equal access to quality models and to consistent mentoring support, by following trainees in their school placements.

The review study showed that PCK development is easier in some components and topics than in others. The less successful development, reported in the review study, was related to orientations and assessment. These components may be worth further exploration by future research. Also, topics like nature of science and science inquiry were found to be more difficult to teach (Smit, et al., 2017; Smit, Rietz and Kreis, 2018). More studies that place a greater emphasis on these challenging topics would be worthwhile.

The review study is limited to PCK approaches. As mentioned earlier in this chapter, other non PCK approaches may bring additional insight into the preparation of science teachers. Future research can make an update of this review to extend the set of evidence base practices by including studies with different approaches to preparing science teachers.

The case study is limited to a small sample from a single SCITT centre. The variability and complexity of the routes into teaching cause issues with clarity which creates confusion among educators and trainee teachers (Carter, 2015). Further research is needed to answer calls for clarity by examining what happens inside of different programmes across different routes into teaching. Such examination might generate additional valuable insights into how to prepare science teachers. The insights also might benefit trainee teachers in their decision on which route to take into teaching according to their own learning needs and preferences. For example, one of the participants in the case study wished to be able to make a comparison between different programmes (for example, PGCE and SCITT) wondering if another route (based on more ‘theoretical learning’ than ‘school learning’) would have been more ‘enjoyable’.

In the last decades, science education has faced many changes (e.g., curriculum changes). In the light of changes, teachers are required to quickly adjust to new requirements and central guidelines. Recently, in the light of significant impact of Covid-19 pandemic on education, experienced and less experienced teachers have been required to rapidly adapt to remote teaching and respectively trainee teachers to remote learning. There is a scarcity of PCK intervention studies that use online activities to support teachers’ preparation. In the context of this study, only three studies (n=3) involved teachers in online learning. When guided, online learning was found to be effective (see Chapter 5). Further research to carry out interventions that combine face to face with online learning activities would be beneficial for trainee teachers’ development.

9.5.2 Insights from the Study

The insights offered by the findings of this study motivate me to expand this research to further check for the applicability and effectiveness of the two developed frameworks (Learning to Teach Framework and Triadic Framework for Learning to Teach) in preparing science teachers through an intervention study. An intervention study (drawing on the theoretical frameworks developed in this study, the set of evidence-based practices and trainee teachers’ views on effective learning opportunities) would give me further opportunities to contribute to trainee science teachers’ development of their foundation base for teaching.

Another area of research inspired by this study, that I would like to undertake, relates to a comparative exploration between preparation programmes for science teachers and other related fields. As teaching profession is often compared with other professions like law and medicine, it would be interesting to discover how practitioners in other professions are differently or similarly prepared.

Due to time and other constraints on this study, a more in-depth exploration of trainee teachers' learning was difficult to undertake. Although the literature highlights the importance of personal factors (e.g., gender, science capital, identity, background) in learning to teach (Decker and Rimm-Kaufman, 2008) these variables were displaced by a general perspective focused exclusively on trainees' perceptions of what was effective for their learning within their training programme. Here, I agree with Gartland (2012), that a general perspective, although useful, provides a 'daunting and constricting view of what is possible within the constraints' that influence trainee teachers' practice (p. 260). Therefore, it would be interesting to explore in depth how these personal characteristics may impact on teachers' development. Ultimately, initial teachers must acknowledge that teaching is an ongoing quest that requires adaptation, flexibility, and creativity.

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Appendices

Appendix A. Scoping Review

Abstract

This paper presents a systematic scoping review of the literature focusing on improving science teachers' Pedagogical Content Knowledge (PCK) and efficacy beliefs. A scoping approach with five-stage methodological framework guided by the Arksey and O'Malley (2005) was employed. Thirty-two relevant studies were identified by searching three databases (Springer direct; Francis and Taylor online; Education database). Studies (published 2008–2018) were analysed to establish the characteristics of existing evidence and to identify themes. The results were organized in tables and took an analytical-descriptive form. The review literature indicated that the most effective strategies used to improve science teachers' practice and outcomes were reflection, experience and collaboration.

Key words: Science teachers and PCK; Science teachers and efficacy beliefs; Science teachers and education courses; Science teachers and methods courses

Introduction

Teachers' s professional knowledge also called Pedagogical Content Knowledge (PCK) has been a subject of debate for a long time (Shulman, 1986). The recent reforms in science education require teachers to have a large repertoire of knowledge – Pedagogical Content Knowledge (PCK). PCK was identified by Shulman (1986) as a unique feature for teachers. It includes a combination of knowledge from various domains and pedagogy – the way in which science teachers help students to understand the content using analogies, reasoning, argumentation, representations, models (Shulman, 1986). Yet, an issue in science education is that science teachers are not always aware of the underpinning evidence of their practice (Kind, 2008). To develop awareness and PCK, teachers must be supported through high quality educational programmes. Such programmes should aim to help teachers to increase their awareness about effective ways of teaching by engaging them in challenging tasks.

The scoping study outlines the existing literature related to improving science teachers' PCK and efficacy beliefs particularly to the opportunities that teachers have for engaging in activities that enhance their practice and outcomes. Scoping reviews are a rigorous and transparent form of secondary research; they map out the evidence base on a certain topic area, outline the breath and type of literature on that topic and identify gaps (Boland&Cherry&Dickson, 2017).

Scoping review carried out in advance of a systematic review helps in refining the systematic review question in the light of what is learnt from it. As scoping reviews are still a new methodology do not possess a universal definition (Boland &Cherry &Dickson, 2017), they are commonly used for 'reconnaissance' – to clarify working definitions and conceptual boundaries of a topic or field, outline what is already known and identify where there is sufficient evidence to conduct a full synthesis or where insufficient evidence exists and further primary research is necessary (Levac & Colquhoun &Brien,2010).

Advantages of a scoping review for the research questions addressed in this paper are:

1. it retrieves an appropriate quality of papers to cover the breadth and depth of the field of science education
2. it identifies theoretical approaches and or new research directions
3. it allows rapid mapping of the key concepts existing in the knowledge field
4. it provides a rigorous and transparent method for mapping areas of research
5. it facilitates the recognition of the importance of science teachers' knowledge and efficacy for students' learning.

The purpose of the scoping review is:

1. to provide an overview of relevant studies (published between 2008 and 2018)
2. through a process of thematic synthesis, to identify opportunities and challenges for science teachers to engage in activities that enhance their PCK and efficacy beliefs so that they can 'teach for understanding movement'.

Methodology

The first methodological framework for undertaking a scoping review was published by Arksey and O'Malley (2005). The scoping review follows this framework using rigorous and transparent methods of a systematic review to increase the reliability of the findings. (Arksey and O'Malley,2005). The main stages of the framework are:

Stage 1. Identifying the research question

Stage 2 Identifying relevant studies

Stage 3 Study selection

Stage 4 Charting the data

Stage 5 Collating, summarising and reporting the results.

Stage 1. Identifying the research question

In devising the research questions an examination of educational programmes aiming to increase teachers' knowledge and efficacy was considered.

The review questions are:

1. What are the opportunities for science teachers to engage in activities which enhance their PCK and efficacy in teaching science for understanding?

2. What activities does research suggest enhancing teachers' PCK and efficacy beliefs?

3.What are the challenges that impact on successful use of knowledge gain in practice (limitations)

Stage 2. Identifying relevant studies

At this stage was adopted eligibility criteria for relevant studies:

Eligibility criteria

Studies were included if they:

1. were published in English language and peer reviewed. This option was chosen because of the cost and time for translating material and because of a broad literature on PCK and efficacy.
2. were related to secondary science teachers as population included in the review. The rationale for this criterion was based on the evidence from research that students lose their motivation and interest in science once they make the transition from primary school to secondary school because of the way in which science is taught.
3. were related to educational programmes (courses, training, workshops, projects) aiming to improve science teachers' knowledge and efficacy. The rationale for this criterion was that teachers' knowledge and efficacy are considered the most reliable predictors of classroom practice.
4. were published between 2008 and 2017 to cover recent major policy changes in science education (curricula changes; practice-oriented teaching).

Electronic databases

Automated searches of selected digital libraries were used to identify relevant research**.** Studies were selected from three databases: Education Database; Taylor & Francis

Online and Springer Direct. Searches were facilitated using three sets of keywords covering 'PCK', 'efficacy beliefs', 'education courses, 'professional development', 'methods course'. The Boolean strings used in databases were 'Science teachers' AND 'Pedagogical content' 'Science teachers' AND knowledge'; 'Science teachers AND efficacy'; 'Science teachers AND professional development'. The searches generated a total of 1124 references.

Stage 3. Study selection

Screening titles, abstracts, and full text of the identified sources

Retrieved papers were included if they addressed any aspect concerning 'Science teacher' knowledge', PCK', 'efficacy' found in the title, abstract, keywords. A number 32 relevant studies were selected for the scoping review.

Stage 4. Charting the data

The information from selected studies were sorted according to key issues and themes following Arksey and O'Malley's framework. The charting approach takes the form of a descriptive-analytical method. The information from selected studies is recorded in tables under the following rubrics:

1. Author(s), year of publication, study location
2. Title of study
3. Study design
4. Theoretical approaches (Framework)
5. Type of activity/duration
6. Aim of the study
7. Findings
8. Factors of improvement
9. Limitations

These data form the basis for analysis: Data Table **1** – Science teachers' PCK; Data Table **2**- Science teachers' efficacy beliefs; Data table 3- Type of educational activity and components of PCK included in each study.

Stage 5. Collating, summarising, and reporting the results

Unlike a systematic review, the scoping study does not assess the quality of the included studies and consequently cannot determine whether the studies provide robust or generalisable findings (Arksey and O'Malley, 2005). A scoping review is used to clarify complex concepts, determine the value of a full systematic review, summarize, and disseminate research findings and identify gaps in the existing literature (Levac, Colquhoun, and Brien, 2010).

Results

Data extracted was organized in descriptive tables.

Overview of the field

A descriptive overview of the characteristics of existing research is presented in this section**.** A range of educational programmes were used with the aim to improve teachers' PCK and efficacy: science (education) courses, method courses, learning study, workshops, collaborative groups, PDP (professional development programmes), projects, self-study.
All the studies focused on improving science teachers' PCK and/or efficacy (see Table 1 and 2). The table 3 includes all the 8 main types of pedagogical activities identified in the selected studies.

Frameworks

All the studies were underpinned by a theoretical framework. Majority of studies aiming to improve science teachers' PCK (16 studies), were guided by Shulman' model of PCK (10 studies) and Magnusson's model of PCK (4 studies). A few studies were guided by other frameworks such as Variation theory (one study), Bybee's 2006, 5E cycle theory (one study), PCK model proposed by Loughran, Berry, and Mulhall (2012) (one study) and Piaget's genetic epistemology (one study). Two studies used a combination of two frameworks (Adadan & Oner,2014; Brown& Friedrichsen &Abell ,2012)**.** Most of the studies aiming to improve science teachers' efficacy beliefs, were guided by Bandura's self-efficacy theory (12 studies). Few of the studies used other frameworks: Enochs & Riggs, 1990 (1 study); Ball and Cohen's (1999) theory of professional development (1 study). One study (Lumpe, Czerniak, Haney & Beltyukova, 2012) used both Bandura's self-efficacy theory and motivation theory.

Methodology

A range of design research was identified. Most of the studies aiming to improve teachers' PCK used qualitative methods: case study (6 studies), phenomenology, action research, learning study. Only one study used quantitative method (Großsched &Harms & Kleickmann &Glowinski, 2015). Most of the studies aiming to improve efficacy beliefs used quantitative methods (5 studies) or mixed methods (7 studies). Two studies used only qualitative methods. The 32 studies were conducted in different countries: USA (11 studies); Turkey (7 studies); Sweden (3 studies); Germany (2 studies); Australia (1); New Zeeland 2 (studies); Canada (1 study); Jordan (1 study); Austria (1 study); Thailand (1 study).

Participants

The total number of participants in all selected studies was 2696 (842 participants in PCK studies and 1856 participants in Efficacy beliefs studies). Some studies focused on large number of participants – over 100 participants (5 studies) while others focused on a small sample up to 10 participants (9 studies). Majority of the participants were pre-service teachers (1977 pre-service teachers) and a smaller part, were in- service teachers (719 in-service teachers).

Themes

The main themes developed for this study were:

1. Components of PCK aimed for improvement
2. Factors affecting efficacy beliefs
3. Effective Instructional Strategies for both PCK and efficacy beliefs

1. Components of PCK

Table 3 presents the components of PCK included in each study. The most studies chose to include the components from Shulman and Magnusson's model of PCK while others (Williams, Eames, Hume & Lockley, 2012; Scheuch, Panhuber, Winter, Finan, Durchhalter & Kapelari, 2018; Hume&Berry, 2010; Adadan & Oner, 2014; Nilsson &Loughran, 2011) chose to develop teachers' knowledge by using different approaches like Content Representation (CoRe) or 5E cycle learning. According to Shulman the main sources of PCK development are teaching experience, methods courses (how to teach); content knowledge courses; teachers' past education; cooperation and reflection on practice. All studies focused on developing more than one component using one or more sources for PCK development; others focused on interaction between components (CoRe studies).

2.Factors affecting teachers' efficacy beliefs

In improving teachers' efficacy beliefs, Bandura (1997) suggested four sources: mastery experiences, vicarious experiences, social persuasion, and physiological–emotional states. He defined them as: mastery experiences, the most important, a cognitive process working on the previous successful experiences (if a teacher believes that he had success this will create an expectation of a future success; if a teacher believes that he/she was not successful, this will lower their level of efficacy for future actions); vicarious experiences - observation of others' practices; social persuasion – feedback/ encouraging/ motivating verbal messages; physiological and affective states- physical and mental readiness for action, vulnerability to fatigue, and susceptibility to a decision to continue or give up (Cinici,2016). All the selected studies related the efficacy beliefs to a better conceptual understanding and pedagogy, and aimed to improve both confidence and Pedagogical Content Knowledge (PCK) engaging teachers in practical activities for gaining mastery experience and vicarious experiences such as: laboratory work (Acikalin, 2013; Atasoy & Cakiroglu, 2018) microteaching experiences (Deehan, Danaia & McKinnon, 2017; d'Alessio,2018; Cinici, 2016) and/or curriculum development (Deehan, Danaia & McKinnon, 2017; Nare, 2015). Through mentoring and post teaching reflection, science teachers were provided with psychological support (Cinici, 2016; d'Alessio, 2018; Lotter& Smiley&Thompson & Dickenson,2016; Sadler, 2016). Verbal and social persuasion was provided through feedback, discussion-based and supportive teaching (Cinici, 2016; Nare, 2015) or peer comments (d'Alessio, 2018; Aydeniz &Ozdilek, 2015).

Findings

Findings from pre-test and post-test are included in tables 1 and 2.

Before-test, majority of studies reported: lack of experience (Hume&Berry,2010; Großschedl &Harms &Kleickmann& Glowinski, 2015; Acikalin, 2013; Frazier& Folta &Holmes &Lamb& Chen, 2012; Menon& Sadler, 2016), misconceptions (Karal & Alev,2016; Demirdöğen & Hanuscin & Kondakci & Köseoğlu,2015), limited content knowledge (Karal & Alev ,2016; Nilsson,2014; Adadan & Oner, 2014), inconsistences between beliefs and practice (Faikhamta & Clarke,2012), traditional approach to teaching (Bravo & Cofré,2016) lack of awareness (Adadan & Oner,2014 Nilsson &Loughran,2011) and low efficacy (Demirdöğen & Hanuscin & Kondakci & Köseoğlu, 2015; Acikalin, 2013).

After test, findings found improvements in: knowledge (Karal & Alev,2016; Scharfenberg & Bogner,2015; Bravo & Cofré,2016; Demirdöğen & Hanuscin & Kondakci & Köseoğlu,2015; Adadan & Oner,2014; Williams, Eames, Hume & Lockley,2012; Khourey-Bowers, Fenk, 2009; Nilsson & Vikström,2015; Brown& Friedrichsen&Abell,2012) efficacy (Hume&Berry,2010; Goodnough & Hung,2009; Lotter& Smiley&Thompson & Dickenson,2016; Aydeniz & Ozdilek, 2015; Acikalin, 2013; Atasoy & Cakiroglu, 2018;

Menon&Sadler, 2016; d'Alessio,2018; Lumpe , Czerniak , Haney & Beltyukova,2012; Fettahlıoğlu,2018; McKeown&Abrams&Slattum, & Kirk, 2016) and changes in orientations and beliefs (Faikhamta, 2012; Demirdöğen & Hanuscin & Kondakci & Köseoğlu,2015; Scharfenberg & Bogner,2015; Goodnough & Hung,2009).

Some studies reported inconsistences (Scharfenberg & Bogner,2015) and negative results in guided inquiry and orientations (Karal & Alev, 2016), understanding of scientific practices (Scheuch &Panhuber &Winter&Finan &Durchhalter & Kapelari, 2018), PCK (Großsched &Harms &Kleickmann &Glowinski, 2015) and outcome efficacy (Cinici, 2016; Lumpe , Czerniak , Haney & Beltyukova, 2012) while others (Brown& Friedrichsen &Abell,2012; Großsched& Harms &Kleickmann &Glowinski, 2015; Demirdöğen1 & Hanuscin & Kondakci & Köseoğlu,2015; Cinici,2016) reported a mixture of results.

3.Effective instructional strategies

Effective strategies which contribute to science teachers' improvements are presented in tables 1 and 2. As shown, a range of educational strategies were used to increase teachers' knowledge and confidence in vary ways of teaching science (teaching through modelling, through argumentation, through inquiry, reasoning, about NOS, dealing with misconceptions). All the studies used more than one strategy. The most used strategies were reflection, collaboration and authentic experiences.

Many studies (Nilsson,2014; Faikhamta & Clarke,2012; Scharfenberg & Bogner,2015; Bravo & Cofré, 2016; Demirdöğen & Hanuscin & Kondakci & Köseoğlu, 2015; Faikhamta,2012; Großschedl &Harms &Kleickmann& Glowinski, 2015; Nilsson & Vikström,2015; Nilsson &Loughran, 2011; Nare, 2015; Aydeniz & Ozdilek, 2015; Christine Lotter, Whitney Smiley, Stephen Thompson & Tammiee Dickenson,2016) stressed the importance of reflection on practice as a mean to enhance awareness, knowledge and confidence. Other authors (Karal & Alev, 2016; Adadan & Oner, 2014; Nare, 2015; Deehan, Danaia & McKinnon,2017; d'Alessio,2018; Cinici, 2016; Lotter, Smiley, Thompson & Dickenson,2016) found that, involving teachers in authentic teaching experiences will diversify their instructional methods like representations, argumentation and reasoning if there is a supportive environment.

Collaboration was found to be an important factor in building a supportive environment to increase teachers' confidence in their teaching; Interaction with peers offers opportunities for teachers to share and learn from each other understanding more perspectives and theoretical orientations (Nilsson & Vikström,2015; Bravo & Cofré,2016; Faikhamta &

Clarke,2012; Acikalin, 2013; James Deehan, Lena Danaia & David H. McKinnon, 2017; Atasoy & Cakiroglu, 2018; Cinici, 2016; Bravo & Cofré,2016).

Limitations/challenges

Limitations of each study and factors that might contribute to a better consistency between teachers' knowledge and students' outcomes are presented in tables 1 &2.

Many articles discussed their limitations and the need for a follow up to assess for retention through a longitudinal study (Adadan & Oner,2010; Lotter& Smiley&Thompson & Tammiee& Dickenson,2016; Deehan& Danaia & McKinnon,2017; Menon&Sadler, 2016; d'Alessio, 2018; Aydeniz & Ozdilek, 2015).

Others (Cinici, 2016; Faikhamta, 2012; Großsched&Harms &Kleickmann &Glowinski, 2015; Nare, 2015) recognised the lack of opportunities for teachers to enhance their practice.

Among factors which make implementation of strategies difficult were mentioned: orientations resistant to change (Brown & Friedrichsen &Abell, 2012) lack of experts (Großschedl &Harms &Kleickmann &Glowinski, 2015) lack of collaboration (Faikhamta & Clarke, 2012) lack of programmes that model effective practice (Lotter& Smiley&Thompson & Dickenson,2016) educational policy (Nare, 2015).

The challenges science teachers experienced, reported in the studies, were related to implementing argumentation lessons (Aydeniz & Ozdilek, 2015), negative prior experiences which require ongoing encouragement to build positive perceptions of themselves as science teachers (Menon&Sadler, 2016; Nare, 2015), limited content knowledge and low confidence (Menon&Sadler, 2016).

Discussion

Despite a significant number of positive results there are still inconsistences and negative outcomes. That means a broader perspective on teachers' development would be more beneficial in designing a programme. According to Bandura 1977, behaviour is influenced by beliefs (cognition) and support provided by other significant environmental factors. Among these, teachers' beliefs or dispositions, culture, context, background, gender or ethnicity are important variables which impact on science teachers' PCK and efficacy beliefs development.

Teachers' personal beliefs are considered by some (Pintrich,1990) the most important factor in teacher training. In the selected studies, rarely such variables were considered. The most common variables included in the selected studies were related to prior experience, gender and context. The culture, power relationships, dispositions, background or ethnicity were not addressed.

Only one study Faikhamta & Clarke (2012) mentioned the need for incorporating a cultural dimension. Understanding the dynamics of race, ethnicity, and culture is essential for teachers to develop the repertoire of tools necessary for teaching diverse student populations with a variety of social backgrounds (Lederman, 2001 in Hudley & Mallinson, 2016).

The programmes to be effective must adopt a multicultural dimension and be designed in a way to be relevant and applicable in practice (classroom). There is not much evidence that teachers applied in the classroom what they learned. Most of the studies lacked a follow-up and some studies (Demirdöğen1 & Hanuscin & Kondakci & Köseoğlu, 2015; Faikhamta, 2012; Goodnough & Hung, 2009; Deehan, Danaia & McKinnon, 2017) reported that teachers' gains were not translated in practice.

Without enough support, a strategy might not be effective for teachers without or limited experience. Much support from more knowledgeable people (experts/specialists) would be more effective (Großsched&Harms& Kleickmann &Glowinski, 2015; Williams& Eames& Hume & Lockley, 2012). The strategies alone without continuous support cannot lead to meaningful changes in practice (Cinici,2016)**.** Only one study (Goodnough & Hung, 2009) stressed the importance of scaffolding strategies as a tool for enhancing teachers practice and confidence.

Most of the studies focused on pre-service teachers. The results showed that teachers had traditional orientations based on their own past educational experiences. The creation of opportunities for teachers to explore and actively experiment new ways of thinking and teaching will help them to change their beliefs and build more confidence in addressing complex issues, both individually and collaboratively (Karal & Alev, 2016; Hume&Berry, 2010).

The number of studies focused on in-service teachers is not significant (10 studies) and most of them used a small number of participants. More opportunities for in-service teachers to enhance their practice must be also created if it is to increase the students' outcomes in the classroom. Experience alone is not enough; to become experts, teachers need on-going and appropriate process of learning (Virkkula & Nissilä, 2014). Expertise in seen as the ability to solve problems and adapt the gained knowledge in new situations since education, policies and life work are continually changing (Virkkula & Nissilä, 2014). Collaboration between teachers, between teachers and other stakeholders (specialists, experts, parents) opens opportunities to improve science education (Virkkula & Nissilä, 2014). A form of professional support, for in-service teachers, which has the potential to increase collaboration by sharing the tacit knowledge and expertise, would be Wenger' Professional Learning Communities - an on-going, instruction-focused teacher learning (Cuddapah & Clayton, 2011).

Another gap identified in the literature was about the theoretical framework that underpinned the research. Most of the studies were guided by a social perspective neglecting other dimensions. Only one study (Khourey-Bowers, Fenk, 2009) looked at teachers' capability of developing scientific models through Piaget's psychological lens. Another study (Lumpe, Czerniak, Haney & Beltyukova, 2012) used motivation theory to understand the relationship between teachers' participation in professional development and student achievement.

A diversification of theoretical approaches will enable an even more understanding of teachers' practices and helps in developing more effective programmes. For example, Piaget and Dewey psychological constructs which help in building a better understanding of student's learning (students' readiness) while other theories (socio-cultural) like Bruner's and Vigotsky's may offer useful insight in scaffolding instructional strategies. Also, Bourdieu's theory of cultural capital and habitus may add more understanding for teachers' behaviour and practices.

Conclusion

This scoping review synthesises the existing literature on developing science teachers' PCK and efficacy beliefs. In recent decade there has been a great interest in teachers' knowledge and efficacy. Most studies focused only on one category (PCK or Efficacy beliefs) while others looked at both (see tables 1 and 2). Across the selected studies, a range of programmes and strategies were used to improve teachers' PCK and efficacy beliefs. This review categorizes these programmes and strategies to make possible a meaningful comparison between studies. Also, the scoping review highlights effective strategies used by researchers to improve science teachers' PCK and efficacy beliefs. Although significant positive results were reported, there is no evidence of the knowledge gain in practice. It is important that the impact of strategies used to increase teachers' knowledge and efficacy to be further investigated given the lack of follow up and assessment for students' outcomes.

The gaps identified in research relate to the lack of follow-up studies to demonstrate that science teachers retain what they learned and apply that knowledge in the classroom; the lack of a well effective standardized tools to assess teachers and programmes and narrow theoretical perspective. Given the heterogeneous nature of the literature and the complexity of PCK and efficacy beliefs, there is a need for thinking more broadly to methods that overcome barriers between what and how teachers learn and what and how they apply that learning in the classroom. Consequently, there is a need for a more detailed perspective to give more and deeper insight in science teachers' construction of Pedagogical Content Knowledge and Efficacy beliefs. A rigorous and transparent systematic review has the potential to increase certainty and understanding in these complex issues.

Scoping Review. Developing science teachers' knowledge and efficacy to foster classroom practice and outcomes

Plan of action – protocol

Type of evidence	Deciding on the type of evidence which must be included: Published and un-published literature for reducing publication bias
Bibliographic databases	Identifying searching databases – electronic and manual such as: Education Database; Biology Database; Library Science Database; Pro-Quest Research Library: SAGE; Science Database; Science direct; Taylor and Francis Online; Web of Science.
Refining key search terms	Deciding on the key words and using Boolean operators (AND, OR and NOT) to identify the relevant studies. Key words so far: 'Science teachers AND PCK';' Science teachers AND efficacy beliefs'; 'Science teachers AND methods courses.
Screening studies against the inclusion and exclusion criteria	Stage 1: screening titles and abstracts- selecting eligible studies Stage2: screening and selecting full-text papers- deciding whether or not a study needs to be included based on inclusion and exclusion criteria
Paper screening and selection tool	Screen potentially relevant full text papers and selecting those relevant to the review question

Reporting the results	'Methods' section: • Description of how inclusion and exclusion criteria are applied • Studies assessed according to the inclusion criteria: selection of studies • Studies excluded are listed in an appendix with reasons for their exclusion. 'Results' section: A diagram, to include the following will be developed • Number of studies identified through electronic searching • Number of studies left after removing duplicates • Screening titles and abstracts and excluding the nonrelevant ones • Full-text studies assessed for inclusion • List of excluded studies with reason • Studies included
Extracting and reporting data	1. Identifying data for extraction: characteristics of individual studies; themes; categories. 2. Data extraction tables and completing data tables
Quality assessment	Identifying elements of quality assessment Developing a checklist for assessing each study- questions related their measure instruments, research design, validity, reliability, generalizability…
Presenting and interpreting the results of individual studies	At this stage it is considered if it is justified to include a meta-analysis
Analysis and Synthesis	Reporting the results: patterns (similarities and differences between studies)

Discussion and Conclusions	Critical interpretation of the results • Main findings • Strengths and limitations • Implications • Conclusions

Appendix B1. Data Extraction Table. Characteristics of the studies

Author Date of publication Country	**Research design**	**Setting Duration Participants**	**Aim**	**PCK components targeted**	**Topic**	**Methods of data collection**
Adadan and Oner 2014 Turkey	Mixed Multiple case study	Methods course One semester 2	To identify and describe the progression of preservice chemistry teachers' PCK representations on the topic	Orientations Knowledge of curriculum Knowledge of learners Knowledge of instructional strategies Knowledge of assessment	Behaviour of gases	CoRes Interviews
Aydin, et al., 2013 Turkey	Qualitative Action research Case study	Practicum course 14 weeks 3	To investigate the development of preservice teachers' knowledge base for science teaching and to identify which aspects of the practicum course contributed to preservice teachers' development	Orientations Knowledge of curriculum Knowledge of learners Knowledge of instructional strategies Knowledge of assessment	Rate of reaction	CoRe, semi-structured interviews reflection papers
Aydin, et al., 2015 Turkey	Qualitative Case study	Practicum course 14 weeks 3	To examine how a CoRe-based mentoring-enriched practicum supported the developing interaction of PCK components in preservice teachers	Orientations Knowledge of curriculum Knowledge of learners Knowledge of instructional strategies Knowledge of assessment	Rate of reaction	Secondary analysis of data from previous study

Aydeniz and Kirbulut 2014 Turkey	Qualitative Case study	Teacher-education programme 60-hour course 30	To design an instrument as teaching tool to enhance pre-service science teachers' topic specific PCK	curriculum, instruction assessment	Electrochemistry (Galvanic cells)	STSPCK instrument Audio taped conversations
Barnett and Friedrichsen 2015 USA	Qualitative Case study	Practicum 9.5 weeks 1	to describe the strategies used by a secondary biology mentor teacher to support the development of a PST's PCK	Orientations Knowledge of curriculum Knowledge of learners Knowledge of instructional strategies Knowledge of assessment	DNA/Protein Synthesis and Evolution	audio recordings, observations, interviews
Bektas, et al., 2013	Qualitative Case study	practice teaching course 14 weeks 7	To Investigate pre-service chemistry teachers' pedagogical content knowledge of the nature of science (NOS) in the content of the particle nature of matter	Orientations knowledge of learners, Instructional strategies Knowledge of assessment	Particle nature of matter	Open-ended questions, interviews, observations, lesson plans, and reflection papers
Brown, Friedrichsen and Abell, 2013 SUA	Qualitative multiple case study	Teacher education program One year 4	To investigate prospective science teachers' knowledge development at the subject specific level	orientations, knowledge of learners, knowledge of instructional sequence	Genetics	semi-structured interviews, two interview-observation cycles, field notes, lesson plans, classroom documents
De Jong, Driel and Verloop 2005	Qualitative instructional design	Postgraduate teacher education	To promote preservice teachers' PCK of using particle models in teaching chemistry topics	Learning difficulties Instructional strategies Content knowledge	Particle models	written answers of to the

The Netherlands	(experimental course module)	One year 12	through a combination of institutional activities and authentic teaching experiences			questions and assignments, reflective lesson reports, audiotape recordings of discussions
Demirdögen and Uzuntiryaki-Kondakçi, 2016 Turkey	Qualitative Case study	teacher education program 2 semesters 30	To investigate how pre-service chemistry teachers' science teaching orientations change during a two-semester intervention	Orientations	NOS instruction	open-ended instrument, interviews, reflection papers, observations, documents, lesson plans
Demirdöğen, 2016 Turkey	Qualitative Case study	Science teacher education program One semester 8	To investigate the interaction between orientation and other PCK components	Orientations and PCK	topics selected not topic specific	Open-ended questions semi-structured interviews CoRe
Demirdöğen et al., 2016	Qualitative Case study	Teacher education program (course) two-semesters 30	To investigate the development and nature of preservice chemistry teachers' PCK for NOS	orientations, knowledge of learners, knowledge of instructional strategies, knowledge of assessment	NOS (not topic specific)	open-ended instruments, interviews, observations, lesson plans reflection papers
Donnelly and Hume 2015 New Zealand	Qualitative Case study	Teacher education course One year 7	To investigate how the introduction of a collaborative technology, a wiki, may enhance existing and new opportunities for pre-service teachers' (PTs) to	Orientations Knowledge of curriculum Knowledge of learners	Redox reactions	CoRes artefacts, a semi-structured focus group interview, reflective essays

			develop pedagogical content knowledge (PCK)	Knowledge of instructional strategies Knowledge of assessment		
Ekiz-Kiran, Boz and Oztay 2020 Turkey	Case study Action research	practicum One semester 4	To improve pedagogical content knowledge (PCK) of pre-service chemistry teachers using a school experience course enriched with PCK development tools	Orientations Knowledge of curriculum Knowledge of learners Knowledge of instructional strategies Knowledge of assessment	Chemical equilibrium	Semi-structured interviews, content representation (CoRe), field notes, reflection papers
Grospietsch, and Mayer 2018 Germany	Quantitative Comparison design	University course 12 weeks 57	To investigate to what extent a university course developed in accordance with a professional conceptual change model can reduce pre-service biology teachers' endorsement of neuromyths	Shulman PCK Professional conceptual change model	Neuroscience (Learning and the brain)	paper-and-pencil tests Questionnaires
Günther et al., 2019 Germany	Mixed Experimental control group design	training program three parts, with two of 90-min sessions 173	develop an elaborate understanding of models and modelling for scientific inquiry	Content knowledge (model competence) Knowledge of strategies and methods	Model competence	open-ended and semi-open-ended items and test cases
Hume and Berry 2011, New Zealand Australia	Qualitative Case study action research	Teacher education course 30 weeks 9	To build the foundations on which novice teachers can begin developing their pedagogical content knowledge (PCK).	Knowledge of curriculum Students' understandings Knowledge of instructional strategies	Atomic structure and bonding. Redox Reactions	reflective journals, audiotaped interviews student artefacts (CoRes) field notes

Hume and Berry 2013 New Zealand Australia	Qualitative Case study action research	Practicum One year 4	To explore how collaboration with school-based mentors (associate teachers) on teaching practice (practicum) might impact on this process and student teachers' development of their pedagogical content knowledge (PCK	Orientations Students' understandings Knowledge of curriculum Knowledge of assessment Knowledge of instructional strategies	Different chemistry topics	CoRes lesson plans Interviews focus group Reflective papers
Juhler, 2016 Norway	Case study Design experiment	Practicum One year 14	To study pre-service teachers' planning of a Physics lesson through the means of Lesson Study	Knowledge of Instructional Strategies Knowledge of Curriculum Pupils' Understandings Knowledge of Assessment	Different topics in Physics	two cycles of planning, teaching and reflecting recorded planning sessions, teaching plans, CoRes and PowerPoint presentations
Juhler, 2018 Norway	Case study Design experiment	Practicum One year 4	To describe and discuss an intervention in which Lesson Study was used in combination with Content Representation in student teachers' field practice.	Knowledge of assessment	Energy	recorded video material reflection stage pre- and post-focus group interviews
Jufri et al 2019 Indonesia	Quantitative Lesson-study -Action research	Teaching Biology course One semester 32	To analyse Lesson Study effects on development of prospective science teachers' scientific literacy and PCK indicators	Orientations Knowledge of content Knowledge of instructional strategies Knowledge of assessment	Chosen topic	scoring rubrics, observation sheets, mind maps

Karal and Alev 2016 Turkey	Qualitative Case study	Teacher training program 3 academic terms 6	To investigate the development of pre-service physics teachers' pedagogical content knowledge (PCK)	Orientations Knowledge of Content Knowledge of instructional strategies Knowledge of learners	Electricity and magnetism	PCK test with open-ended questions, classroom observations lesson plans informal interviews
Mavhunga and Rollnick 2013 South Africa	Case study Mixed methods	Teacher education Programme - methodology class 6 weeks 16	To improve the quality of PCK in chemistry pre- service teachers in a specified topic	Learner prior knowledge Curricular saliency What is difficult to understand Representations and analogies Conceptual teaching strategies	Chemical equilibrium.	written class activities audio recordings of class discussions developed CoRes written text of the discussions copies of student assignments
Mavhunga and Rollnick 2016 South Africa	Case study Mixed-methods-research	Teacher education Programme-methodology class 6 weeks 16	To investigate the relationship between TSPCK and underlying science teacher beliefs following an intervention targeting the improvement of TSPCK in the topic chemical equilibrium	Learner prior knowledge curricular saliency what is difficult to understand representations and analogies conceptual teaching strategies	Chemical equilibrium	TSPCK instrument, Teacher Belief Instrument (TBI) audio-recorded class discussions, written class activities Content Representation (CoRe) on chemical

						equilibrium assignment
Mavhunga, 2016 South Africa	Case study Mixed-methods-research	Chemistry methodology class 6 weeks 36	To develop the competence of preservice teachers to transform concepts in the topic of particulate nature of matter	learner prior knowledge curricular saliency what is difficult to understand representations and analogies conceptual teaching strategies	The particulate nature of matter/ chemical equilibrium as the topic of transfer	TSPCK tests CoRes class activities Vignette Recorded lessons
Mavhunga 2018 South Africa	Qualitative Case study	Chemistry methodology course 6 weeks 15	To improve the quality of PCK in core chemistry and physics topics, one of which is chemical equilibrium	Learner prior knowledge Curricular saliency What is difficult to understand Representations and analogies Conceptual teaching strategies	Chemical equilibrium	CoRes with expanded lesson plans, observation notes and responses to short class tutorials and activities
Mavhunga et al 2016 South Africa	Qualitative Case study	Physics methodology class 6-weeks 10	To investigate the transfer of the competence to transform content knowledge learned in electric circuits to a new topic in either chemistry or physics	Learner prior knowledge Curricular saliency What is difficult to understand Representations and analogies Conceptual teaching strategies	Electric circuits Other topics	CoRes Written papers

Milner-Bolotin et al., 2016 Canada	Quantitative Action research study	Physics methods course 13 weeks 8	To investigate how physics TCs' engagement with designing, answering, and commenting on conceptual multiple-choice physics questions via a Peer Wise platform influenced the development of their physics PCK	question's cognitive level, explanation's cognitive level, question targets students' difficulties, science accuracy distractors' quality, justification of the answer clarity of the question	Multiple-choice conceptual questions	Pre and post Peer Wise online collaborative tool
Rutt and Mumba, 2019 USA	Mixed	History of science course One semester online 11	To describe the effects of an online history of science course on preservice teachers' perceptions of and content and pedagogical knowledge for history of science–integrated science instruction.	Content knowledge, Instructional strategies – representations for HOS Curricular knowledge Integration of HOS	History of science	discussion forums, written reflections class assignments resources collection, the three HOS-integrated science activities a pot intervention survey
Scharfenber and Bogner 2016 Germany	Mixed method Quasi-experimental Treatment group /	Outreach lab module 3 days 92	To investigate the impact of a teacher education module including systematic student-tutor-teacher role changes in an outreach lab on individual PCK development	Orientations toward biology teaching Knowledge of students' difficulties knowledge of instructional strategies Assessment	Genetic Fingerprinting	Pre and post open questionnaire

	control group					
Scharfenberg and Bogner 2019 Germany	Mixed Quasi experimental	Outreach lab module 3 days 36	To investigate how preservice teachers might develop more adequate tutor–student interactions during students' experimentation	PCK interactions	Genetic Fingerprinting	Audiotaped tutor–student interactions
Schechter and Michalsky 2014 Columbia	Mixed Quasi-experimental	practicum 24 weekly practical workshops 124 students 36 mentors	To explore the construct of PCK in relation to LFP (Learning from problems) and LFS (Learning from successes)	Comprehension skills Designing skills Teaching skills Self-efficacy	Light energy Gravitational force Friction	Videotaped lessons STEBI-B instrument
Smit, Rietz and Kreis 2018 Germany and Switzerland	Quantitative Quasi-experimental	Teacher education Two years 121	To determine the effects of a pre-service teacher training module on content-focused peer coaching	Attitudes Knowledge of students Knowledge of instructional strategies	Accommodation and adaptation of the eye	Open-ended questions DAS Instrument, videotaped presentations, Survey
Smit, et al., 2017 Germany and Switzerland	Quantitative Quasi-experimental longitudinal	Teacher education One year 121	To investigate quantitatively the longitudinal relationship between pre-service teachers' knowledge and attitudes on scientific inquiry teaching	Attitudes Content knowledge Knowledge of students Knowledge of instructional strategies	Visual perception'	Open-ended questions, DAS Instrument, videotaped presentations
Tolsdorf and Markic 2017 Germany	Qualitative Cross-level study	University teacher training 108	development and modification of diagnostic competence in chemistry teacher trainees.	Diagnostic competence - (Knowledge of students and Knowledge of assessment)	General Chemistry	Questionnaire with open ended questions

Wheeldon 2017 UK	Qualitative Case study	Teacher education 2 hours session 92	To support teachers in rejecting the 'conservation of force' AC and replacing this with scientific causal arguments	Knowledge of content Alternative conceptions	Ionisation energy values	True/false diagnostic quiz audio recorded semi-structured interviews electronic questionnaire
Weitzel and Blank 2019 Germany and Switzerland	Mixed-method quasi-experimental pre-post design study	Teacher Education four workshops of 90 minutes 121	To examine the extent to which Content-Focused Peer Coaching supports pre-service biology teachers in planning lessons for teaching scientific methods	Subject matter Students' understandings Instructional strategies Assessment	Scientific methods for visual perception (adaptation, accommodation)	Videography and full transcripts of the dialogs and lesson plans
Van Driel, et al., 2002 The Netherlands	Qualitative	Education programme one semester 12	To investigate the development of PCK among 12 preservice chemistry teachers	Knowledge of subject matter Knowledge of learning difficulties Knowledge of instructional strategies	Chosen topic	written questionnaire videotaped sessions interviews

Appendix B2. Extraction Data Table. Characteristics of the Studies

AUTHOR	**Approaches**	**Instructional features**	**Findings**	**Limitations/ no evidence of/**
Adadan, E. & Oner, D. 2014	CoRes approach	Previous courses, challenging students' conceptions, reading papers about students' conceptions of the topic, discussions with peers while they were creating the CoRe documents. First-hand experiences of different methods of instruction, the types of inquiry (POE, guided inquiry, and open-ended inquiry), argumentation, and the use of multiple representations Critical reflection on experiences and sharing ideas with the class	**Initial** - limited repertoire of representations for all five components of PCK, lack of awareness **After** - increased number of representations, but the extent of growth across the participants was different **Reasons why** - differences in the amount of knowledge, prior experiences, lack of experience in teaching **Other gains: Awareness** of students' conceptions **Progress in their thinking** about students' science ideas due to their formal instruction on student thinking **understanding** of students' possible non-scientific conceptions and learning difficulties.	the instructor did not allot time to discuss or critically explore the enacted curriculum
Brown, P., Friedrichsen, P. & Abell, S. 2013	**Learning cycle and 5E model of instruction**	reflection on views and practice	**Initially** – orientations based on their K-16 learning experiences and other background experiences; held views of teaching as telling **Over time** - became **more aware** of student learning difficulties, and therefore, developed more **elaborated knowledge** of the requirements of learning.	difficulty implementing the 5Es in their teaching they did not use the 5Es in their internship classrooms

			the interaction becomes more integrated	
Aydin, S., et al, 2015	CoRes /educative mentoring approach	microteaching, reflection, educative mentoring, teaching observations, PCK maps	**Initially** - the interplay among the PCK components was fragmented **After course** – integrated- participants were more able to utilize and relate all PCK components by the end of the practicum Become more aware of the interplay	Unable to enact a good interplay in teaching
Aydin, S., et al., 2013	PCK/CoRe/educative mentoring	CoRe design, microteaching, reflection on practice, reflection papers, mentoring opportunities, preintervention (collaboratively planning – with mentors before microteaching). Observing peers' microteaching, explicit PCK introduction	**Initially** - the big ideas and objectives were seldom parallel to each other, fragmented knowledge **Afte**r- participants focused on big ideas congruent with the objectives; more integrated knowledge	
Aydeniz, M. & Kirbulut, Z.D. 2014	Secondary teachers' scientific pedagogical content knowledge - STSPCK instrument	STSPCK group discussions	**Initially-** underdeveloped PCK related to galvanic cells **Post**- participants came to **a deeper understanding** of the elements of reform-based curriculum, instruction, and assessment; made some students **aware** of their misconceptions related to inquiry	no evidence of translating in practice their beliefs
Barnett, E. & Friedrichsen, P.J. 2015	Educative mentoring	Modelling, critical reflection of the strategies, discussions,	**Initially**- teacher -led approach **After** - a more student-centred science teaching orientation.	
Bektas, O., et al., 2013 Turkey	NOS	classroom discussions on the NOS aspects; writing reflection papers	**Initially** - some of the participants possessed inadequate views on the theories/laws and tentativeness aspects of NOS at the	

			beginning of the study; participants, who had a naive view on theories/laws and tentativeness aspects of NOS, could not give a proper example on the topic of PNM and could not explain how to teach the target aspects of NOS within the PNM content. **After** - most of the PCTs showed improvement in the target aspects of NOS; PCTs broadened their understanding of NOS throughout the course. **The reason** why they could not use the aspects of NOS in their instruction might be their insufficient knowledge of PNM (particular nature of matter)	
De Jong, H. Van Driel, Verloop, 2005	Through learning from teaching	textbook analyses and discussions	**Initially** – teachers' recollections were fragmented; difficulties in understanding the invisibility of particles, and difficulties in relating the properties of substances to the characteristics of the constituent particles. **After -** their PCK was extended and became more structured; all preservice teachers demonstrated a deeper understanding of their students' problems with the use of particle models. In addition, about half of the participants had become more aware of the possibilities and limitations of using particle models in specific teaching situations.	
Demirdö en, B. & Uzuntiryaki-	explicit-reflective NOS instruction	Reflection, use of PCK	**Initially** - various misconceptions about NOS **After**- almost the same orientations before and after NOS instruction	

Kondakç, E. 2016			Reason - adequate NOS understanding is not enough to stimulate a change in pre-service chemistry teachers' science teaching orientations All of the pre-service chemistry teachers had NOS related orientations (i.e., structure of science or science, technology, and decisions) after PCK for NOS instruction	
Demirdöğen, B. 2016	CoRes	meaningful and explicit experiences with PCK throughout the study, reflection, mentoring, Explicit and reflective thinking	one's purpose for science teaching determines the PCK component(s) with which it interacts their beliefs about NOS did not translate into their planning because they did not interact with their goals and purposes of science teaching.	
Demirdöğen, B., et al., 2016	PCK for NOS	reflection, explicit-reflective discussions of PCK for NOS components	**Initially** – had various misconceptions about NOS **After** - all participants developed PCK for NOS	
Donnelly & Anne Hume (2015) New Zealand	collaborative technology, a wiki,	experiential activities, collaborative CoRe design	The use of technology to support CoRes warrants further research. Wikis show some potential in the hosting of CoRes, but issues in simultaneous posting and lack of chat functionality may have also hindered the PTs' ability to easily critique each other's work	
Grospietsch, F. & Mayer, J. 2018	Sustainable learning	Explicit and implicit reflection Conceptual change texts	**Initially -** constructivist beliefs about teaching and learning were strong at pre-test and did not increase from pre- to post-test	

			After - significant increase in students' scores in all three areas of professional knowledge; transmissive beliefs declined in the post-test;	
Günther et al 2019 Germany	learning cases/ case method	combination of practical elements and explicit reflection lesson plans	increasing development from pre- to post assessment, especially in the experimental group, the training program consolidated preservice biology teachers' diagnostic and teaching knowledge regarding model competence. Integrating the case method into a training program was such a successful approach because the preservice teachers were able to diagnose students' answers and to reflect on special teaching strategies in more detail, After the training the preservice biology teachers' model competence (CK) was able to be fostered successfully, we could identify the strongest development in the category of reflection on models	
Hume, A. & Berry, A. 2011	CoRe	scaffolding strategies CoRe design collaborative approach	**Initially** - **After**- explanations and elaborations within the CoRes were more detailed; awareness of how the act of CoRe design was heightening awareness of the components of PCK; capabilities they developed that appeared to be transferable	
Hume, A. & Berry, A. 2013	CoRes	collaborative CoRe design feedback Professional dialogues Mentoring critical reflection	Research and thought they put into their draft CoRes informed their PCK, particularly in terms of curriculum components, and gave them sufficient background to engage meaningfully and confidently in discussions	

			with their associates, which led to the development of their PCK	
Juhler, M.V. 2016	LS in combination with CoRe.	the combination of LS and CoRes theoretical elements	**Initially** - pre-service teachers' main concern when planning a lesson was on Instructional strategies **After** - more uniform focus on all of the four main categories. During the intervention, as opposed to the current state of practice, the pre-service teachers focused much more on pupils' understanding of Physics and Assessment of understanding, while spending less time on Instructional Strategies	
Juhler, M.V. 2018	LS in combination with CoRe		**Initiall**y - The group did not manage to engage profoundly during the planning step/ they did not manage to keep a research lens throughout the Lesson Study/ lack of comprehension. **After** - focus much more on assessment than is usually the case	
Jufri et al 2019	Lesson study	lesson study cycles -three cycles that included the planning stage (plan), the implementation stage (do), and the reflection stage (see) working in groups, analyse-design-develop-evaluate activities role play, discussions, Facilitation and guidance, concept maps,	Results of this research also revealed that all PSTs acquired knowledge and insight related to indicators of scientific literacy and PCK The students' knowledge of science concepts and scientific competencies increased slightly from the first cycle of lesson study to the second and third cycles In this current research, activities focused on analysing basic competencies of science lesson, creating concept maps, thinking and designing learning experiences, and	

			formulating assessment based on the science concepts and knowledge of scientific competencies were believed to have contributed to the improvement of the PSTs' PCK.	
Karal, I.S. & Alev, N. 2016	PCK development of knowledge		**Initiall**y -PTs had a limited SMK in these topics Reasons why- difficulties of understanding the field concepts in general, and how these topics were taught/ misconceptions **After**- increased on average again as they had taught the topics and/or observed others' teaching throughout teaching experience at schools/ diversified their repertoire of knowledge of representation throughout their training period in which they had taken methodology courses/ The orientations held by the PTs, due to their past experiences, were found to be affected by the teacher training program in the direction of academic rigor	
Mavhunga, E. & Rollnick, M. 2013	Topic-Specific PCK	explicit discussions. TPCK, discussions of the content-specific components of Topic-Specific PCK starting with that of students' prior knowledge -through the five content specific components were carried out one component at a time/ reading task/ explicit explanations/CoRes/ tutorial sessions- interactive online platform	**Initially**- pre-service teachers found the topic difficult in terms of the components of curricular saliency, representations and conceptual teaching strategies **After-** preservice teachers experienced an improvement in the quality of PCK specifically in Chemical Equilibrium. Thus, they have improved their ability to reason about the topic	

Mavhunga, E. & Rollnick, M. 2016	TSPCK –	Discussions, CoRes,	**Initially** - At the beginning of the intervention pre-service teachers had predominately ‘limited’ and ‘basic’ TSPCK in chemical equilibrium and ‘traditional’ and ‘instructive’ teacher beliefs **Afte**r - the majority of pre-service teachers had a ‘developing’ TSPCK in chemical equilibrium, Their teacher science beliefs shifted, in a spread across the map of belief categories	
Mavhunga, E. 2016	TSPCK –	Discussions on each component, explorations of the concepts, CoRes	**Initially -** **After-** pre-service teachers experienced an improvement in the quality of their TSPCK.	
Mavhunga, E. 2018,	TSPCK –	Discussions on each component, explorations of the concepts, CoRes	**Initially -** **After-** PSTs generated TSPCK episodes with component interactions that are varied in combinations and peculiar to each participant	
Mavhunga et al 2016	TSPCK	Development of a concept map Cores lesson planning	preservice teachers consistently demonstrated a higher performance in the TSPCK components in the topic of choice, which we linked to transfer**.** Distinct features of the intervention like the use of some form of a classification map as a step towards formulating Big Ideas and the emphasis of the simultaneous use of representations at different levels were shown to be explicitly applied with the topic of transfer they valued the distinct strategy learned in the intervention for using representations	

Milner-Bolotin et al., 2016 Canada	Peer-Wise online collaborative educational technology i	Peer Instruction, feedback from peers	these results strongly suggest that for all seven dimensions of the rubric the ratings of the multiple-choice questions produced by the TCs improved significantly during the methods course. All of the ratings were significantly higher at the post-test as compared to the pre=test	
Rutt and Mumba, 2019 USA				
Scharfenberg, F. & Bogner, F.X. 2016	Role change approach	outreach lab- new environment (catalyst for change); role change, reflection phases	The control group did not significantly change in DASTT-C scores/ The treatment group participants' orientations toward teaching biology significantly changed toward a more student-centred view Participation in the PST module changed core PCK components of the treatment group PSTs/	
Scharfenberg and Bogner (2019	role-play-based tutor training	role play, group discussions, assignment exercise, promotive interaction as a core condition of cooperative learning	PSTs showed less interaction time and less interaction frequencies. Especially, their non requested interventions decreased, representing the main inadequate interaction without training. two-step trained tutors unexpectedly showed descriptively more premature answer than three-step trained tutors.	

Schechter and Michalsky, 2014	four different reflective methods	dual reflection into both problematic and successful events, reflection together with the mentor and peers, peer mentoring, collective reflection	all treatment groups improved their PCK components (comprehending, designing, and teaching) over the course of the study	
Smit, R., Rietz, F. & Kreis, A. 2018	content-focused peer coaching	Core Issues of lesson planning/ experimentation/ collaborative planning- peer coaching	**Initially** - lightly more positive scientific inquiry teaching beliefs. **After** - the students showed slightly higher attitudes; they possessed a little more PCK than before the lesson planning session; Planning competence and PCK correlated significantly before and after the collaborative planning session, but there was no significant correlation between planning competence and inquiry attitudes; the practice-oriented transfer (lesson planning) itself seemed not to have added much to the development of professional knowledge despite the postulated effects of reflection as part of successful teacher training in other studies	
Smit, R., Weitzel, H., Blank, R., Rietz, F., Tardent, J. & Robin, N. 2017	peer coaching	peer coaching	Weaker scientific inquiry attitudes compared with the attitudes presented after the teacher training. pre-service teachers with strong self-efficacy beliefs appeared to be less oriented toward scientific inquiry after the project; the practice-oriented transfer (lesson planning) did not appear to substantially contribute to the growth of professional knowledge despite the postulated effects of reflection; there was no significant relation between CK and PCK at both time points	

Tolsdorf, Y. & Markic, S. 2017	combination of theoretical learning units with practical phases (internships	experience and work with different diagnostic instruments, diagnosing and planning chemistry lessons and discuss various teaching methods. The focus during the internship is on diagnosing, planning, and teaching chemistry	the results of this study seem to indicate that the methods and tools learned became more noticeably present after the internship phase. the practical experience provided by the internships and the mentors seems to have influenced student teachers' diagnostic competence on a high level.	.
	interaction between TSR and PCK components.	forethought, performance, self-reflection, and motivation phases microteaching sessions;	deficient knowledge about instructional strategies; participants paid more attention to selecting activities and representations rather than focusing on how to implement them to ensure meaningful learning; poor SMK;	
Wheeldon, R. 2017	Focus-Action-Reflection (FAR) approach	common alternative conception (AC) analogies,	The changes before and after intervention are statistically significant and show a large effect size for a change.	
Weitzel & Blank (2019 Germany	Content-Focused Peer Coaching (CPC	collaborative lesson planning dialogs	the peers of the intervention group discuss a wider range and a larger number of PCK issues than the control group and record more changes in their planning documents. the results also reveal that important PCK issues are rarely addressed in the peers' lesson-planning dialogs (e.g., dealing with students' conceptions and reflecting on lesson processes and results). Therefore, the potential of peer coaching approaches to develop PCK might be limited	
Van Driel. et. al., 2002	multimethod approach Macro-micro perspective	Classroom teaching experience, the questions students posed during lesson, Correction of students' answers to written tests, The responses of students to	**Initially-** preservice teachers' PCK about macro–micro at the start of the program was, without exceptions, very limited **After**- All but two of the participating preservice teachers had expanded their PCK	

		specific assignments, The observation of students' behaviour during lessons taught by the mentor or a peer. University-based workshop- reading and discussing, meetings with mentor.	concerning macro–micro; extended their subject matter knowledge.	

Appendix C. Table of Evidence for PCK Development

Study	***Setting***	***Aim***	***Study findings contributing to RQ1 synthesis -*** *Themes and sub-themes and their associated codes*	***Study findings contributing to RQ2*** *synthesis of effective learning opportunities. Themes and sub-themes with their initial codes*
1.Adadan, E. & Oner, D. 2014 ***Turkey***	Methods course	to map out the two participants' PCK progression	**Positive results** -set the development of science process skills as a goal for teaching (**Og);** changed in quantity **(CrK);** showed awareness about the discrepancy between subject matter knowledge and what was included in the curriculum **(Ua):** aware of the scope of the curriculum **(Ua);** described numerous AC; demonstrated knowledge about the existence of alternative conceptions among students (**LK**). was also able to identify several possible sources of such alternative conceptions that students might have **(KL);** recognized the probable origins of such alternative conceptions **(LK);** representations about KSU expanded considerably **(LK);** demonstrated a notable expansion and elaboration in knowledge;	CoRe task provided an opportunity for the preservice chemistry teachers to examine the national curriculum and some available materials (**planning**- **direct experience**); peer collaboration; engaging them in various **conflicting situations** (**direct experiences**); individual **reading several papers** about students' conceptions of the behaviour of gases, and they **discussed t**hem with their peers while they were creating the CoRe documents (**planning - direct experiences, collaboration- vicarious experience**); **first hand experiences** of different methods of instruction, the types of inquiry (POE,

			mixed results **(ISK);** intended to employ multiple assessment strategies adopting a variety of strategies to assess students' science learning **(AK);** able to make certain decisions about what to exclude (**CrK**);	guided inquiry, and open-ended inquiry), argumentation, and the use of multiple representations (**direct experiences**); modelled such approaches (**vicarious experience**); critically reflected on those experiences and shared their ideas with the class (**Direct experiences**); discussions (v**icarious**),
2.Aydeniz, M. & Kirbulut, Z.D. 2014 ***Turkey***	teacher-education programme	to develop an instrument (i.e., a praxis tool) that could be used to measure pre-service science teachers' PCK of electrochemistry and to help pre-service science teachers develop topic specific PCK.	**Mixed results** (naïve, developed, sophisticated - significant differences **Ck, ISK, AK, Ua**	engaged students in **group discussion -** feedback and confirmation from their peers (**cognitive and psychological support),** sought confirmation about understanding,

3.Aydin, S., et al., 2013 ***Turkey***	practicum course	to investigate the development of preservice teachers' knowledge base for science teaching on the rate of reaction topic and to identify which aspects of the practicum course contributed to preservice teachers' development	**Positive results** -developed big ideas and expectations **(CK)** enlarged their view (**Ov)** change in their thoughts **(Ot**), **Ua**, preservice teachers' ideas about learners' difficulties became more sophisticated **(LK),** developed a deeper understanding of students' misconceptions (**Ua, LK)** made some progress in addressing misconceptions during their instruction (**LK)** knew to use appropriate sources to learn about misconceptions **(LK)** all participants had made progress in effectively selecting and using topic-specific instructional strategies for teaching **(ISK)** used more diverse and richer repertories of such strategies **(ISK),** aligned the strategies with orientations for teaching **(Og),** developed knowledge of assessment in terms of what to assess **(AK);** realized the importance of eliciting learners' prior knowledge (**Ua),** able to state why to assess **(Ui)**	participants stated that mentoring, teaching experience, and observing peers' microteaching helped them to realize the importance of learners' prerequisite knowledge, difficulties, and misconceptions (**mastery, vicarious, cognitive support)**
4.Aydin, S., et al, 2015	practicum course	To examine how a CoRe-based	**Positive results**-participants were more able to utilize and relate all PCK components by the end of	planning with mentors (**cognitive support**)

Turkey		mentoring-enriched practicum supported the developing interaction of PCK components in preservice teachers	the practicum **(Ui),** showed an increase in the interplay of assessment with other components(**Ui)** participants began to connect knowledge of curriculum with other components **(Ui),** All participants' maps showed an increase in interplay between science teaching orientation and other components of PCK **(Og),** the frequency of connections between knowledge of curriculum and knowledge of assessment and between knowledge of curriculum and knowledge of learner increased, **(Ui**,**Ua, Pp)**	the CoRe aspect of the practicum enabled participants to articulate their PCK and forced them to connect the components due to its matrix format **(direct experiences)**
5.Barnett, E. & Friedrichsen, P.J. 2015 ***USA***	teacher education program-**practicum**	to describe the strategies used by a secondary biology mentor teacher to support the development of a PST's PCK	**Positive results-** reconsidered the lesson and proposed a way to make it more learner-centred **(Ob);** shift in orientation (**Ob),** explained the importance of instructional strategies **(ISK),** temptation to correct a misconception (**LK),** redesigned a question to better assess students' knowledge of selective pressures; co-examining and revising previous unit examination questions to better assess students' understanding **(AK);** developed his knowledge of sequencing **(AK**), **Pp**	**Encouragement** (Prodding and pushing in that direction) – (**cognitive support**); **modelling critical reflection** of strategies (**vicarious experience**), encouraged to take same critical stance (**mentoring support); co-planning** (planning with the mentor) – (**vicarious, direct experience)** and **reflection** on it (**mastery experience)**

6.Bektas, O., et al., 2013 ***Turkey***	chemistry teacher education program - practice teaching course	To investigate pre-service chemistry teachers' pedagogical content knowledge of the nature of science (NOS) in the content of the particle nature of matter	**Mixed results** -developed idea from a naïve to transitional (**Ov);** showed huge development of NOS **(CK);** showed an improvement in their understanding of NOS (**Ua);** , gave more detailed explanations at the end of the course **(LK**); intended to use the theories/laws aspect of NOS, used this aspect of NOS as mentioned in lesson plans **(Pp);** improved their knowledge on how they could integrate the target aspects of NOS **(Ui);** able to explain how to use teaching strategies in their instruction in a rather detailed way (**ISK, Ui);** developed their PCK of NOS concerning knowledge of instructional strategies (KPCK); proposed many different kinds of instructional strategies**(ISK**); gave examples of their evaluation techniques (**AK**);	Improvement due to teaching experience (**direct experience**); observed other participants' instructions integrating NOS aspects into chemistry topics (**vicarious experience**); **observing** their mentors and utilizing chemistry **textbooks** while preparing their instructions (**vicarious experiences).**
7.Brown, P., Friedrichsen, P. & Abell, S. 2013 ***USA***	teacher education program	To investigate prospective science teachers' knowledge development at	**Positive results/ negative aspects (did not implement 5E model)-** Their ideas expanded as a result of their experiences in the secondary science methods courses (**Ov**); developed a growing awareness of student difficulties (**Ua**); and	multiple experiences during the STEP programme; experienced, and **designed** 5E instructional sequences in science methods courses (**mastery experiences)**; providing

		the subject specific level	broadened their knowledge of the requirements for science learning **(LK);** provided students with multiple opportunities **(Pt);** developed additional ideas about learners(**Ob**); able to combine ideas about discovery learning and evidence-based explanations to create a more sophisticated idea about how students can learn **(Pp**); All four participants' knowledge of instructional strategies developed **(ISK);** teachers developed knowledge of learners and instructional sequence (**LK ISK);**	opportunities for **reflection** on views and practice (d**irect experiences**);
8. De Jong, H. Van Driel, Verloop, 2005 *The Netherlands*	teacher education program	To promote preservice teachers' PCK of using particle models in teaching chemistry topics through a combination of institutional activities and	**Positive results-** wrote and discussed learning difficulties **(LK);** wrote down and discussed instructional strategies that they considered potentially useful to enhance students' understanding **(ISK);** identified specific learning difficulties **(LK);** practiced modelling activities with her students (**Pt);** a detailed account of the design of this series of lessons was presented **(Pp);** gained a better understanding of the possibilities and the limitations (**ISK).** gained a better	their PCK was extended and became more structured after they analysed and discussed sections of a chemistry **textbook** (**direct experiences and vicarious experiences)** because of experimenting with the use of particle models during their series of lessons (**direct experiences – authentic experiences);**

	authentic teaching experiences	understanding of the possibilities and the limitations of the use of such models **(Ua);**	
9.Demirdö en, B. & Uzuntiryaki-Kondakç, E. 2016 ***Turkey***	to investigate how pre-service chemistry teachers' science teaching orientations change during a two-semester intervention designed to enhance their pedagogical content knowledge (PCK) for teaching the	**Mostly positive (**acknowledging but not applying)- Participants' NOS views changed in the desired way after the NOS instruction(**Ov);** participants were able to translate the change in their orientation into their instructional planning(**Ui, Pp**); aware that students may have misconceptions and difficulties regarding NOS (**Ua**); they assessed students' understanding of NOS using several assessment techniques (**AK)** used instructional strategies **(ISK**); aligned their instructional strategy with their orientation of teaching NOS **(Ui**);	substantial increase in the percentage of participants with informed views on most of the NOS aspects because of **Explicit reflective NOS instruction (Direct experiences).** various settings, namely, argumentation, inquiry, and history of science, served as context throughout the **explicit-reflective NOS instruction** in this study; various discussions **(vicarious activities);**

		nature of science (NOS).		
10.Demirdöğen, B. 2016 ***Turkey***	science teacher education program	to investigate the interaction between orientation and other PCK components	**Mixed results** -not translated in planning; all purposes related to teaching science content (i.e., correct explanation and solid foundation) interacted with all other PCK components: knowledge of curriculum, instructional strategies, learner, and assessment(**Ui);** aware of the difficulties and misconceptions students might have (**Ua);** included curriculum objectives that indicated her knowledge of curriculum (**CuK);** focused on students' misconceptions **(LK);** designed an activity (**Pp);** provided an explanation **(Ui);** designed an assessment **(AK);** used topic-specific instructional strategies- included various examples, **(ISK);** Developing students' scientific process skills (**Ob);** had sophisticated views about the NOS **(Ov);**	meaningful and explicit experiences with PCK throughout the study -CoRes (**direct experiences**); **reflection** on their orientation (**direct experience**); **explicit use of PCK**

11.Demirdöğen, B., et al., 2016 ***Turkey***	Chemistry Education Course	to investigate the development and nature of preservice chemistry teachers' PCK for NOS	**Mixed results-** highly, somewhat and non-integrated realized the importance of nature of science **(Ua);** believed in the importance of learning NOS for their students **(Ob);** designed a lesson to teach at least one aspect of NOS **(Pp);** developed PCK for NOS (**K** all) and integrated it in lesson plans **(Ui);** successfully aligned instructional strategy, learner, and assessment with teaching orientation in lesson plan (**Ui, Pp);** participants' NOS views changed in the desired way **(Ov**);	explicit reflective instruction (**direct experiences, vicarious**), explicit-reflective discussions of PCK for NOS components (**vicarious experiences)**
12.Donnelly & Anne Hume (2015) ***New Zealand***	chemistry teacher education course	To enhance opportunities for pre-service teachers' (PTs) to develop pedagogical content knowledge by introduction of a collaborative	**Mostly negative wiki technology in supporting Core design** In their CoRes, PTs frequently made explicit reference to possible difficulties for students in understanding the concept being taught (**ISK);** noted student difficulties and common student misconceptions **(LK);** CoRe encouraged them to think more about possible student misconceptions **(Pp**); improved their curriculum knowledge and planning by considering and recognising the	CoRe helped me isolate what I needed to work on before being able to present the material to the students (**planning – direct experience); t**he PTs appreciated how the big ideas could be generated from CoRe design and how more appropriate ways of structuring concepts could be developed in efforts to avoid misconceptions – coRe **planning (direct experience);** found the CoRe framework useful as a means of

		technology (wiki)	difficulties they had with the topic at that age**(CK);** a myriad of instructional strategies highlighted in the CoRes **(ISK**); illustrated a range of assessment modes (AK); noted their lack of knowledge of student misconceptions and their own misconceptions as problematic**(Ua)**	engaging their associate teachers (ATs) in discussion about the reasoning behind their choice of instructional strategies **(discussions- vicarious experience**); discussed their CoRe with their AT and that their AT's suggestions on their CoRes were very helpful (**vicarious experience**).
13Ekiz-Kiran, Boz and Oztay 2021 Turkey	Practicum	To improve pedagogical content knowledge (PCK) of pre-service chemistry teachers using a school experience course enriched with PCK development tools	**Positive results-**	

14.Hume, A. & Berry, A. 2011 ***New Zealand*** *Australia*	Teacher education	To build the foundations on which novice teachers can begin developing their pedagogical content knowledge (PCK).	**Positive results** - capabilities they developed that appeared to be transferable **(Ut**); tackled CoRe design with more purpose and confidence (**Pp, C**); more readily located relevant information and did this with increased independence of her as their lecturer **(Ce);** selection and expression of the key ideas as full standalone statements (**PCK, Ua**); explanations and elaborations within the CoRes were more detailed (**Utr**); showed keener awareness of issues around students' understandings **(LK**); a greater repertoire of potentially useful instructional strategies **(ISK**); indicated awareness of how the act of CoRe design was heightening awareness of the components of PCK (**Ua**);	scaffolding strategies built the capacity of student teachers to locate and select/determine relevant information for CoRe design; collaborative approach to developing a CoRe **(direct and vicarious experience);**
15.Hume, A. & Berry, A. 2013 ***New Zealand*** *Australia*	teaching practicum	To broaden the collaboration with school-based mentors on teaching practice (practicum) that	able to make adjustments to her CoRe to refine her content knowledge **(Pp, CK**); made decisions about the content (**CK**); provided important insights into the learning characteristics of students **(LK**); realised how little she had known about the learning difficulties **(Ua**); refining her PCK as she tested,	**collaborative CoRe design** with their associates (direct and vicarious experience); Production and discussion of the CoRe (diret experience, vicarious experience); interactions with associate teachers (vicarious experience);) feedback

		might impact on student teachers' development of their pedagogical content knowledge (PCK	evaluated and modified her initial CoRe teacher**(Pp**); incorporated all additions and changes she had made to draft 2 after teaching and reflection had finished (**Pp, Pa**);	on their CoRes and suggestions to aid planning for teaching of the topic (**cognitive support);** able to watch her associate teach the class (Vicarious experience); **discussions** really made me verbalise the extent of my increased content knowledge, my pedagogy and knowledge of the learners in how would be best to teach the section; **Professional dialogues** with associates; **discussions** helped develop my skills and knowledge in areas such as knowledge of learners
16.Grospietsch, F. & Mayer, J. 2018 ***Germany***	University course based on the professional conceptual change model	To investigate whether and to what extent a university course developed in accordance with a professional conceptual change model	**Positive results-** significant increase in students' scores in all three areas of professional knowledge, with a large effect size (**CK, PCK**); transmissive beliefs declined in the post-test (**Ob**); knowledge increased in all three areas (**PPK,CK,and PCK**)	conceptual change texts (**explicit reflection – direct experiences)** over reflection tasks on one's own learning (implicit reflection

		can reduce pre-service biology teachers' endorsement of neuromyths		
17.Günther et al 2019 ***Germany***	Training programme	to foster preservice biology teachers' diagnostic and teaching knowledge (PCK) related to model competence	**Positive results**- considerable development of model competence (CK); data revealed the positive development of diagnostic and teaching knowledge (PCK);	the strongest development in the category of **reflection on models (direct activities); explicit reflection; using models (vicarious experiences);** embedding of learning in authentic contexts
18.Jufri et al 2019 ***Indonesia***	Strategies for Teaching Biology course.	to analyse the effects of a lesson study-based action research intervention on development of	**Positive results -** the students' knowledge of science concepts and scientific competencies increased slightly from the first cycle of lesson study to the second and third cycles (**CK, ISK, AK, Ob)**	Facilitation and guidance, as well as direction from the model lecturer, led to **student interactions** that were more meaningful and effective (**cognitive support);** increasing number of students engaged actively in **discussions** within their groups (**vicarious experiences**);

		prospective science teacher (PST) scientific literacy and PCK indicators		guided by the lecturers to engage in **group reflection** which contributed to the significant increase in their scientific literacy and PCK competencies (**vicarious experiences);** analyzing essential concepts, selecting teaching strategies, **designing lesson plan**, constructing instruments, and **practicing teaching** in their working groups provided opportunities for them to improve their content knowledge, and their PCK competencies (**direct experiences);**
19Juhler, M.V. 2016 ***Norway***	teacher education Field practice	to investigate pre-service teachers' learning during field practice, focusing about Physics as a subset of science	**Positive results** as a group not at individual level= shift in focus occurred **(CuK),** three times greater **(LK**); increased threefold in the INT(**AK**); much more uniform focus on all the four main categories (**CuK, ISK, LK, AK**) than in the other group	LS and CoRe direct teachers to focus on a more learner-centred approach **to planning** (**direct experiences);** focus was on Goals for Instruction and Scope and Sequencing, with little focus on National standards and Resources and textbooks was connected to theoretical knowledge about disciplinary content;

20.Juhler, M.V. 2018 ***USA***	teacher education Field practice	to investigate how pre-service teachers use assessment during field practice, focusing about Physics as a subset of science	**Negative results** – only one student of three used some evidence as the basis for assessing the lesson (**AK)**. Lesson Study method, when used in combination with CoRe, **only had a limited effect on the participants' focus on assessment.**	***Recommendations;*** **Familiarization** with **planning stage**. the group could benefit from having an expert teacher leading the Lesson Study process, thereby facilitating the transition from novice into getting a deep understanding for the Lesson Study process (v**icarious experience). scaffold** the difficult transition into the Lesson Study method (**cognitive support**).
21.Karal, I.S. & Alev, N. 2016 ***Turkey***	Teacher training program	To investigate the development of pre-service physics teachers' pedagogical content knowledge (PCK	**Mixed results**- the total scores in CK increased **(CK);** types of representations are diversified **(Utr);** used representations of explanation, illustration, analogy and problem solving in teaching (**Pt);** the predictions of PTs about students' prior knowledge showed differences (**LK) increased/decreased/no change**); attempt to check what students have learned in previous lessons, before starting teaching **(Pt, LK**); variations of the predictions about learners: students' learning difficulties throughout applications (**increased, decreased, no variation**) (**LK, Pp);** one PT	Increasing in test as result of PTs' **teaching experience** (**direct experiences);** advanced after teaching experience (**direct experiences);** improvement due to **observation** of another PT's teaching (**vicarious experiences**); improvement due to direct contact and **communication** with students themselves, **textbooks**, and **the syllabus** (**vicarious experiences);**

			designed and performed an experiment (**Pp);** emphasized a student misconception in his teaching session (**LK**), discussed questions with students in the classroom to eliminate misconceptions (**Pt; LK);** , explained learning difficulties in detail to prevent possible occurrence (LK). **(Pt**); others wrote in lesson plan misconceptions but did not mention or explain anything about these during teaching; diversified their repertoire of knowledge of representation throughout their training period in which they had taken methodology courses **(PCK);**	
22.Mavhunga, E. 2016 ***South Africa***	Chemistry methodology class	To develop the competence to transform concepts in the topic of particulate nature of matter	**Positive results -** pre-service teachers applied their learnt competence to transform content knowledge in the topic of intervention successfully, thereby improving their TSPCK in the topic **(Utr, CK);** improvement in the quality of their TSPCK **(CK);** expanded explanations of the main concepts **(Utr);** identified correctly three 'Big Ideas' (**CK);** identified specific concepts that may cause potential difficulty for learners **(LK);** used representations at multiple levels of explanation (**ISK);** drawing on	written evaluation of the video-recorded lesson (**vicarious activities)** exposed to discussions in an intervention that explicitly interrogated the concepts of the topic of intervention from the perspective of the TSPCK components, and in using them interactively, to bring in-depth responses (explicit discussions- **vicarious activities);** improvement due to 'developing' TSPCK level through a

	multiple TSPCK complementary components **(Ui);** display of improved content knowledge in the topic **(CK);** increased awareness of what concepts are difficult for the learners to understand (**Ua);** provide an expanded explanation (**Utr);** displays evidence of the interaction of TSPCK components in bringing depth to an explanation **(Ui**); displays an example of an emerging, original ability to anticipate potential learner difficulty **(LK);** provided expanded explanations to test items (**Utr**); demonstrated evidence of drawing interactively on different components of TSPCK to attain depth in the explanations (**Ui);** effort to identify the possible source of misconception in a learner's statement**(LK);** responses demonstrated transformed content knowledge, suitable for learner understanding (**Pp**, **Ui, Ut**); engage with the new topic from the same approach as in the intervention (**Ut**).	rigorous process of engagement (**direct experiences); explicit demonstrations** in the intervention of the breaking down of the TSPCK construct into its individual components has been useful (**vicarious experiences);** collective and interactive use of the components of TSPCK (**direct experiences**);

23.Mavhunga, E. 2018 ***Intervention*** ***South Africa***	Chemistry methodology course	to improve the quality of PCK in core chemistry and physics topics, one of which is chemical equilibrium	**Positive results** -addressed common learner misconception **(LK);** displayed understanding of pre-concepts **(CK);** components interact in a complex manner (**Ui)**; connections explicitly indicated **(Ui**); explained from multiple, but different considerations **(Utr**); the content-specific components of TSPCK interact in clearly distinguishable structural formats **(Ui);** reflected a slightly increased level of sophistication (**Ui, Ut**);	**reflecting collective** TSPCK in the topic (**direct experiences, vicarious experiences**); planning CoRe **(direct experiences)**
24.Mavhunga, E. & Rollnick, M. 2013 ***South Africa***	Teacher education programme	To improve the quality of PCK in chemistry pre-service teachers in a specified topic	**Positive results-** improved their ability to reason about the topic **(Utr);** the extent of difficulty was generally decreased after the intervention **(Ui**); understanding about common misconception **(UaLK);** interplay with another (use of representations) (**ISK);** awareness of the common misconception (**Ua**); increased knowledge of aspects of curricular saliency **(CuK);** the interplay with other components naturally emerged **(Ui).**	**explicit discussions** (**vicarious experiences);** unpacking PCK at Topic level – **planning and discussions** (**direct experiences, vicarious experiences);** **discussions** about transformation of topic concepts (**vicarious experiences**)
25.Mavhunga, E. & Rollnick, M. 2016	Teacher education	To investigate the relationship between TSPCK	**Positive results -** improved their thinking about the teaching of concepts in chemical equilibrium in ways that transformed them into a form suitable for	unpacking PCK at Topic level – **planning and discussions** (**direct experiences, vicarious experiences)** discussing

South Africa	Programme-methodology class	and underlying science teacher beliefs following an intervention targeting the improvement of TSPCK in the topic chemical equilibrium	teaching (**Ot, Utr);** developing ability of the pre-service teachers to focus on 'what is most important' in a given situation **(Utr);** explicit description of the nature of their representation (**CK, Utr);** organizing the topic of chemical equilibrium into big ideas **(CK); mixed shifts** in the post-test towards learner-centred beliefs **(Ob**); shift from traditional towards the responsive/reform-based teacher science beliefs **(Ob);**	representations as one of the components of the TSPCK construct.
26.Mavhunga et al 2016 ***South Africa***	physics methodology class	To investigate the transfer of the competence to transform content knowledge learned in electric circuits to a new topic in either chemistry or physics		

27.Milner-Bolotin et al., 2016 ***Canada***	physics methods course	to investigate how physics TCs' engagement with designing, answering, and commenting on conceptual multiple-choice physics questions via a PeerWise platform influenced the development of their physics PCK	**Positive results** - the ratings of the multiple-choice questions produced by the TCs improved significantly during the methods course. TCs were able to improve their skills in asking meaningful conceptual multiple-choice questions, in designing scientifically meaningful distracters, and providing scientifically plausible and pedagogically sound explanations to their questions **(PCK);** TCs become aware of their own knowledge deficiencies **(Ua);** development of more effective questioning skills by knowledge of physics pedagogy **(PCK)**	**Peer Instruction (vicarious experiences); feedback** provided by their peers, by the instructor and by the teaching assistant (**cognitive support**), as well as to the face-to-face in-class **discussions** (**vicarious experiences). meaningful discussions, collaboration** on designing physics teaching resources (**vicarious experiences, direct experiences**); **designing** pedagogically effective teaching resources (**direct experiences**)
28.Scharfenberg, F. & Bogner, F.X. 2016	teacher education module	To determine whether biology teacher education module	**Positive results** - treatment group participants' orientations toward teaching biology significantly changed toward a more student-centred view (**OV);** changed individual views on potential instructional	Improvement due **to hands-on experience** and in role as teachers (**direct experiences);** role being an adviser

Germany		Learning, and Teaching in the Outreach Lab has a potential influence on the development of the PSTs’ PCK components: LK, ISK, O)	strategies for avoiding learning difficulties **(ISK);** PSTs had a different view of student difficulties **(LK);** PSTs changed their strategies for avoiding students’ difficulties (**LK**);	(**cognitive support**); authentic experiences (direct experiences)
29.Scharfenberg and Bogner (2019 ***Germany***		how preservice teachers might develop more adequate tutor–student interactions during students’ experimentation	**Positive results in terms of tutor–student interactions interactions;** avoid the inadequate non requested intervention, presensitized to which questions students might ask and which experimental steps might be difficult from the students’ perspective (**LK);** less interaction time and less interaction frequencies	**Discussions in group** (**vicarious activities**); their peers’ tutor play has been argued both to “effectively stimulate substantive **reflection,**” and to be “useful for developing a critical stance toward instruction **(vicarious experiences**); cooperative learning **(vicarious experiences); individual feedback (cognitive support);**
30.Schechter and Michalsky 2014	teacher education practicum	to examine the effect of integrating	Positive results- all treatment groups improved their **PCK (**comprehension, design, and teaching – **Ua, Pp, Ut)**; all treatment groups improved their	dual **reflection** into both problematic and successful events (**direct experiences**); **collaborative** endeavour with the mentor

Israel		systematic learning from problematic as well as successful experiences in preparatory programs on physics student teachers' PCK and sense of teaching efficacy	**STEBI-B** components (**PSTE and STOE**) **(Ce, Co, Cb);**	and student teachers (**cognitive support, vicarious**); **reflection** together with the mentor and peers (**vicarious and cognitive support); guidance** of an experienced mentor-moderator **(a more capable peer) (cognitive support); collective reflection (vicarious experiences); successful teaching experiences (direct experiences); peer discourse (vicarious experiences);**
31.Smit, R., et al 2017 ***Germany and Switzerland***	pre-service teacher education	To investigate quantitatively the longitudinal relationship between pre-service teachers' knowledge and attitudes on	**Mostly negative results -** pre-service teachers appear to present strong cognitive beliefs regarding scientific inquiry teaching and moderate control and affective beliefs **(Ob, Ce);**	deeper and more substantive **rethinking on** teaching that led to an understanding of the theory that underlies inquiry and student learning occurred for some teachers prior to the training experience (vicarious **experiences);**

		scientific inquiry teaching		
32.Smit, R., Rietz, F. & Kreis, A. 2018 ***Germany and Switzerland***	pre-service teacher education	to determine the effects of a pre-service teacher training module on content-focused peer coaching	**Mostly negative results-** showed slightly higher attitudes (**Ob**), possessed a little more PCK than before the lesson planning session **(PCK); PCK** and attitudes towards scientific inquiry teaching (ATT) have increased slightly but significantly	Negative - Peer coaching (**vicarious experiences**); lesson planning discussion (**vicarious experience**);
33.Tolsdorf, Y. & Markic, S. 2017 ***Germany***	university teacher training	To develop diagnostic competence in chemistry teacher trainees (how to deal with pupils' misconceptions and perception)	**Mixed results - group 3 had the highest** coding in all of the categories, Student teachers in Group 3 mentioned more concrete ideas for changing their materials and teaching in order to deal with heterogeneity (e.g., tools for adapting worksheets or experiments), high level of diagnosis for group 3 **(LK)** described concrete ways of designing materials or adding content help and linguistic aids **(LK);** the second and third groups went deeper into understanding chemistry and gaining content knowledge **(CK);**	work experience, practical experience **(direct experience);** mentors, mentoring and support **(cognitive support);**

34.Van Driel, et. al., 2002 ***The Netherlands***	teacher education program	To Investigate the development of PCK among 12 preservice chemistry teachers- Interrelations between components	**Mixed results (**all but two) More extensive description (**CK, LK**); addition of an explicit reference to students' problems or conceptions (**LK**); increased understanding of learning difficulties (**LK);** become aware that students often have problems to relate or distinguish the macro and micro levels (**Ua**); gave a detailed description of examples (**ISK**); all but two of the participating preservice teachers had expanded their **PCK** concerning macro–micro; become aware, in a general sense, that students might have their own conceptions (**LK);** extended their subject matter knowledge (**CK);** increased awareness of the nature of atoms and molecules as models (**Ua);**	Classroom **teaching experience (direct experience); discussion** during the workshop **(vicarious experiences); reading and discussing** the paper - **research literature** in relation to their own beliefs and teaching experiences at the time (**vicarious experiences**); **discussions** with their mentors (**vicarious experiences,**
35.Weitzel & Blank (2019 ***Germany***	Pre-Service Teacher Education for Teaching Scientific Inquiry	to support pre-service biology teachers in planning lessons for teaching scientific methods through	**Mixed – mostly limited** (collaborative planning, peer dialogues) -pre-service teachers discuss predominantly prior knowledge) and how to address it **(LK);** detailed design of the planning, implementation and/or evaluation of the experimental setting more frequently in intervention group (**CK);**the discussion of instructional	reflection between peers (**vicarious experiences**);

		Content-Focused Peer Coaching (CPC) supports	strategies significantly more frequently by the **IG (ISK);** peers discuss numerous modifications during their planning dialogs **(Pp**); the number and range of changes recorded in the lesson plans is significantly higher in the IG than in the CG (**Pp**);	
36.Wheeldon, R. 2017 ***UK***	Initial Teacher education	to support PSCT in rejecting the 'conservation of force' AC and replacing this with scientific causal arguments; to develop teachers' understanding of ionisation energy values and to evaluate the potential of diagnostic testing	**Mixed results** - The changes before and after intervention are statistically significant **(CK);** elaborated on her explanation (ISK); used analogy to help her explain subsequent ionisation energies without prompting (ISK)	Focus-Action-Reflection – the tutor offered prompts to support the use and mapping of the analogy drawing on the example of atom and solar system - **prompts** to use analogies as models (**vicarious experiences**);

Appendix D. Studies included in the review on subjects

Biology

Author/s/Date	Country	Aim/emphasis	PCK components	TSPCK
Brown, P., Friedrichsen, P. & Abell, S. 2013,	USA	describe and understand prospective science teachers' knowledge development.	Magnusson science teaching orientations, knowledge of science learners, and knowledge of instructional sequence	Genetics, Heart
Barnett, E. & Friedrichsen, P.J. 2015,	USA	to describe the strategies used by a secondary biology mentor teacher to support the development of a PST's PCK	PCK model of Magnusson – all components	DNA/Protein Synthesis and Evolution
Grospietsch, F. & Mayer, J. 2018,	Germany	Conceptual change – identifying	Shulman PCK CK about curricular content in neuroscience, PPK about the psychology of human learning, and PCK about instructional strategies for sustainable learning	The structure and function of the brain
Günther et al 2019	Germany			
Jufri et al 2019	Indonesia			
Scharfenberg, F. & Bogner, F.X. 2016	Germany	The influence of a systematic student-tutor-teacher role changes in an outreach lab on individual PCK development	PCK knowledge of students' content-specific learning difficulties, (b) knowledge of potential	Genetic Fingerprinting

			instructional strategies for avoiding the experienced learning difficulties, and (c) orientations toward biology teaching	
Scharfenberg and Bogner (2019	Germany			
Smit, R., Rietz, F. & Kreis, A. 2018	Germany and Switzerland	(Content-focused peer coaching	PCK: Knowledge of student understanding of science knowledge of instructional strategies	Accommodation and adaptation of the eye
Weitzel & Blank (2019	Germany			

Chemistry

Author/s/Date	Country	Aim/emphasis	PCK components	Chemistry topic
Adadan, E. & Oner, D. 2014,	Turkey	Teachers' learning progressions	Magnuson (5 components)	Behaviour of gases
Aydeniz, M. & Kirbulut, Z.D. 2014,	Turkey	Designing and assessing instruments as teaching tool to enhance pre-service science teachers' TPCK	Magnusson (curriculum, instruction, and assessment)	Galvanic cells

Aydin, S., et al., 2013	Turkey	Investigate the development of preservice teachers’ knowledge base for science teaching	PCK model of Magnusson – all components, CoRes	Rate of reaction
Aydin, S., et al, 2015	Turkey	Interaction of PCK components	PCK model of Magnusson – all components, CoRes	Different Chemistry topics
Bektas, O., et al., 2013	Turkey	To Investigate pre-service chemistry teachers’ pedagogical content knowledge of the nature of science (NOS	PCK model of Magnusson (Knowledge of learners, instructional methods/strategies, and assessment	NOS for Particle nature of matter
De Jong, H. Van Driel, Verloop, 2005	The Netherlands	combination of institutional activities and authentic teaching experiences (offering opportunities for learning from teaching, rather than learning of teaching)	PCK	particle models
Demirdögen, B. & Uzuntiryaki-Kondakç, E. 2016,	Turkey	to enhance their pedagogical content knowledge (PCK) for teaching the nature of science (NOS	PCK model of Magnusson	NOS
Demirdöğen, B. 2016,	Turkey	interaction between orientation and other PCK components	PCK model of Magnusson	topics selected by participants

Demirdöğen, B., et al., 2016,	Turkey	to investigate the development and nature of preservice chemistry teachers' PCK for NOS	PCK model of Magnusson	NOS
Donnelly & Anne Hume (2015)	New Zealand			
Hume, A. & Berry, A. 2011	Australia, New Zealand	Building the foundations on which novice teachers can begin developing their PCK	PCK all the components	Atomic structure and bonding/ Redox Reaction
Hume, A. & Berry, A. 2013	New Zealand, The Netherlands	Collaboration with school-based mentors	PCK model of Magnusson	Different chemistry topics
Mavhunga, E. & Rollnick, M. 2013	South Africa	Improving the quality of PCK in chemistry pre- service teachers in a specified topic	PCK suggested by Grossman TSPCK	Chemical equilibrium.
Mavhunga, E. & Rollnick, M. 2016	South Africa	relationship between TSPCK and science teacher beliefs about the topic	TSPCK (with the five components), beliefs	Chemical equilibrium

Mavhunga (2016)	South Africa.	developing the competence to transform concepts in the topic of particulate nature of matter	TSPCK (with the five components	Particulate nature of matter
Mavhunga (2018)	South Africa	improve the quality of PCK in core chemistry and physics topics, one of which is chemical equilibrium	TSPCK (with the five components	Chemical equilibrium
Tolsdorf, Y. & Markic, S. 2017	Germany			
Van Driel, et. al., (2002)	The Netherlands	Investigating interrelations between PCK components- factors contributing to the development of elements of PCK	PCK Students' learning difficulties, content knowledge	Chosen topic on macroscopic phenomena
Wheeldon (2017)	UK	interventions to develop teachers' CK and PCK by use of analogies	PCK CK and PCK	ionisation energy values

Physics

Author/s/Date	Country	Aim/emphasis	PCK components	TSPCK
Juhler (2016)	Norway	Combining CoRes with Learning study for developing PCK	PCK model	Physics
Juhler (2018)	USA	Combination of both Lesson Study and CoRe.	PCK model	Physics
Karal and Alev (2016)	Turkey	To investigate the development of pre-service physics teachers'	Magnusson PCK model	Electricity and magnetism

		pedagogical content knowledge (PCK) throughout their training		
Schechter and Michalsky 2014	Israel	the contribution of four methods to the dependent variables (PCK and sense of self-efficacy	PCK and efficacy beliefs: (comprehending, designing, and teaching	light energy gravitational force friction
Rutt and Mumba, 2019/ USA	USA	To develop teachers' conceptual understanding of and pedagogical knowledge for incorporating history of science into their science instruction	PCK for NOS	HOS

Appendix E. Quality assessment table

Author	**Aims and objective**	**Reflectiveness, Transparency and Dialogue**	**Ethical considerations**	**Narrative**	**Usefulness**	**Total score**
	1	2	3	4	5	
Adadan and Oner, 2014	yes	yes	partial	yes	yes	5/5
Aydeniz and Kirbulut, 2014	yes	yes	partial	yes	yes	5/5
Brown, Friedrichsenan and Abell, 2013	yes	yes	yes	yes	yes	5/5
Aydin, et al., 2013	yes	yes	partial	yes	yes	5/5
Aydin et al, 2015	yes	yes	partial	yes	yes	5/5
Barnett and Friedrichsen, 2015	yes	yes	partial	yes	yes	5/5
Bektas et al.,2013	yes	yes	yes	yes	yes	5/5
De Jong, Driel and Verloop 2005	yes	yes	yes	yes	yes	5/5
Demirdögen and Uzuntiryaki-Kondakçi, 2016	yes	yes	yes	yes	yes	5/5
Demirdöğen, 2016	yes	yes	yes	yes	yes	5/5
Demirdöğen, et al., 2016	yes	yes	yes	yes	yes	5/5
Donelly and Hume, 2015	yes	yes	yes	yes	yes	5/5
Ekiz-Kiran, Boz and Oztay	yes	yes	yes	yes	yes	5/5

2020						
Grospietsch and Mayer, 2018	yes	yes	yes	yes	yes	5/5
Gunther, et al.,2019	yes	yes	yes	yes	yes	5/5
Hume and Berry, 2011	yes	yes	partial	partial	yes	4/5
Hume and Berry, 2013	yes	yes	yes	yes	yes	5/5
Juhler, 2016	yes	yes	yes	yes	yes	5/5
Juhler, 2018	yes	yes	yes	yes	yes	5/5
Jufri et. al., 2019	yes	no	partial	partial	partial	2/5
Karal and Alev, 2016	yes	yes	yes	yes	yes	2/5
Mavhunga and Rollnick, 2013	yes	yes	yes	yes	yes	5/5
Mavhunga and Rollnick, 2016	yes	yes	yes	yes	yes	5/5
Mavhunga, 2016	yes	yes	yes	yes	yes	5/5
Mavhunga, 2018	yes	yes	yes	yes	yes	5/5
Mavhunga et al., 2016	yes	yes	yes	yes	yes	5/5
Milner -Bolotin et al., 2016	yes	yes	yes	yes	yes	5/5
Rutt and Mumba, 2019	yes	yes	yes	yes	yes	5/5
Scharfenberg and Bogner, 2016	yes	yes	yes	yes	yes	5/5
Scharfenberg and Bogner 2019	yes	yes	yes	yes	yes	5/5
Schechter and Michalsky, 2014	yes	yes	yes	yes	yes	5/5
Smit et.al., 2018	yes	yes	yes	yes	yes	5/5
Smit et. al., 2017	yes	yes	yes	yes	yes	5/5

Tolsdorf and Markic, 2017	yes	no	yes	no	yes	3/5
Van Driel, et. al., 2002	yes	yes	yes	yes	yes	5/5
Wheeldon, 2017	yes	yes	yes	yes	yes	5/5
Weitzel and Blank, 2019	yes	yes	yes	yes	yes	5/5

Appendix F. Questionnaire

RESEARCH TITLE

Enhancing ITT to Teach Science in 21st Secondary Schools

QUESTIONNAIRE

Please complete all the questions. All information is confidential**.**

A. Background information

B.

1. **You describe yourself as:**
   - O Male
   - O Female
   - O Prefer not to say

2. What is your age
   - O 20-25
   - O 26-30
   - O 31-40
   - O more than 40 years

3. What Qualification do you hold?
   - O Diploma degree BA/BSc
   - O Masters' degree
   - O Other Postgraduate degree
   - O Other qualifications ___________

4. What is your subject of specialism ___________

5. Do you have experience in schools other than teaching? (e.g., supporting learning, teacher assistant, administration)
   - O yes
   - O no

If yes, please provide details:

____

6. Do you have any direct teaching experience?
   - O no experience
   - O less than 1 year
   - O 1-2 years
   - O more than 2 years

7. If so, what subject have you taught?
   - O Chemistry

- O Physics
- O Biology
- O Other: ______________________

8. How would you describe your own science learning experiences as a student in secondary school?

- O Very Good
- O Good
- O Acceptable
- O Poor
- O Very Poor

Please give a reason:

____

9. What has motivated you to become a science teacher?

____

B. TEACHING AND LEARNING SCIENCE

Teaching strategies

For each statement below please select one choice that best fits your opinion	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Effective/good teachers demonstrate to students the correct way to solve a problem					
Thinking and reasoning processes are more important than specific curriculum content.					
Students learn best by finding solutions to problems on their own					
Instruction should be built around ideas that most students can grasp quickly					
My role as a teacher is to facilitate students’ own inquiry					
How much students learn depends on how much background knowledge they can gain.					
Students should be allowed to think of solutions to practical problems themselves before the teacher shows them how they are solved.					
Instruction should be built around problems with clear, correct answers.					
A quiet classroom is generally needed for effective learning.					

Professional development

For each type of knowledge/skill listed below, please mark one choice that you would like to develop in your training programme.	Not at all	A little	To some extent	A lot	To a great extent
Deepening my own science content knowledge					
Learning how to handle the classroom management					
Deeping my knowledge about science curricula (for KS3/KS4, GCSE/A level)					
Learning about how to identify and overcome students' difficulties in science topics.					
Learning how to select and use science materials and resources in teaching					
Learning from experienced teachers (e.g., by observing teaching)					
Learning how to plan a differentiated instruction lesson					
Learning how to assess students' understanding of a particular topic					
Learning how to provide experiences for students that relate to the real world					
Learning how to use multiple strategies in teaching a lesson					
Learning how to motivate students' participation in learning					
Learning how to make connections between science and other disciplines					
Others, namely……………………………………………………………………….					

How familiar are you with the KS3/KS4/A level science standards (curriculum)

	Not at all familiar	Somewhat familiar	Fairly familiar	Very familiar
KS3				
KS4				
A level				

To what extent do you feel prepared to teach science in schools?

- O Not at all
- O Somewhat
- O Fairly well
- O Very well

SCIENCE DESCRIPTORS

Within the science descriptors listed below, please select the option the extent to which you feel prepared to teach each subject.

BIOLOGY

To what extent do you feel prepared to teach each subject	Not adequately prepared	Somewhat prepared	Fairly well prepared	Very well prepared
Cell biology				
Structure and function of organisms				
Genetics				
Evolution				
Ecology/Ecosystems				
Others …………………………….				

CHEMISTRY

To what extent do you feel prepared to teach each subject	Not adequately prepared	Somewhat prepared	Fairly well prepared	Very well prepared
Elements, compounds and mixtures				
The periodic table				
Atomic structure				
States, classes and properties of matter				
Chemical bonding, equations, and reactions				
Properties of solutions				
Earth and atmosphere				
Others …………………………….				

PHSYSICS

To what extent do you feel prepared to teach each subject	Not adequately prepared	Somewhat prepared	Fairly well prepared	Very well prepared
Forces and motions				
Energy transfers, transformation, and conservation				
Properties and behaviour of waves				
Electricity and magnetism				
Modern physics /space physics				
Others …………………………….				

C. Opportunities for practice

On a scale from 1 to 5, where 1 is "not needed" and 5 is "very much needed", which aspects of teaching would you like more opportunities to practice on your ITT course?	1	2	3	4	5
Lesson planning					
Practice or rehearsing teacher role (e.g., leading whole classes or a group of students or peers, leading small-group discussions with students or/and peers)					
Analysing pupils' learning (e.g., view pupils' work, videos, transcripts)					

On a scale from 1 to 5, where 1 is "not needed" and 5 is "very much needed", which aspects of teaching would you like more opportunities to practice on your ITT course?	1	2	3	4	5
Analysing resources (e.g., discuss, analyse real class resources: videos of teachers, samples)					
Talking about field placements and field experiences (e.g., bring in your own's pupils' work)					
Understanding pupils' perspectives (e.g., do work that your pupils will do – e.g. read text that the pupils will do; do a practical that the pupils will do)					
Seeing models of teaching					
Seeing connection to science curriculum					
Others, ……………………………………					

SUPPORT

What kind of support is important for you? Tick in order of preference, where 1 is your top preference.	1	2	3
Feedback from peers			
Feedback from tutors			
Feedback from students			

Are there any challenges/constraints that you expect to encounter during your training? Please explain below:

The end of the questionnaire

Thank you for giving up your time to complete the questionnaire.
Your thoughts, feedback and input you provided are highly appreciated.

Appendix G. Interview Protocol

Semi-Structured Interview Schedule
(For the selected sample)

Thank you for agreeing to participate in this interview. I want to remind you that your participation is voluntary. This interview is going to last around 0ne hour. The interview will be audiotaped. You will be given the opportunity to review the transcribed interview and check for accuracy. All transcriptions will be kept confidential. Do you have any questions?

Interviewee name: ____

Warm up questions

A. Introductory questions

1. Could you to tell me your name and which areas of science you've taken courses in, in the past?
2. Tell me about your decision to be a science teacher? What made you want to do it? Why this route and not others?
3. What were your expectations of the course before you started your training?
   Can you comment on whether these expectations have been met so far?
4. Describe your experience in the programme so far.
5. What things about teaching secondary science have you learned this semester?
6. What can you say about the content/activities delivered?
   Probes:
   - How are activities presented/ delivered? E.g., power point, lecture.
   - Are the activities engaging (interactive)? (Active, passive learning) If so, in what ways?
   - What learning strategy do you like best? Why?
   - Have your ideas about science teaching changed over the semester? If so, in what ways?
   - What has influenced those changes the most? (If any)

C. Now, I would like to ask you some questions about your learning experiences in your school placements.

1. Can you describe a day in school?

   Probes:

   What do you do in a school day? What is it like?
2. What knowledge and skills do you feel you gained during your time in school placement?
3. How do you see the balance between the coursework at the University and your practice in the classroom?

   Probes:

   Can you give an example of something that you learned in the course and was useful in the classroom?
4. Can you describe an example of effective practice that you have observed and has served as a model of teaching for you? How that benefited you?
5. If you had to pick one thing from this semester, that has helped you learn to teach science the most, what would that one thing be and why? Can you talk about a great learning experience you've had and what made it effective?
6. Has your confidence in teaching science increased over the semester? If yes, what has contributed to this?

D. Collaboration and support

Next, I would like to ask you about the support and feedback you got during the semester

1. What was the support like?
   - From where and who have you received support?
   - What aspects of learning do you feel you need more support with?
   - To what extent have you received advice /support within the school (from other members of staff)? Can you comment on the level of collaboration with other staff in the school?
   - What kind of support have you received from your mentor? (Sharing forms, assignments, portfolios, discussions, feedback on lesson plans)?
   - When and in what ways have you received input from your course leader? (Feedback on teaching, on lesson plans, etc). Was this helpful? If so, how?

Now, the last questions

1. Do you feel that your learning experiences in the programme so far have adequately prepared you for a good start in teaching science at the secondary level? Why/Why not?
2. What do you think will be the main challenges for you in the first year of teaching?
3. Do you have any comments which may help the IIT centre or school to be of greater assistance to trainees?

Thank you for your participation in this study.

Semi-Structured Interview Schedule
(For educator)

Thank you for agreeing to participate in this interview. I want to remind you that your participation is voluntary. This interview is going to last no more than 45 minutes. The interview will be audiotaped. You will be given the opportunity to review the transcribed interview and make any changes if you feel so. All transcriptions will be kept confidential. Do you have any questions?

Interviewee name: ____

1. Could you tell me about being an instructor on the programme?
2. How would you describe a training day at the University?
3. I'd like to explore a little about the content and the way that content is delivered to and learned by new teachers.
    - What topics are covered in the programme?
    - How are they delivered?
    - What instructional strategies are used in teaching?
    - How do you manage to engage the trainee in the activities?
    - What strategies do you consider most effective? Why?
    - What topics do you think teachers find more challenging to learn? Why?

- What can you say about teachers' views of teaching and learning science? Do you think they need to change their views of teaching? How do you think trainees' views can be effectively challenged?
- What kinds of support or follow-up do teachers benefit from, during and after their participation in the training sessions?
- What knowledge and skills do trainees need to be effective teachers?
- What can you say about national polices? How do they impact on the programme?
- How do you think about the balance between theory and practice? What are some challenges for trainee in applying the theory in practice?

Now, the last questions

- Is there anything that you would change in the programme? If yes, what suggestions would you make?
- Is there anything else you would like to add?

Appendix H. The analysis of the six transcripts (sub-cases)

Sub-Case 1. Lisa's learning experiences in the school-based training programme

A short personal background

Lisa had a biology degree and A level in Chemistry and Physics. After she graduated entered in primary school as a teaching assistant to gain experience. Because science was almost absent from primary curricula and she 'missed science part of it' she thought to apply for being a science teacher in secondary school. Although she initially considered other routes into teaching, the SCITT route has been chosen from many reasons. It was more convenient (close to home) got a bursary and it has been recommended 'by lots of people' in her previous job. Additionally, the fact that the route has been said to be 'practical based', she was interested to 'get the school experience right from the start'. Although she expected to be a lot of work, the course exceeded her expectations in intensity and thought that switching to part time would enable her to keep a good balance between personal and professional life.

'I didn't think they'd be quite… it would be quite intense as it has been. And I did switch to part time because of that. I was finding it, absolutely…. it was taking over my life completely.

Lisa's perceived effective features for developing LtTF components

Lisa entered the training with no experience in teaching secondary school children. She considered that her science knowledge at secondary level was much limited given the long time since she graduated. Entering the training with limited content of science knowledge and no teaching experience in secondary schools, at the beginning, she found the training activities overwhelming.

I really enjoy it. But I found it quite overwhelming at times. I found the amount of work and the amount of information to be quite overwhelming. And I think partly it's because I hadn't… obviously, I'm an older person and haven't been in school for a long, long time. Things changed a lot, and I haven't done science for a long time.'

She came to acknowledge the complexity of teaching in secondary schools, by learning triple science subject knowledge with general pedagogy in terms of how to manage children behaviour, knowledge about learners, methods of instructions as well as about assessment.

'A lot about behaviour management. I think that's been one of the major things I've learned because although I had lots of primary experience, the strategies in secondary are different from primary…From my observations, I've learned very different strategies that you need for managing the children…a lot of the pedagogy, about what's required in terms of assessment

and differentiation …about what works and what doesn't work. And I learned a lot about the type of things that engage the students.'

The amount and intensity of the training activities challenged a lot her initial beliefs and expectations. She rapidly found that there was a big difference between primary and secondary children and the way they are taught, and consequently she needed to incorporate in her teaching methods and strategies that she never applied and thought at before. Applying in the classroom the strategies she learned in the course or from observing teaching, was the main feature of her preparation that she considered have benefited her most. Equally, reteaching lessons gave her opportunity to improve her teaching of the same topic by reflecting to what worked and what didn't and to adapt accordingly.

,One of the things that benefited me most was reteaching a lesson that hadn't engaged the pupils the first time I taught it. By teaching it again in a different way I could see how changes in my teaching methods could have a big impact in the classroom.... I felt that I'd incorporated more of the strategies I'd learnt on the course.'

Lisa valued the activities that helped her to develop teaching skills with respect to conducting practical works and timing lessons and the way in which to approach children although she felt that all the knowledge came to a very fast speed without sufficient time to assimilate, consolidate and to apply it in the classroom.

I've learned practical skills about timing of a lesson, pace of lesson, how to conduct practical experiments, just generally the routine of the school as well. At the start I found the amount information we had to take on board regarding all the documentation to be submitted and what this entailed was quite daunting, quite overwhelming, and still is at certain points as well.'

Having opportunities to observe different ways of teaching in secondary school she developed a good understanding of the complexity of teaching at that level. Additionally, she acknowledged the big differences between primary and secondary school settings. Being used in her previous role to support lower and struggle ability groups of children, she had developed a habit to focus on this group and considered this aspect 'luxury' in secondary classroom where the individual time for struggling children was quite limited.

'I understand the importance of teaching knowledge, recall practice and questioning and how important that is in science teaching. So, I had to moderate my teaching to take this into account. As a teacher, I have to teach to the top of the class and to the most able and… so I find that quite tricky. The difference was not being able to look after those and nurture the youngsters as they would be nurtured in a primary school…'.

Her confidence in teaching was perceived low at the beginning. She mainly felt that she built more confidence with the increased subject knowledge and pedagogy, with more classroom experience and developing positive relationships with children.

'it's my increased subject knowledge, the increased pedagogy knowledge and, having the opportunity to try and put into practice some of the things I've learnt and getting to know the students. I think, it is relationship building that's given me confidence. I think once you get to know the students it's a lot easier to teach them, which has given me confidence.'

The main challenge for Lisa to develop her knowledge and teaching skills was to keep up with the speed of the activities as mentioned at the beginning. Apart from this 'the structure of curriculum' in Lisa's school placement didn't enable her to apply the knowledge she learned on course. She felt that in secondary schools, children are thought more facts than giving them opportunities to do more exploration.

'I found the content of the course I've had to teach so intense that I haven't actually been able to quite teach in the way I'd like to. I think that's partly because of the school I'm in and the way they structure the curriculum in the sense that they teach the GCSE course right from the start in key stage three, and so it's very intense and very knowledge heavy. Whereas at key stage 3, I think is more allowance for a bit more exploration work and allowing children to work things out and experience the science hands on, rather than being just loaded up with normal facts. That's my impression so far.'

She also felt that the information she needed to teach, didn't match with the information presented on the course. Although useful and valuable for 'later on', she wished to be equipped with the relevant knowledge that she needed for immediate application. More specifically, she was assigned upper classes in her school placement while at that time, she received on the course more knowledge on lower classes.

'I found it is sometimes, some of the things we've been taught, especially in our subject knowledge, we don't actually have the chance to put into practice until a lot further down the line by which time there's been so much other information thrown at us. It's hard to recall. There's no time to consolidate that knowledge when it's given.'

Lisa felt that she would have benefited more from differentiation strategies and more resources to help with planning effective lessons. Also, good feedback on lesson planning before teaching would have given her more space to improve rather than feedback after the lesson.

'I think it would be good to get earlier feedback on documents uploaded to know whether they are satisfactory and how they could be improved; it might have been helpful for me,

particularly at the start, to be given more resources, which are now coming through a lot more.'

Another barrier Lisa felt she had was the quality of mentoring support she received in her placement school. The busy life within the school placement left too little room for personalised guidance from mentors. The observation of teaching didn't help her to see the relevance of what she needed to do either. She wished better feedback and more discussions on how to improve.

'I don't feel I've had that much support or guide on lesson planning and what works, well, on differentiation particularly doesn't seem to be used as far as I can see in my observations. Yet we're expected to do that, so I'm getting no guidance from the school as to what sort of differentiation would work.'

Being a part timer early in the training and national lockdown due to Covid 19, Lisa didn't have the chance to go in the second placement. She was confused whether it's the school or different mentors that offer different kind of formal and informal support.

> 'I think feedback is something that maybe could be improved. Feel we can go and discuss, with somebody. But then I guess it's… I haven't had an experience in a different school with a different mentor, and I don't know whether it's a school or whether it's the norm or whether some, some people are giving formal help, informal tutoring…'

Overall, Lysa felt happy with what she learned on the subject knowledge course, but she wished more individual support and a more alignment between what she learned and what she needed to teach.

> 'It may be worth the SCITT tutors, knowing a bit more about how…the different schools operate… because I think they're very different in the way everyone's experience is very different. Some people get a lot more support than others at the start with what's available to them to use. And, also, I think, the subject knowledge days are all very useful, but all the science ones were geared to take to key stage three when we were starting, and I was teaching key stage four…'

1. Lisa's perceived effective features for developing LtTF components and challenges in learning

Knowledge	Orientations	Practice	Understandings	Efficacy	Challenges

Knowledge of content Differentiation strategies Assessment strategies General pedagogy Knowledge about learners Engaging strategies	Cognitive dissonance Goal oriented teaching	Practicing the strategies learned Applying in practice what has been learned in the course Reteaching lessons Conducting practical/experiments Guided lesson planning Hands on activities	**U**sing different resources Developing insights from observing teaching Acknowledging strategies for managing behaviour of children/engaging strategies/strategies that work Awareness of differentiation strategies Acknowledging the complexity of teaching	Subject knowledge Pedagogy knowledge Teaching experience Building relationships with children	Sheer amount of planning Insufficient support and feedback Lack of alignment between theoretical part of the course and practice Lack/limited access to resources Intensity of the activities Lack of discussions

Sub-Case 2. Ryan's learning experiences in the school-based training programme

A short personal background

Ryan is another career changer who entered the teacher training with a PSE in chemistry and a degree in physics and had work and school experience other than teaching. His main role was with chemistry working in a laboratory for many years. Before embarking on SCITT route he experienced another route but due to health problems he needed to stop his training. Between his programmes he had a couple of school experience as a science technician. His orientation towards teaching came mainly from his desire and pleasure he took in working with children during his work in an Analytical Chemistry and Quality Control Laboratory. In addition, he made a passion for science especially for Physics and wished to take the opportunity to pass this on to children. Because family commitments, Ryan chose the route near his home. His expectations from the course were based on previous experiences before becoming ill and as he told 'snipped a much better'. He was satisfied with the layout of the programme and the diversity of the activities and people leading them. He appreciated the time spent in school and the feeling of school community.

'So much better because you get fully integrated into the schools when you're there. You really are literally a member of the team.'

Ryan's perceived effective features for developing LtTF components

The knowledge he felt he needed most was knowledge outside his specialism and behaviour management. He felt very confident in Chemistry and Physics, and what he needed more was knowledge in Biology.

*'So, in terms of my subject knowledge, biology really is where I've learned…*So, it's more the biology that I needed more, more help on…*And I think the thing I've learned over this course is how amazingly interesting molecular biology and things like that are, genetics, that kind of stuff… I've really, really taken to it... For me, this course mainly is providing me with a lot of biology knowledge, which, which is fascinating.'*

A feature that he felt helped him to learn how to teach in a captivating way and create a good learning environment for children were techniques for behaviour management. Having opportunities to watch videos on behaviour management followed by discussions and reasoning on action and to read recommended books on behaviour management, he learned powerful ways about learners and how to control the classroom. Different strategies for differentiation and useful misconceptions he witnessed contributed to his repertoire of instructional knowledge.

'…he's got some really good videos out there, which actually you can watch him doing stuff and you can see how he responds to the kids and then he gives you a little bit like a live chat afterwards, you get this whole overall picture of what he's really doing.'

Ryan recognised that his goal was always driven by interest and usefulness. The activities in the course sparked Ryan's interest in his own speciality but also in others with knowledge that he didn't hear or had interest in before. The activities within the course particularly challenged Ryan's assumptions about teaching and learning science. He quickly became aware of his traditional beliefs and shifted towards more constructivist ones. He came to acknowledge that knowledge is 'constantly updating and changing' and he 'taught the way he was taught.'

'I taught for seven months on maternity cover…yeah. I very… I taught the way I was taught. You know... I was… when I went to school, the teachers stood at the front. They told you a load of facts and information, you write them down or didn't… that's sort of my perception of teaching …we stand at the front and lecture, but what I've discovered is… it's doing the learning for kids. You don't learn when you just sit there, passive, and the result, they don't absorb. So, they need to actually be doing stuff, so learning is an active process, and I think that's, that's the biggest message that I've had this year, is that they need to actually do things to learn things.'

'…an idea that you had from 20 years ago just is not valid anymore. But unless you go back to them, you never know… taking you back to preconceived ideas…'

For Ryan teaching experience was the main interest and motivator factor throughout the course. He wanted to grasp strategies that can be directly applied in the classroom. He learned how to teach mainly from observing experienced teachers and tried to apply in his classroom what he observed and liked.

'*a lot of your learning comes from your mentors…, watching them and then trying what they did and those kind of things… the stuff that they get, you can actually take it, use it in your own practice and apply it and get some positive result back from that, which is sort of what I'm looking for...'*

Although he was fascinated about how some lessons were taught, he also acknowledged some limitations for learning by observing experienced teachers.

…observations of teachers don't necessarily show you the surface… you can't see what's going on underneath. And it's just like looking at a swan in a pond and thinking, wow, what a majestic great job! You can see the result. We can't necessarily see how they got to that result, which it's really interesting'.

Ryan discovered that getting to know how others approach the same topic contributes to a good understanding of a topic which allows for an effective transformation and transfer of knowledge. Discussions and sharing experiences with peers are the way, in which he felt, enriches his repertoire of alternative approaches on the same topic. Sharing information is for Ryan one of the most important sources for learning about teaching alongside with constant feedback through practice and experience. The training activities helped Ryan to gain a good understanding of how to teach. He acknowledged the need for transforming the knowledge in accessible forms for students to grasp. He also talks about how important it is to know the topic from multiple perspectives, using a multiapproach to teaching to maximise students' understandings and differentiating.

'I think having, having, like discussions….and I think pair share. You know, I think that's really, really useful where you could talk to other people who are doing the same thing you are… 'sharing ideas is almost as important as when they present us with new material because we need to absorb it. And I think discussing how these applies and how other people are applying it to their practice'… 'it's finding these new and more varied ways of explaining the same thing '.

A good understanding and reasoning on practice is much emphasised in Ryan' narration. He considered that having opportunities to build explanations and analogies and to practice them increases his teaching skills.

'I think the more you explain stuff, the better you get… if your explanation is not simple, you don't really understand it'

For Ryan, confidence in teaching is much over the teaching itself. He started teaching with low confidence which originated in his prior negative experiences in managing behaviour. In his view, confidence arises mainly from 'being constantly in that position', from rehearsing practice and applying multiple perspectives on practice.

'I think most of teaching is about confidence. Very little else is very much important… So, I think in a lot of ways, being confident and knowing what you're doing is really what carries you through teaching…The more times you can do it, and in the more diverse ways that you do it, the more confident you get.'

A central point in gaining confidence is also the feedback and support he receives from mentors and peers and especially a good management of behaviour which give him the feeling of 'control of the classroom'.

'I'll get somebody to come in and help me deal with that, which puts me back in the power position. And I think it's things like that really build confidence'.

From Ryan's interview resulted that confidence and behaviour management are key factors for successful teaching.

I would have said that behavioural management is the biggest thing. For the simple reason that it doesn't matter how good a teacher you are if nobody listens to you. I think that's been one of the biggest steps that I've made. So, though it's not necessarily about my science knowledge or my delivery of science, I think, I think in some ways that's so secondary, you need control of the room, you need to be in charge, and you need to have the kids in a position where they can learn'

Ryan acknowledged some of the challenges as well. The assessment for learning is what he felt needs more support with. The subject knowledge for upper classes was also seen as a weakness. Though, his passion for science gives him intrinsic motivation to improve constantly his practice through deliberate and independent learning and team collaboration - characteristics so needed for 21st century.

'And I certainly know how to resolve problems and find answers myself. And obviously, I've, you know…, created a huge, huge group of colleagues who I can ask, who I can rely on, and I think …that's, also really valuable.'

2. **Ryan's perceived effective features for developing LtTF components & Challenges in learning**

K	*O*	*P*	*U*	*E*	*C/B*
Learning from outside of specialism Watching videos on behaviour management followed by discussions / reasoning on action Reading books on behaviour management Building instructional strategies Sharing experiences	Relevant knowledge Applicable knowledge Cognitive dissonance Goal oriented learning Feeling of authority /Controlling the room.	Applying what has been observed/learned from mentors in practice. Discussions and pair sharing Rehearsing practice Trying out different strategies	Reasoning on action Acknowledging limitations of observations Transformation of knowledge/Transfer of ideas Acknowledging alternative perspectives on practice/alternative strategies for some topic Observing models/teaching Building explanations and analogies Expanding the repertoire of strategies	Familiarity with the context Subject knowledge Feeling as a member of the community Successful experiences Feedback and support Classroom experience Pair learning	Irrelevant knowledge Assessment strategies The models' tacit knowledge Paperwork Uncertainty caused by the pandemic

Sub-Case 3. Laura's learning experiences in the school-based training programme

A short personal background

Laura had a degree in biology and intended to enter straight into teaching at the end of her undergraduate studies. During the final year of her study, she took the opportunity within the University to try out teaching to high school students. Laura realised that she was too close in age to the students and decided to gain some 'life experience' before embarking into teaching. She worked in the pharmacy domain for two years when she entered the training programme to follow her dream – to become a science teacher. During her quest to find the best training programme for herself, she decided that a school- based programme will equip her better with 'how to teach' skills than a HEI based programme. Her expectations from the programme have been much exceeded regarding the amount of work she was expected to do.

At the start of the programme, she found herself 'all over the place' and enveloped in a sheer amount of paperwork and assignments. As she said:

'.... the only thing that really shocked me is how much paperwork there is each week that has to be submitted.'

Laura's perceived effective features for developing LtTF components

With a degree in Biology, Laura felt that she needed knowledge for all the sciences particularly in area outside her specialism. The training activities helped Laura to add to her repertoire of engaging strategies for making science interesting to children as well as differentiation strategies and behavioural techniques. She was interested and found useful to observe how experienced teachers dealt with classroom management and managed to engage students with additional language and SEN.

'I am biology specialist…it's been knowledge with chemistry and physics as well. My knowledge needs to be brought up to what it just like gone over…'

'I've learned ways to make science interesting .... there's a lot of kids that don't find science interesting…, find it really, really, hard… it was useful for seeing things so like, science …is a very practical subject and the room is big enough that students can get up and walk around, unlike in a history classroom or maths classroom. They're literally pending so they can't get up and walk around. So, if you have a student with ADHD like I did, I wanted to see how, how he would behave in that space because he can't get up and walk around. So, what does he do and how does the teacher manage that? And that was really, really, useful just… to see.'

Laura came to acknowledge and appreciate in a short time that teaching is a very challenging profession. Her views and beliefs about science teaching had been much based on her science teachers who made science easy and accessible which contributed to Laura's perceptions about the kind of teacher she 'wanted to be'. Coming to fully acknowledge the complexity of teaching she developed an even more appreciation of experienced teachers who 'can just go into any biology, chemistry or physics at the drop of a hat and teach a lesson'.

'It's just I have even more respect for them now than I did when I was at school, because I know how challenging it must have been to get to that point.'

For Laura teaching experience was central in learning how to teach. She valued being in front of children and applying in lessons the strategies she learned through observation of teachers in her placement schools.

'I think a lot of it is experience. And obviously I'm not going to get that experience until I just get stuck in…I've been in school, and I've been in front of classes and that's been really, really, good……through experience I've been taught how to teach…so I feel like I can differentiate the work, which I didn't even know what that was before I saw teaching... I *feel like my behaviour management is quite good and the kids don't really mess me around… I've been able to take on my own classes and build relationships with those classes.'*

Equally, she valued the activities modelled by instructors during the subject knowledge courses having opportunities to practice those activities and to apply them in her classes.

…at subject knowledge days… usually it'd be practical… just go in over different practical steps that show something really nice… so going over different practical work and practice in those different practical... so I had a chance to do them myself because it's really important…I do like trying out practical... and doing it that way.'

Laura's experiences in the programme helped her not only to acknowledge the complexity of teaching but also to develop her understandings of what means to make the content accessible to students by sequencing. She narrated about an instructor who demonstrated how to break down a difficult concept in chemistry for students to understand.

'It's been how to make it interesting as well when how to break it down for the kids, so they actually understand it and how to chunk it. So, you're not just kind of overwhelming them with information, because if you overwhelm them, they'll straightaway switch off and they won't actually want to learn anything.'

The positive experiences she had in the programme increased her confidence in teaching science. Laura was 'scared' that won't be able to answer to students' questions. She managed to build positive relationships with them and felt that students gave her positive feedback. This coupled with the support she received from colleagues within the school improved her confidence.

…but it has happened a couple of times and, I said, I don't know, can I find out and get back to you next lesson and they were more than happy with that, and I have done… and it's just improved your confidence a little bit…. and it just shows the kids that everyone's still learning that everyone's on a learning journey, so it's a good example…I just pop my head round one of their doors and the head of biology especially, she shares everything with me.

She shares resources like little tips and tricks...If I'm doing a practical, methods, she'll share absolutely everything with me.'

Laura's experiences in the programme were mixed with lots of challenging steps especially at the beginning. As a newcomer to teaching, the support and feedback weighted more in increasing her knowledge and confidence development. Unluckily, she felt that she didn't receive the right support from the mentors that were supposed to guide her. She narrated:

'...experiences with me were with support…. so, you have your personal tutor who is meant to be there for you in... like a pastoral way… and…. although we really get on... sometimes one of some of the things she says isn't particularly supportive… I think she's unnecessarily harsh sometimes…. so, for example, the first time she ever came to watch me, she called my lesson futile… which... that was the first observation I ever had by anyone. And the lesson got called futile, which really upset me actually for quite a long time ….'

The inconsistence of feedback on teaching was something that, Laura felt, hindered her improvement of teaching by leading her into confusion about what was right and not in teaching a lesson. She also felt that it was difficult to find openness for discussions due to the 'busy' time her mentors had.

'Whenever my lessons are observed, they say… okay, these are the two things you need to improve on… so… differentiation and assessment for learning. No one actually, gives me any techniques on how to do that… so they just expect me to know how to do it … so I tried to differentiate a whole lesson the other day and I thought I'd done it really, really, well. And then my feedback was – don't differentiate. So, it's really, really confusing… I just find it so confusing, and it makes it really unclear what is actually expected of you.'

A similar confusion she encountered for lesson plans. She felt she didn't have proper feedback on her lesson plans and sometimes the feedback was misguided or lacked totally. She recognised that planning took her a lot of time at the beginning but through experience 'she became better and quicker at it'. She felt unhappy when the class teacher whose class she was going to teach in, didn't pay careful attention to her plan so that she can prepare an effective lesson, as she narrated:

I send my lesson plans to the teacher of the class that I was going to be teaching. ...sometimes they don't even e-mail back to say that they've received it, or sometimes they'll email back saying, okay, looks good. But then afterwards, when I get my feedback, they'll say, oh, well, why didn't you do this, this, and this? And I say, well, why didn't you tell me that before, so I could have done it before when I went through the lesson plan and then they say, oh, well, I didn't actually have time to read it properly.'

It was clear from Laura's narration that her understandings develop more when she has the opportunity to observe good quality teaching and becoming aware of how different strategies apply in teaching. She valued much the modelled activities that enabled her to see how the experienced teachers transform the knowledge for teaching and how they differentiate the work for children. Yet not always the activities were made explicit, and Laura felt she didn't enhance her knowledge. She remembered an episode outside her specialism:

'*…but like other physics subject knowledge days, it's been very practical, heavy, and then there was no explanation afterwards, so I really struggled with that because…, well the physics specialists understood what was going on and why, but I didn't, so I did this practical and then I had no clue why happened what happened, and then we just moved on to the next practical and there wasn't any explanation to it, actually, I didn't feel like I actually enhanced my knowledge. So, I'd say I do enjoy the practical work, but I think there definitely does need to be a consolidation and an explanation afterwards …even if it's just a couple of bullet points, I'd prefer that, so, there's something to look back over because you can't write a practical down. And when you come to look back over it, to remind yourself of what you did, there's nothing there. So, I do prefer that, but I like an explanation as well.'*

Overall, Laura enjoyed the experiences in the programme and felt adequately prepared for teaching science. In her view, teaching experience does matter most and 'getting used with everything in her school, becoming a permanent, a fully member of the department' was taken as a challenge to reach in the first year of teaching.

3. Laura's perceived effective features for developing LtTF components & Challenges in learning

K	O	P	U	E	C/B
Outside of specialism Engaging strategies Differentiation strategies Behavioural techniques Observing teaching	Challenging assumptions	Teaching experience Practicing activities Applying in the classroom what has been learned Building relationships with children	Observing teaching Acknowledging complexity of teaching Transforming knowledge by sequencing Reasoning on action (explanations)	Positive experiences Positive feedback from students Support from colleagues Teaching experience Subject knowledge Familiarity with the context	Lack of right support (guidance) Inconsistent feedback Lack of feedback Limited discussion on lessons Lack of reasoning on

					modelled activities Sheer amount of paperwork

Sub-Case 4. Freddie's learning experiences in the school-based training programme

A short personal background

Freddie entered the teacher training programme being passioned by science in general and biology, in particular. With a degree in biology and research he enjoyed a science career in an informal context of postgraduate education. He was mainly inspired by his teachers since was a teenager but 'couldn't imagine being teacher in his early 20' in secondary school. He narrated how a few years back, volunteered for a refugee camp where there were schools set up for refugee teenagers to help them with their education. He was impressed by the number and dedication of many teachers around the countries who had spent their weekends trying to educate those teenagers in the refugee camps. His experience in refugee camp, guided the 'spark' in his mind wishing to go into teaching and ‚change people's life and inspire them'. Freddie, initially applied for a different route into teaching which seemed ‚ideal' to his needs, but he was advised to apply for SCITT route because of the experience in preparing career changer people. His expectations from the course were ‚idealistic and naive' based on his initial information that the programme 'was all about getting people into schools as soon as possible'. He was surprised by the intensity and demands of the training programme recognising that he wasn't aware of many of the details and was difficult to know to prioritise things. Like other colleagues he appreciated the ‚gentle introduction' of the first week in which there was an introduction into the things they needed to know 'right at the start'.

Freddie's perceived effective features for developing LtTF components

With no experience in teaching science at secondary level, Freddie had the opportunity to have an ‚extra training' in the first half term which was very valuable for him. Learning knowledge from outside his specialism has been the most useful:

'I would say that the physics training for me has been the most helpful because the trainer is very good and he has very engaging ways of teaching, but also because physics is my weakest subject. The key stage four physics is quite challenging… for me to understand'

Also not having experience in communicating with young students, Freddie valued the pedagogy and behaviour management techniques. He 'had to relearn many ways of communicating' he 'used to do every day' alongside with learning different strategies for differentiation and how to engage students in their learning.

'I think that's the most important thing for me… it's just the basic pedagogy and the basic behaviour management, which all teachers, regardless the subject, have to do…. the kind of things you need to be aware of all the time in classes to make sure that you have a good environment for learning.'

He entered the program with kind of traditional orientations to teaching due to his previous experience of lecturing to postgraduates. He recognised that he 'came in with very kind of idealistic kind of expectations' and was surprised by the difference between teaching to adults and teaching and educating secondary students. He shortly came to acknowledge his 'ingrained habits of standing in front of people and interacting with them' and looked to learn the basic teaching skills that help him to engage students and communicate knowledge 'without sophistication' for students to understand.

'I can still remember the first lesson that I took charge of back in September and realizing how much I was not seeing that I was standing and looking at the class of students… I just was not conscious of because I'm used to dealing with adults… and you don't have to be watching adults all the time because you can trust the adults as being adults. But you obviously can't do that with 13 years old. And so that's I think… that is really, really basic… teacher skills are the most important things.'

For Freddie, basic skills for teaching were paramount in order to change his style of teaching to match the new context. Thus, he valued much the experience of being in front of classes and learning to teach 'by doing'. The modelled activities within the training programme equipped him with teaching skills like timing a lesson, handling practical and doing demonstrations.

So being having the chance to work with children of that level and learn from my own experience about good ways of teaching children has been a really, positive part of the program

I've learned over that time as well about explaining certain scientific topics and addressing misconceptions, handling practical, acting classes, and doing demonstrations, which are all vitally important to science teachers....

A valuable feature that helped Freddie to develop a good understanding of what means to be a science teacher in secondary school was to learn how to convey information to students especially difficult concepts in all the three sciences. He was happy to have the chance to assist to different approaches in making science accessible to students being ‚impressed' by the ‚effective ways' the trainers managed to demonstrate and explain difficult concepts so that students to understand.

I think that different trainers have different styles. So, they're trying to communicate different things in different ways. I think there are some common themes which…to a great extent are concerned with addressing misconceptions…, which is the most important misconceptions, insights that we need to face with our students….and linked with that is the finding of ways to communicate more difficult concepts to the children.

Certainly, Freddie's attention was maximised, given the flow of new innovative ways of teaching, and learning he witnessed. He absorbed as much as he could and thought it was helpful in becoming aware of things that he 'didn't even thought, before'. For him having effective ways to convey information to students was more important than a deep understanding of the content. From the vast experiences he had in his training programme he liked to take with him especially the basics he felt he needed for a start as a science teacher.

‚I think the most important things I've learnt have been some of the most basic things about teaching' '…having seen ways to communicate things that weren't clear to me before… that it's going to help me pass that to students, but also, having really intuitive ways to explain things… I don't necessarily have to have the deep understanding but having an effective way to communicate something effectively without having to articulate things in quite sophisticated way…so having that kind of training as a science trainee outside of a specialism…yeah, we couldn't survive without a good quality training like that'.

Given his prior experiences with adults, Freddie entered the programme 'overconfident about what it was going to be like in the classroom'. Over the course he realised that he had to learn a lot, especially to change his habits. He had a good confidence in subject knowledge and felt that his confidence increased over the course due to a ‚refresh' in subject knowledge and positive experiences.

I started out in September's study overconfident about what it was going to be like in the classroom… and then over the course of the first term, first couple of months, realized how much I need to learn, how much I need to unlearn some habits. I think since January I felt like I've been making good progress and gaining some kind of confidence… this really looks like a word...but gaining some more kind of positivity, actually able to do things reasonably well and …constantly improving… and then by the end of this year, reasonably competent in teaching science.

The support and feedback Freddie received during his training programme, helped him to become aware of his own practice and to build confidence. Although not a fan of writing lesson plans, the support Freddie received for preparing effective lessons had a great contribution to his increased confidence. This was coupled with discussions and sharing experiences and resources with fellow trainees. Also, having successful experiences due to a similarity in style with students' usual teacher, has been useful for improvement.

I've been given strategies before lessons. This I can see it's help in terms of lesson planning and… and pedagogy and explanations and misconceptions before lessons from subject knowledge trainers, from… from the professional, from the subject tutor, as well as my mentors. And… lots of I mean, general advice about how to approach things from my SCITT tutors. I also had some support from my fellow trainees… so all the science trainees share materials... And also, just that at the training days there is… you know…, we talk to each other and we … we share experiences, and we can learn about how we're getting on by talking and seeing how other people are getting on and comparing their experiences'.

However, Freddie's journey through the training programme was not without challenges. He didn't have a proper support and feedback in his first school placement. Because his school mentor 'was going through difficult times' he relied on the schoolteachers for support. Shortly he realised that schoolteachers have other priorities rather that to guide trainees. So, he started in confusion not knowing what worth prioritising was.

'...my first term was really, really tough because I was not getting very much support and I wasn't getting very much feedback about my own teaching in the school. So, it's very hard for me to improve my practice because I wasn't told how to improve…probably I started out being a bit too positive about this since that I wasn't aware… I wasn't aware of what to begin with about how little progress I was making and how little feedback, useful feedback I was getting…. and so probably over the course of that first term, it became clear to everyone that I wasn't doing very well because I wasn't being given the feedback that I needed to improve my practice'.

A common feature among trainees was to learn from observing experienced teachers. Although a lot can be learned from experts, Freddie found sometimes learning from observations of experienced teachers may be ’the most difficult to pick up’. He narrated:

’Naturally many of the fantastic teachers I've seen in school, are really quite hard to emulate because it's not always obvious how what they're doing is working… so when you see very experienced teachers teaching, you are watching them and you're learning from them without really understanding how they're doing, what they're doing…and also, I think, very often they find it very hard to explain what they're doing because it's entirely expressive of them, practically… so they've never actually can articulate perfectly what they're doing…they can't explain it…they're probably not even conscious of it…. many of the times. But what they're doing is using non-verbal cues to the students, doing… having ways of conveying things to students for you…it's… it's not always transparent. So, they are conveying things to the students, and you don't even notice that they're doing it and…that's…. that's difficult and it's... it’s impossible for trainees to really pick up’.

Freddie experiences in the programme are mostly positive and he is happy with what he learned. However, the amount of paperwork he needed to fill in for every lesson took up from his time which he ‘could use more profitably just thinking …. and preparing his teaching material…a bit better’. Also, Freddie felt that the activities were too intense and complex for a beginning teacher and wished a more focus on ‘basics’ so that he can grasp more effectively what is ‘absolute’ necessary for teaching science before building complexity as he explained:

‘I would really be covering the absolute basics of what you have to do in the lesson to begin with and then gradually build up the complexity or build up the sophistication of it. OK, now you can work. Now you can stop running. And probably some people disagree. I think that's the way it goes in practice, at least for me in my experience of this course, I think that we were kind of asked to run a bit before we could walk.’

4. Freddie’s perceived effective features for developing LtTF components & Challenges in learning

K	O	P	U	E	C/B
Knowledge outside of specialism	Challenging assumptions Cognitive dissonance	Teaching experience Handling practical	Transforming knowledge for students	Increased Subject knowledge	The models’ tacit knowledge

Engaging strategies Differentiation strategies Behavioural techniques Observing teaching Questioning strategies	Matching style of teaching	Doing demonstrations Planning lesson, practical/ Demonstrations Reflection	Observing teaching Modelled activities Reasoning on action Multiple perspectives/ approaches Weekly reflexions	Positive experiences Successful lessons Support from tutors Support from peers Discussions Sharing resources Sharing experiences	Lack of feedback on practice Sheer amount of paperwork Intensive and complex activities

Sub-Case 5. Nathan's learning experiences in the school-based training programme

A short personal background

Nathan completed a master's degree in a physics related domain. Before enrolling the teacher training, he was asked to work in school as a physics instructor. After one year of working in school, he decided that he would like to be a science teacher so his decision to be a science teacher appeared more 'from accident'. He didn't come in with 'lots of expectations' because his purpose was to gain a qualification 'to be able to teach'. He knew from the beginning what route to take into teaching, 'deliberately' choosing a school-based route for being able to continue working and gaining experience in school. At the time of this interview, the schools had been closed because of the pandemic COVID 19 which led to the first national lockdown. This was disturbing for all trainees enrolled in the programme because as Nathan said 'that's affected the course slightly for me because it's now no longer a school centred simply because it is closed'.

Nathan's perceived effective features for developing LtTF components

As a physics specialist he felt he needed more knowledge outside his specialism alongside with teaching techniques and classroom management. Having some experience in teaching he was aware about what was expected from teachers to know and do in school. Given this kind of familiarity with the school environment at secondary level, he felt he came in with 'cultural experience' which helped him to 'had a step up amongst people' and to make good progress.

'I kind of expected to be given a bit more knowledge in biology and chemistry because they're

the subjects in science that aren't my specialism. Biology is a lot more complicated than I thought it was. I mean, Physics, essentially, I've been able to teach physics, no problem. But it's things that I've learned …the best ways of approaching the biology topics. I mean, I think that's why I switch on more when it comes to biology, I'm really switched on and focused.…

What Nathan also learned from his training course was how to manage the behaviour of children especially in a science classroom by having opportunities to observe experienced teachers. At some points he could find some discrepancies between what he observed in school placement and what has been told in the course. Yet, he could see that there are many strategies in which a problem can be approached.

I think managing the classroom is one of the biggest things. So being able to pick up on those behaviour management strategies, especially in a science classroom, were really, important. …the most effective form of getting the kids to be quiet came from the most experienced teachers in the science department. As you just go shh, through a whole class, they just stopped talking, so, things I learnt while in my school sometimes differed from what I got taught in the training course.

Gaining school experience before teacher training course it was helpful for Nathan to develop realistic expectations about his own needs. Thus, the course activities didn't change his perceptions about teaching and learning but contributed to his repertoire of teaching strategies. Doing demonstrations and practical work proved to be a good way for Nathan to learn especially in subjects outside his specialism. An effective feature that helped Nathan to add to his teaching repertoire was to see that he can apply in the classroom powerful engaging tools modelled by experienced teachers as he remembered:

' I'm thinking about just watching my mentor from my second placement school. He was teaching a new topic of infra-red radiation, and the way he approached it was …he sets up the experiment exactly, the same way as William Pearson did and then have the students to discover infrared radiation for themselves. So, this was quite a unique way that I've never really considered before, but then I gave it a go myself, and it's, an incredibly engaging tool…so, finding examples of that might be a bit of a challenge, but I think that is the most valuable thing I'll take away from my science teaching this year at home, using historical stories to actually teach about discovery.'

Another line of interest was for him to to see and grasp an understanding of how 'the culture' in a lab is managed by experienced teachers. With science being a very practical subject, seeing how others in similar conditions manage to conduct a practical work whilst using dangerous objects or substances was very useful.

I even went outside of science, and I did a few (observations) in technology. I chose to do that because they're in a similar situation in the sense that they've got a practical lesson. So, while we've got dangerous chemicals and bombs and burners and all that sort of stuff, in technology, they've got like saws, drills, soldering irons, all that equipment. So, it was interesting to see how that culture was also managed.

Nathan’s confidence built on his previous experience in teaching. In his school he had the opportunity to teach to upper classes due to a shortage of physics teachers. Teaching in his own specialism to ‘elite’ classes he could practice teaching in a good environment which gave him confidence in his ability to teach. Also, the control veteran teachers gave him to manage classrooms with children with misbehaviour further increased his confidence.

‘*I was pretty confident … when I started teaching, I was quite excited to be able to share my passion for physics. I was putting originally at A level teaching….so they wanted me to take the elite physics classes… they were quite happy to put me in front of the 30 worst year 10 students who misbehave, and they'd be quite confident in my ability to sort of manage that classroom. I guess my confidence has grown with the accumulation of all these teaching strategies, but I think from the beginning I was quite confident.’*

The support and feedback he received during the programme contributed even further to his confidence improvement. He valued the feedback on his lessons that helped him improve teaching as well as the open dialogue with his mentors and tutors. He also valued he support from colleagues within the school placements.

> ‘there's an incredible amount of feedback. I mean, there's loads of verbal communication, e-mails never go unanswered, so that was really, good…’In both placement schools that I was at, any time you would throw a question to the room, there’ll always be 1 million answers.’

Nathan’s journey through his training programme wasn’t marked by big challenges. He felt adequately prepared for teaching science at secondary level, especially in the school where he experienced already teaching and was familiar to him.

> So, having that confidence of knowing that I might teach science effective and being able to teach at what is considered one of the best schools in the area, so boosted my confidence a lot to up to the point where I really am happy with absolutely everything. I know that I've actually taken a lot off from this course and I'm ready to start teaching in September.

The only challenges for him were to continue writing coursework for assignment and with regard to the changes brought by COVID 19 to the dynamic of the classroom when he would need to adapt the strategies used in normal conditions for demonstrating frontal activities, new strategies that he couldn't observe during his training before school closure.

5. **Nathan's perceived effective features for developing LtTF components & Challenges in learning**

K	O	P	U	E	C/B
Knowledge outside of specialism Engaging strategies Differentiation strategies Behavioural techniques Observing teaching	Familiarity with school expectations Teaching style similarity	Practicing demonstrations Doing practical work Applying in classroom what has been observed	Increasing awareness of multiple perspective/alternative approaches on the same topic Observing teaching Observing modelled activities Explanations and demonstrations	Teaching experience Expanding the repertoire of teaching strategies Support and feedback Collaboration with colleagues Feeling a member of the school	Writing coursework Changes due to COVID 19 teaching.

Sub-Case 6. Sonya's learning experiences in the school-based training programme

A short personal background

Sonya is specialised in physics at a master level and has a research degree in computer science. She conducted a research project in education and technology based in school from where she got her motivation for being a science teacher. During her studies she commuted between towns and felt that was spending much time away from her family not sure if it was 'worthwhile'. She decided to go into teaching to make meaning to her life and a difference in children's life. She was going to choose the route specially created for getting researchers in schools but was more attracted by SCITT route from two reasons: it was more locally, closer to her family, and more based in school which was more favourable since she didn't have much experience in teaching and wanted to 'maximise' her time spent in school. Apart from expecting to spend much time in school she didn't know what else to expect from the course. Therefore, she was surprised by the intensity of the activities which sometimes it felt 'overwhelming' and made difficult to know what needs to be prioritised. Acknowledging that feeling 'busy' may be sometimes 'normal' she focused on her 'motivation' that helped her to go on and to enjoy the overall experiences offered by the programme.

Sonya's perceived effective features for developing LtTF components

Sonya enjoyed and took in knowledge from all the sources offered. Whilst she looked with interest in the subject of biology in which she considered she knew least, she also enjoyed and equally focused on the knowledge in her own speciality. Not only she felt that it passed a long time since she got her degree, but also, she was aware that what she learned at degree level doesn't match the type of knowledge taught at secondary level. Therefore, she was interested to accumulate knowledge about how to explain things to students and what makes difficult for them to understand.

'I've really enjoyed the biology ones because I didn't do A level biology, so it's the one that I do know least about. And so, doing things like dissections, which I've never done before and some of the other practical work, things like extracting DNA from the strawberries and amylase and… I've really enjoyed doing the ones inside my specialism as well… the physics ones, because even when you feel like you know it, and I don't really feel like I know it because it's quite a long time since I did my physics degree and you kind of do a different set of physics in a way at degree level than of what they would learn at high school level'.

From observation of teaching, she came to acknowledge different ways of communicating information to students. Observing others' perspectives or ways of teaching not only brings new insights but also has the potential to change beliefs. As she narrated her beliefs about teaching and learning were more based on a traditional orientation. Seeing different approaches to teaching she realised the importance of having a focus on understanding of aspects of learning for students.

'I guess initially you imagine teaching, standing at the front and talking or, or doing a practical. Actually…, there's a lot of other ways of communicating information… I came into teaching with this idea that with practical work, you would do a lot of kind of a lot of discovery learning, in the idea that they would almost discover it completely for themselves. But I'm realizing, although you might do something which is exploratory, you also really need to make sure that you, kind of back it up with scientific knowledge to make sure that they're really understanding it…and then maybe you go back to the practical work afterwards as well, so they can apply their knowledge as well. So, the practical work isn't just about discovering, but it's also about applying knowledge'.

By having opportunities to practice demonstrations and explanations in a supportive environment and to successfully apply in classroom the strategies observed in lessons was very helpful to probe her teaching effectiveness and improve her practice. When teaching to one another between colleagues she could find what aspects of learning were not well understood by others which gave her the opportunity to improve by having identified what might be students' learning difficulties. Thus, participating in discussions in small groups and reflecting on aspects of teaching was a very valuable feature of her training.

'...practicing explaining it to people who have, like a biology specialism, that is helpful because ... seeing the things that other people find difficult… you know that will be difficult for your students as well…. I observed a teacher teaching a unit and then I taught the same unit with this way of explaining, demonstrating frequency and wavelength using videos…. and that teaching was really, really, effective…

A very valuable feature that helped in improving her practice were also opportunities to repeatedly teach the same topic. By following a sequence of three steps -observing, teaching, and reteaching, Sonya felt that she got a 'really good learning experience' and got 'better than was before'.

'I observe this teacher teaching six lessons and then the next time around I taught basic lesson and then a time after that, I got to teach that unit again before I had to leave. And being able to repeat, first to observe and then to get it and then repeat it and get to be better than I was before… that was a really good learning experience.'

Observing teaching was an effective way for Sonya to develop an understanding of different ways of teaching. However, Sonya acknowledged that seeing different methods of teaching cannot be applied straightforward in the classroom. In her view, to develop teaching skills 'you have to go wrong in order to get it right'.

… watching other teachers and seeing how they teach, trying to think why their lessons go really, well, but also, when you teach…, you learn a lot because… it's a skill…you can know the theory of how to teach, but you also need to learn how to put it into practice. And that's, that's a really hard bit because you have to go wrong in order to get it right.'

When it comes to confidence, Sonya experienced ups and downs. She started being 'nervous' and gradually developed her confidence as she gained more teaching experience. Her confidence decreased when she needed to move to the second placement where the school environment was different and more challenging in terms of behaviour management. Sonya needed to change the things she got used with to match the new requirements. This took her a time till to get used with the new environment, but her previous positive experiences kept her motivation to keep up and raise to the challenges.

’The more I taught, the more confident I got, and I felt much more confident by the end of the first term than the second term…because you suddenly get to move and in the second school everything was a bit different, and the students and pace were a bit different. And I juggled quite a long time to get used to doing it a different way and, and because I found behaviour more challenging there as well’….

The support Sonya had in both the placements as well from the tutors was encouraging. She felt very well supported emotionally in difficult moments. Sonya believes that personal motivation is an important factor for building confidence. And with a proper support and feedback in a friendly environment, what is left depends only on own practice, and as an ‘independent person’, she’s ‘good at asking for help’ when needed.

‘I'm not going to leave the confidence that I built up, but I did at least know that I can get back because, I got back the first time, and I know I can get back again’… I just need to practice more, I think…I don't know if there's anything else…. it's that finding a happy medium and that will take you forward.’

What Sonya considered her ‘real biggest challenge’ was how to manage behaviour of children, where she felt she needed to improve. She recognised that the kind of authority and the feeling to be in charge depends very much on the ‘kind of confidence and a familiarity with the situation’. A thing that she thought would have benefited her more was a more closed collaboration with her colleagues to have the opportunity to share experiences which could be then applied in their classroom.

‘I think it would be nice to see people on a more regular basis…to be out of school one day a week on a regular basis because… sometimes, you want to learn something and be able to apply it the next day… and sometimes… you want to be able to see the other trainees and talk to them on a regular basis. I think you could build up more close relationships with other students if you saw them on a regular basis rather than seeing them intensely for a week and then not seeing them for a long time.’

6. Sonya’s perceived effective features for developing LtTF components & Challenges in learning

K	O	P	U	E	C/B
Knowledge outside of specialism	Challenging assumptions Cognitive dissonance	Practicing explanations and demonstrations	Alternative ways of explaining. Discussions	Teaching experience Rehearsing teaching	Managing Behaviour Lack of collective work/collaboration

Subject knowledge Observing teaching Instructional strategies Differentiation strategies Behavioural techniques Questioning strategies		Doing practical work Rehearsing teaching Microteaching Planning practical work Applying in practice what has been learned. Organising knowledge Creating resources	Reflecting on teaching in small groups Acknowledging limitations Sharing experiences	Motivation Successful/positive experiences Feedback and support Familiarity with the context	with colleagues on a regular basis.

Appendix I. Cross-case analysis for each component of LtTF

Trainee	**Features that develop knowledge**	*Examples of evidence*
Lisa	Knowledge of content Differentiation strategies Assessment strategies Classroom management techniques Knowledge about learners Engaging strategies	I learned a lot of the pedagogy, about what's required in terms of assessment and differentiation and behaviour management I gained a lot of knowledge about the pupils I teach
Ryan	Learning from outside of specialism Watching videos on behaviour management Discussions / reasoning on action Reading books on behaviour management Building instructional strategies Sharing information	For me, this course mainly is providing me with a lot of biology knowledge, which, which is fascinating.' you can see how he responds to the kids and then he gives you a little bit like a live chat afterwards, you get this whole overall picture of what he's really doing was very informative on application. So, how you can apply it, misconceptions of the knowledge and things to look out I think the more you explain stuff, the better you get.
Laura	Knowledge from outside of specialism Engaging strategies Differentiation strategies Behavioural techniques Observing teaching	'I am biology specialist…it's been knowledge with chemistry and physics as well I wanted to see how he would behave in that space because he can't get up and walk around. So, what does he do and how does the teacher manage that? through experience I've been taught how to teach…so I feel like I can, and I feel like I can differentiate the work, which I didn't even know what that was before I saw teaching… I've learned ways to make science interesting. some of the techniques that he came up with to help engage them
Freddie	Knowledge outside of specialism Engaging strategies Differentiation strategies Behavioural techniques Observing teaching Questioning strategies	physics training for me has been the most helpful .. it's just the basic pedagogy and the basic behaviour management, the kind of things you need to be aware of all the time in classes to make sure that you have a good environment for learning But the range of things you'd need to think about… different activities and tasks for the students… for different students…. I just I didn't know about that kind of thing. explaining certain scientific topics and addressing misconceptions, handling practical

		acting classes, and doing demonstrations, which are all vitally important to science teachers
Nathan	Knowledge outside of specialism Engaging strategies Differentiation strategies Behavioural techniques Observing teaching	it's things that I've learned of really the best ways of approaching the biology topics I was expecting to get a lot of teaching techniques, so how to differentiate work properly, so being able to pick up on those behaviour management strategies, especially in a science classroom, were really, important. if anything, that I've learned from being in my placement schools is that there are many ways of teaching the same topic.
Sonya	Knowledge outside of specialism Subject knowledge Observing teaching Instructional strategies Differentiation strategies Behavioural techniques Questioning strategies	I've really enjoyed the biology ones because I didn't do A level biology, so it's the one that I do know least about the behaviour management side of things, which is my real biggest challenge the things like no hand's up methods, that with the questioning; that was one thing that I have tried in the classroom, and it does work I observed a teacher teaching a unit and then I taught the same unit with this way of, explaining

Trainees	**Features that challenge orientations**	
Lisa	Cognitive dissonance Goal oriented teaching	Things have changed a lot and I haven't done science for a long time. I was thinking I'd be following that up by doing similar things maybe to a higher level, but I found that I haven't, yet.
Ryan	Relevant knowledge Applicable knowledge Cognitive dissonance Goal oriented learning Feeling of authority /Controlling the room.	but it's the teaching I want to do, so it's like everything I read and everything in all the training stuff that we do, I'm looking for - How can I use this? How is this going to help me teach in the future? And of course, how am I going to remember it? you need control of the room; you need to be in charge, and you need to have the kids in a position where they can learn' I taught the way I was taught. You know, I was, when I went to school, the teachers stood at the front and so that's sort of my perception of teaching. We stand at the front and lecture, but what I've discovered is, it's doing the learning for kids
Laura	Challenging assumptions	I knew what kind of a science teacher I wanted to be based on them.

Freddie	Challenging assumptions Cognitive dissonance Matching style of teaching	… I came in with very kind of idealistic kind of expectations I was not seeing that I was standing and looking at the class of students… It's just seeing the techniques that people use and those ….and seeing how best teachers are teaching now, which is different from how method was taught when I was in school I'm more of an introvert and more of a bookish kind of person. I'm never going to be that kind of student teacher. that's something I can appreciate as a trainee, but I'm not so likely to put into practice
Nathan	Teaching style similarity	my first mentor was a biologist, but thankfully, our teaching styles were reasonably similar
Sonya	Challenging assumptions Cognitive dissonance	I think, well, they're still changing, so I don't know where I am, but I guess initially you imagine teaching, standing at the front So, the practical work isn't just about discovering, but it's also about applying knowledge.

Trainees	**Features that develop practice**	
Liza	Practicing the strategies learned Applying in practice what has been learned in the course Reteaching lessons Conducting practical/experiments Guided lesson planning Hands on activities	I've learned practical skills about timing of a lesson, pace of lesson, how to conduct practical experiments, it is putting things I've learned into practice from the course One of the things that benefited me most was reteaching a lesson that hadn't engaged the pupils the first time I taught it... I felt that I'd incorporated more of the strategies I'd learnt on the course we had lots of hands-on activities doing some of that required practical in the laboratory.
Ryan	Applying what has been observed/learned from mentors in practice. Discussions and pair sharing Rehearsing practice Trying out different strategies	, watching them and then trying what they did and those kinds of things.' I've used it in the class as well. And it really does work. Those kinds of strategies are simple things that you can remember and then just apply
Laura	Teaching experience Practicing activities Applying in the classroom what has been learned Building relationships with children	I've been in school, and I've been in front of classes and that's been really, really, good. We've kind of been taught how to teach. I've been able to take on my own classes or build relationships with those classes. the lesson planning took ages, but I am getting better at it

		so going over different practical and practice in those different practical... so I had a chance to do them myself because it's really, important we had a couple of sessions with several rules on behaviour management and that was really, really, useful at the start of the year because you could immediately apply to your classes
Freddie	Teaching experience Handling practical Doing demonstrations Planning lessons Reflection	the most basic things about how to construct a lesson, how…. how to engage them in the learning process it's been good to be forced into thinking about certain things before the lessons and the forms we have to be filled in encourage us to think about certain things. it's good practice always to practice your demonstrations or your practical
Nathan	Practicing demonstrations Doing practical work Applying in classroom what has been observed Observing effective teaching	Physical demonstrations doing practical work is often one of the best ways for me to learn I've modelled my teaching on this chap's teams and this maths teacher is teaching just because his form of differentiation and its cultural management are incredibly effective. We were able to demonstrate a lot of these experiments it was interesting to see how that culture was also managed being in his classrooms was incredibly
Sonya	Practicing explanations and demonstrations Doing practical work Rehearsing teaching Microteaching Planning practical work Applying in practice what has been learned Organising knowledge Creating resources	then practicing explaining it to people… is helpful because it gives you, seeing the things that other people find difficult, so that, you know that will be difficult for your students as well I really, generally like the way that they delivered it because there is a lot more practical work and hands on and discussion and being able to repeat…that was a really, good learning experience. I observed a teacher teaching a unit and then I taught the same unit with this way of, explaining we just did the knowledge organizer as an activity, and I found that focused my reading around the subject I generally plan over lessons myself. I make some of my own resources

Trainees	**Features that develop understandings**	

Lisa	Using different resources Developing insights from observing teaching Acknowledging strategies for managing behaviour of children/engaging strategies/strategies that work Awareness of differentiation strategies Acknowledging the complexity of teaching	From my observations, I've learned very different strategies that you need for managing the children I've really learned the role of the teacher I understand the importance of teaching knowledge, recall practice and questioning and how important that is in science teaching. So, I have had to moderate in my teaching to take this into account
Ryan	Reasoning on action Acknowledging limitations of observations Transformation of knowledge/Transfer of ideas Acknowledging alternative perspectives on practice/alternative strategies for the same topic Observing models/teaching Building explanations and analogies Expanding the repertoire of strategies	I think being able to get the ideas across is something that really, it's teaching I think that's really, really useful where you could talk to other people who are doing the same thing you are.' And I think discussing how these applies and how other people are applying it to their practice' it's finding these new and more varied ways of explaining the same thing
Laura	Observing teaching Acknowledging complexity of teaching Transforming knowledge by sequencing Reasoning on action (explanations)	It's been how to make it interesting as well when how to break it down for the kids, so they actually understand it And he said, I do it like this and then he taught us as if we were his class and he broke it down just using whiteboard pens…
Freddie	Transforming knowledge for students Observing teaching Modelled activities Reasoning on action Multiple perspectives/ approaches Weekly reflexions	I think it's just given us a lot of thought… say in practice, when he was a physics teacher The chemistry training was very good at providing ways of explaining difficult concepts the biology training, again, has focused quite a bit on looking at common misconceptions and some of the practical rules learning from the teachers within schools… ways of managing that information learned in individual lessons and using…. recall kind of quizzes to boost memorization. I've seen similarities in the tools in my two placement schools in approaches for doing different things as well as differences. It's been very interesting,

		we have been given a range of strategies which …which I've used, and I will continue using and in which I was not aware of at the start and the reasons why.
Nathan	Increasing awareness of multiple perspective/alternative approaches on the same topic Observing teaching Observing modelled activities Explanations and demonstrations	this was quite a unique way that I've never really considered before I mean, that was incredibly engaging. We were able to demonstrate a lot of these experiments and not just physics, but biology and chemistry really , if anything, that I've learned from being in my placement schools is that there are many ways of teaching the same topic. I was expecting to get a lot of teaching techniques, so how to differentiate work properly,
Sonya	Alternative ways of explaining Discussions Reflecting on teaching in small groups Acknowledging limitations Sharing experiences	there's always a different way to explain it, so, hearing somebody else explain it gives you something different, we all were students together, then practicing explaining it to people who have like a biology specialism, that is helpful , you can know the theory of how to teach, but you also need to learn how to put it into practice. it really gives you those ideas, you get to see different teaching methods

Trainees	**Features that develop efficacy**	
Lisa	Subject knowledge Pedagogy knowledge Teaching experience Building relationships with children	it's my increased subject knowledge, the increased pedagogy knowledge and, having the opportunity to try and put into practice some of the things I've learnt and getting to know the students
Ryan	Familiarity with the context Subject knowledge Feeling as a member of the community Successful experiences Feedback and support Classroom experience Pair learning	’ You need help from and support in in trying to achieve the goals that you need. They were fantastic in offering advice and resources and things like that. it's more being constantly in that position’ The more times you can do it in, and in the more diverse ways that you do it, the more confident you get’ ‘it's a constant feedback process’ ‘it's reflecting on what did work, what didn't work ‘I'll get somebody to come in and help me deal with that, which puts me back in the power

		position. And I think it's things like that really build confidence' , I've, you know, create a huge, huge group now of colleagues who I can ask who I can rely on
Laura	Positive experiences Positive feedback from students Support from colleagues Teaching experience Subject knowledge Familiarity with the context	And it's just improved your confidence a little bit when, like you can admit, it's fine to admit you don't know something She shares resources like little tips and tricks I think a lot of it is experience. And obviously I'm not going to get that experience until I just get stuck in getting used to everything in my school, so actually becoming like a permanent, fully member of the department
Freddie	Increased Subject knowledge Positive experiences Successful lessons Support from tutors Support from peers Discussions Sharing resources Sharing experiences	'He shared all of his resources and he has a website, a web store that we can access those resources I will use'. 'My confidence in that regard has increased because I've refreshed my knowledge.' 'Actually, able to do things reasonably well and a little confidence… constantly improving and then by the end of this year, reasonably competent in teaching science. my personal tutor has always been…. always been fantastic and very supportive…and, you know, we had to have reflections every' 'So, when I'm in her classes, things tend to go quite well because the students kind of see me as a normal kind of teacher because I'm quite similar to their usual teacher and it's just worked quite well as well as for lesson materials that have been provided from the school, I've been given strategies before lessons. This I can see it's help in terms of lesson planning and… and pedagogy and explanations and misconceptions before lessons from subject knowledge trainers, from… from the professional, from the subject tutor, as well as my mentors. And… lots of I mean, general advice about how to approach things from my SCITT tutors.
Nathan	Teaching experience Expanding the repertoire of teaching strategies Support and feedback Collaboration with colleagues	I think managing the classroom is one of the biggest things they'd be quite confident in my ability to sort of manage that classroom my confidence has grown with the accumulation of all these teaching strategies

	Feeling a member of the school	I was able to get feedback of many of the areas where I could improve So, there's an incredible amount of feedback There's always loads of support from colleagues at school. we (mentor)were able to communicate quite a lot on the physics side of things ...The fact that he'd ask me for ideas or how to teach something, having that confidence of knowing that I might teach science effective being able to teach at what is considered one of the best schools in the area, so boosted my confidence
Sonya	Teaching experience Rehearsing teaching Motivation Successful/positive experiences Feedback and support Familiarity with the context	I think my confidence has gone up and down. I think, so, the first term I was really, nervous to start with. And the more I taught, the more confident I got I got back the first time, and I know I can get back again they really want you to feel positive and they really want to help me it's that finding a happy medium and that will take you forward but then you might have a good lesson a few days later or even the next day and then things feel better again

Trainees	**Challenges and Barriers**	
Lisa	Sheer amount of planning Insufficient support and feedback Lack of alignment between theoretical part of the course and practice Lack/access of resources Intensity of the activities Lack of discussions	I don't feel I've had that much support or guide on lesson planning and what works well in terms of differentiation. I think feedback is something that maybe could be improved. We don't actually have the chance to put into practice until a lot further down the line by which time there's been so much other information thrown at us. Some people get a lot more support than others at the start with what's available to them to use in terms of resources and schemes of work to follow.
Ryan	Irrelevant knowledge Assessment strategies Tacit knowledge	observations of teachers don't necessarily show you the surface,
Laura	Lack of right support (guidance) Inconsistent feedback Lack of feedback	so, I did this practical and then I had no clue why happened what happened… and then we just moved on to the next practical

	Limited discussion on lessons Lack of reasoning on modelled activities	and there wasn't any explanation to it…actually, I didn't feel like I actually enhance my knowledge And the lesson got called futile, which really upset me actually for quite a long time I just find it so confusing, and it makes it really unclear what is actually expected of you.
Freddie	The models' tacit knowledge Lack of feedback on practice Sheer amount of paperwork Intensive and complex activities	I still kind of resent quite a bit having to write up this for every lesson because it feels like it's time would really be covering the absolute basics of what you have to do in the lesson to begin with and then gradually build up the complexity or build up the sophistication of it. OK, now you can work. Now you can stop running. because I was not getting very much support and I wasn't getting very much feedback about my own teaching in the school. So, it's very hard for me to improve my practice because I wasn't told how to improve… I haven't realized the extent to which when you're in schools, you're relying on help from teachers who are so busy with their own work naturally many of the fantastic teachers I've seen in school, are really, quite hard to emulate because it's not always obvious how what they're doing is working he schools as a whole in my first placement was not very supportive…they didn't have structures in place to guide trainee teachers through their training, so the teachers didn't have much time to devote to my requirements. And so, I didn't get very much feedback from my… from my fellow… from my colleagues in my first placement school…so I was relying more on my SCITT tutors… … I wasn't aware of what to begin with about how little progress I was making and how little feedback, useful feedback I was getting…. and so probably over the course of that first term, it became clear to everyone that I wasn't doing very well because I wasn't

		being given the feedback that I needed to improve my practice
Nathan	Writing coursework Changes due to COVID 19 teaching.	It's just how am I going to change the dynamics of the classroom, and then will I be able to adapt to that style of class,
Sonya	Behaviour management Lack of collective work/collaboration with colleagues on a regular basis	the behaviour management side of things, which is my real biggest challenge, and I'm still really working on it you want to be able to see the other trainees and talk to them on a regular basis. I think you could build up more close relationships with other students, if you saw them on a regular basis rather than seeing them intensely for a week and then not seeing them for a long time,

Appendix J. Informed Consent Form

The University of Suffolk expects all research to be carried out in accordance with the following principles:

- The emotional well-being, physical well-being, rights, dignity, and personal values of research participants should be secured.
- Research participants and contributors should be fully informed regarding the purpose, methods, and end use of the research. They should be clear on what their participation involves and any risks that are associated with the process. These risks should be clearly articulated and if possible quantified.
- Research participants must participate in a voluntary way, free from coercion. Participants have the right to withdraw at any time.

This research has been approved by the University of Suffolk Ethics Panel. Should you have any concerns about the Ethics of this research, please feel free to contact the Chair of the Ethics Panel, Professor Emma Bond e.bond@uos.ac.uk (01473 338564) or the Research Development Manager, Andreea Tocca a.tocca@uos.ac.uk (01473 338656).

Study Title: Supporting student science teachers' knowledge and efficacy beliefs for teaching and learning science

Main Investigator: PhD. Student: Violeta Negrea

Academic Supervisor (for Student Research): Prof. Nic Bury; Dr Clare Gartland; Dr Cristian Dogaru

Please initial the boxes below.

I confirm that I have read and understand the information sheet dated 20/04/20 explaining the above research project and I have had the	☐

☐

opportunity to ask questions about the project. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. I understand that my responses will be anonymised and any personal or identifying information removed from published materials I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. I understand that the data I provide will be used solely for the purposes of the research study outlined and will not be used for any other purpose. I also understand how long my data will be stored for.	☐ ☐ ☐

I agree to take part in the above research project.	☐

______________________	______________	________________
Name of Participant	Date	Signature
______________________	______________	________________
Researcher	Date	Signature

I understand that the contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk. I understand that for any issues or questions regarding this research that were not satisfactorily addressed I may contact Prof. Nic Bury, Supervisor, Suffolk University, Ipswich, e-mail address: n.bury@uos.ac.uk or Dr. Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr. Cristian Dogaru, email address: c.dogaru@uos.ac.uk

Participation Information Sheet

PhD Research Title: Supporting student science teachers' knowledge and efficacy beliefs through high quality training activities

PhD Student: Violeta Negrea

Academic supervisors: Prof. Nic Bury; Dr. Clare Gartland; Dr. Cristian Dogaru

Dear science teacher,

You are invited to take part in a study on supporting student science teachers' knowledge and confidence in teaching science at the secondary level.

I am currently conducting research towards my PhD at Suffolk University. The purpose of the research is to explore ways in which science teachers can better be supported in developing their knowledge and confidence in teaching science. I believe that your input will be a very valuable source of information for completing my thesis, and I would like to invite you to join the study.

To complete this research project, it is important to know what and how student teachers learn during their training programme and how they understand their own learning. I am asking your permission to directly observe some of the activities during your coursework.

During the observation, I'll join you in activities and take notes about the daily routine such as the activities delivered, strategies used, kinds of feedback and support, interrelationships, etc.

You will not be asked to do or say anything in particular. I will make efforts that my presence does not disturb the natural course of the activities.

All the observations will be reported in a manner in which individuals and the institution in which they learn cannot be identified, so the right to anonymity and confidentiality will be respected.

The observation data will be used to inform a model of instruction which has the potential to enhance science teachers' knowledge and confidence in teaching science.

All the information will be kept securely on a computer with password protection no longer than necessary for allowing further writing and publishing.

Your participation is voluntarily, and you will have the right to withdraw within one week after the interview takes place, without any explanation.

If you are happy for me to join you in activities during the course, please fill out in the attached form on the next pages. Thank you in advance for your consideration.

Yours sincerely,

Violeta Negrea

PhD student

The contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk For any issues or questions regarding this research that are not satisfactorily addressed you may contact Prof. Nic Bury, Supervisor, e-mail address: n.bury@uos.ac.uk or Dr Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr Cristian Dogaru, email address: c.dogaru@uos.ac.uk

Questionnaire Cover Letter

Dear science teacher,

You are invited to participate in a study titled "Supporting student teachers' knowledge and efficacy beliefs for teaching and learning science at the secondary level. I am a PhD student at Suffolk University working towards my thesis and I would really appreciate your input. The purpose of the study is to explore ways in which science teachers can better be supported in developing their knowledge and confidence in teaching science at the secondary level.

To conduct this research project, it is important to know trainees' professional needs and expectations at the beginning of a training programme. Understanding their views and needs is a first step for designing an effective training activity. The questionnaire should take no more than 5 minutes to complete. Individual responses to this questionnaire are kept confidential and anonymous.

The information you reveal will be used to inform a framework for learning which has the potential to enhance science teachers' knowledge and confidence more effectively in teaching science. The data will be kept securely for 5 years to allow further writing and publication and then destroyed. You may also need to know that your participation is voluntary and have the right to withdraw without any explanation.

Thank you in advance for your time and assistance with this research project.
Yours sincerely,
Violeta Negrea
PhD student
Suffolk University

The contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk. For any issues or questions regarding this research that are not satisfactorily addressed you may contact Prof. Nic Bury, Supervisor, e-mail address: n.bury@uos.ac.uk or Dr Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr Cristian Dogaru, email address: c.dogaru@uos.ac.

Participation Information Sheet

(For the course observation; for the whole cohort of student teachers)

PhD Research Title: Supporting student science teachers' knowledge and efficacy beliefs through high quality training activities

PhD Student: Violeta Negrea

Academic supervisors: Prof. Nic Bury; Dr Clare Gartland; Dr Cristian Dogaru

Dear science teacher,

You are invited to take part in a study on supporting student science teachers' knowledge and confidence in teaching science at the secondary level.

I am currently conducting research towards my PhD at Suffolk University. The purpose of the research is to explore ways in which science teachers can better be supported in developing their knowledge and confidence in teaching science. I believe that your input will be a very valuable source of information for completing my thesis, and I would like to invite you to join the study.

To complete this research project, it is important to know what and how student teachers learn during their training programme and how they understand their own learning. I am asking your permission to directly observe some of the activities during your coursework. During the observation, I'll join you in activities and take notes about the daily routine including the activities delivered, strategies used, kinds of feedback and support, interrelationships, etc. You will not be asked to do or say anything in particular. I will make efforts that my presence does not disturb the natural course of the activities. All the observations will be reported in a way that individuals and the institution in which they learn cannot be identified, so the right to anonymity and confidentiality will be respected. The observation data will be used to inform a model of instruction which has the potential to enhance science teachers' knowledge and confidence in teaching science. All the information will be kept securely on a computer with password protection no longer than necessary for allowing further writing and publishing. Your participation is voluntarily, and you will have the right to withdraw without any explanation.

If you are happy for me to join you in activities during the course, please fill out your name on the next page. Thank you in advance for your consideration.

Yours sincerely,

Violeta Negrea

PhD student

The contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk For any issues or questions regarding this research that are not satisfactorily addressed you may contact Prof. Nic Bury, Supervisor, e-mail address: n.bury@uos.ac.uk or Dr Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr Cristian Dogaru, email address: c.dogaru@uos.ac.uk

Participation Information Sheet
(For selected interview participants)

PhD Research Title: Supporting student science teachers' knowledge and efficacy beliefs through high quality training activities
PhD Student: Violeta Negrea

Academic supervisors: Prof. Nic Bury; Dr. Clare Gartland; Dr. Cristian Dogaru

Dear science teacher,

Thank you for taking part in the study so far. Your participation has been very valuable to the study. You are further invited to take part in the study on supporting student science teachers' knowledge and confidence in teaching science at the secondary level. The purpose of the study is to explore ways in which teachers can more effectively be supported in their knowledge and teaching skills development. Your input continues to be a very valuable source of information for completing this study, and I would like to invite you for a one-to-one interview. The interview will take place at a convenient time and place and should last approximately 40 minutes. In the interview you will be asked to talk about your views and experiences within the programme. I will be recording the interview to transcribe it and check for accuracy. Transcripts will be anonymised as far as possible, and a pseudonym used. You may be quoted in the study, but it will be done in such a way that your identity will not be revealed. The people and schools you may mention will also be anonymised.

The findings will be summarized and shared with you to verify that the findings are a true reflection of your experiences. All the data that is collected will be kept confidential. Transcripts will be kept for a maximum of three years after the project ends to allow time for further writing and publication and then destroyed. Once you participate in the interview you further have the right to withdraw up to one month after the interview takes place.

There are not risks associated with you personally. However, I recognise that, to participate you need to give up some of your free time. This is much appreciated, and I hope the study may benefit you by gaining valuable knowledge and better understanding of the teaching profession. Refreshments will be offered on site to compensate you if you miss lunch or a coffee/tea break. Your participation is voluntarily. Please fill out your name on the next page and return to me at your earliest convenience. Thank you in advance for your consideration.

The contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk For any issues or questions regarding this research that are not satisfactorily addressed you may contact Prof. Nic Bury, Supervisor, e-mail address: n.bury@uos.ac.uk or Dr Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr Cristian Dogaru, email address: c.dogaru@uos.ac.uk

Yours sincerely,
PhD student: Violeta Negrea

Site Consent Form

Violeta Negrea, UCS, S176150

June 2019

To

Gatekeeper for Norfolk and Suffolk SCITT Centre

Dear course leader,

I am currently a PhD student at Suffolk University. I am conducting a qualitative case study to explore trainee secondary science teachers' learning experiences within their training programme. The purpose of the research is to identify approaches through which science teachers can more effectively be supported in developing their knowledge and confidence in teaching science at a secondary level. To complete this research project, I must collect data in three phases: a questionnaire at the beginning of the programme; direct observations of some of the training activities and a semi-structured interview at the end of the semester. The questionnaire will gather data about trainees' background and their perceived confidence in teaching science. It will take around 5 minutes to complete. During the observation of the training activities, I will be observing the daily routine, including the activities delivered to trainee and how they learn and make sense of their learning. The interview, which will be focused on a few participants and their trainers, will give more insight in their learning experiences, and clarify the observed activities. During the interviews, I will be taking notes and recording the interview to transcribe it, as well as re-listen to the interview. I will summarize and share my findings with the participants to verify that the findings are a true reflection of their experiences. The findings will be used to inform a model of instruction which has the potential to support both trainers and their trainees in enhancing their knowledge and confidence in teaching science. All the information collected will be kept confidential and not be used in any evaluative manner. The institution and all the participants will be anonymised. The data will be stored securely in a locked drawer and on a computer with password protection, no more than necessary for further writing and publishing.

I am requesting permission to pursue this research with science teacher voluntary participants within your facility. If you have any questions or concerns regarding this research, please do not hesitate to ask. Thank you in advance for your time, consideration, and support.

Sincerely,

Violeta Negrea

The contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk

For any issues or questions regarding this research that were not satisfactorily addressed I may contact Prof. Nic Bury, e-mail address: n.bury@uos.ac.uk or Dr. Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr. Cristian Dogaru, email address: c.dogaru@uos.ac.uk

By providing a signature below, I agree to permit and support Violeta Negrea' s access to this site so that she can collect data from science teachers who have agreed to participate in the above-described research exploring their perceptions and experiences within the programme.

Name(print):______________________________ Signature: ________________________________ Date:___________________

Participant Information Sheet

(For the educator)

Study Title: Supporting student science teachers' knowledge and efficacy beliefs through high quality training activities

PhD student: Violeta Negrea

Academic Supervisors: Prof. Nic Bury; Dr. Clare Gartland; Dr. Cristian Dogaru

Dear course leader,

You are invited to take part in a study on supporting student science teachers' knowledge and confidence in teaching science at the secondary level.

I am currently conducting research towards my PhD at Suffolk University. The purpose of the study is to explore ways in which science teachers can better be supported in developing their knowledge and confidence in teaching science at the secondary level. Your input and experience will be a very valuable source of information and I would very much appreciate it if you would agree to join the study. To complete this research project, I will be conducting interviews with the ITT leaders and tutors to collect information about their perceptions as instructors regarding the current approaches to teaching and learning science. The interview will last around 40 minutes and will take place at a convenient time and location. I will be recording the interview to transcribe it and check for accuracy. You may be quoted in the study, but your identity will not be revealed. The people you may mention will also be anonymised. I will summarise and share my findings with you to check for accuracy. Transcripts will be stored securely for a maximum of five years after the project ends to allow time for further writing and publication and then destroyed. You will still have the right to withdraw if you change your mind in one month after the interview takes place.

There are not benefits or risks associated with you directly. However, the research will reveal some information about teaching and learning science that may interest you. I recognise that, to participate you need to give from your free time. While this is much appreciated, there will be compensations for your missing lunch or coffee/tea break. Your participation is voluntarily. If you agree to participate in this qualitative research case study, please fill out your name on the next page and return to me at your earliest convenience. Thank you in advance for your consideration.

Yours sincerely,

Violeta Negrea

PhD student

The contact person for any questions regarding this research is Violeta Negrea, e-mail address: v.negrea@uos.ac.uk. For any issues or questions regarding this research that are not satisfactorily addressed you may contact Prof. Nic Bury, Supervisor, e-mail address: n.bury@uos.ac.uk or Dr. Clare Gartland, e-mail address: c.gartland@uos.ac.uk and/or Dr. Cristian Dogaru, email address: c.dogaru@uos.ac.uk

Appendix K. Ethics Approvals

University of Suffolk

Waterfront Building,
Neptune Quay,
Ipswich IP4 1QJ

+44 (0)1473 338 000
info@uos.ac.uk
uos.ac.uk

14 August 2019

Project Lead: Violeta Negrea
Subject: Supporting student science teachers' knowledge and efficacy beliefs through high quality training activities
Type of study: Postgraduate Research
Start Date: 2 September 2019
End Date: 1 January 2021
Primary Supervisor: Professor Nic Bury
Second Supervisor: Dr Clare Gartland and Dr Cristian Dogaru

Dear Violeta

Following the submission of your application for ethical approval to the Committee on 12 August 2019, the University of Suffolk Research Ethics Committee have reviewed your application to conduct the above mentioned study with yourself as the Principal Investigator.

The Committee discussed the application and I have approved the application via Chair's action on condition, that you must attend the next available research ethics training session within the Researcher Development Programme. You cannot proceed with your research study until you have attended the Ethics workshop.

The Graduate School will be circulating dates for future sessions, which will start in the next academic year or, if easier, at UEA at your earliest opportunity. Research Ethics Training is compulsory for students intending to submit an application for ethical approval.

The University Research Ethics Committee expects to be informed about the progress of the study, any revision in the protocol and participant information/informed consent or participant related documents and ask to be provided a copy of the final report.

This Ethics committee is working in accordance to the University of Suffolk research governance guidelines, policies and procedures.

Yours sincerely

Emma Bond

Professor Emma Bond
Director of Research and Chair of the University Research Ethics Committee
University of Suffolk

CC – All three supervisors: Prof Nic Bury, Dr Clare Gartland and Dr Cristian Dogaru

Changes to Ethics Approval Permission
Amendment Form

Researcher details:	
Name:	**VIOLETA NEGREA**
School:	Heritage and Education
University of Suffolk email address:	**v.negrea@ucs.ac.uk**
If this is a student project:	
Student ID:	**S176150**
Course title:	
School:	
Supervisor/tutor name	**Nic Bury, Clare Gartland, Cristian Dogaru**

<u>VERSION and DATE for the new documents</u>
(Proposal, PIS, ICF and/or other relevant documents)
Please describe the nature of the change and impact on ethics:

Replacing the face-to-face interviews with phone/virtual interviews.

The change does not have impact on ethics. Anonymity in reporting, confidentiality, voluntary, and informed consent will be adhered to. The participants will receive the Informed Consent Form and Participation Information Sheet via email. Also, data will be protected and erased at the time specified in the previous Ethics form.

PLEASE SIGN AND DATE:

For Student Research:

SUPERVISOR ……………………………

STUDENT…

DATE 1/4/20

University of Suffolk

Waterfront Building,
Neptune Quay,
Ipswich IP4 1QJ

+44 (0)1473 338 000
info@uos.ac.uk
uos.ac.uk

22 April 2020

Project Lead: Violeta Negrea
Subject: Supporting student science teachers' knowledge and efficacy beliefs through high quality training activities
Type of study: Postgraduate Research
Start Date: 2 September 2019
End Date: 1 January 2021
Primary Supervisor: Professor Nic Bury
Second Supervisor: Dr Clare Gartland and Dr Cristian Dogaru
Paper Number: RETH19/004

Dear Violeta

Following the re-submission of your application for ethical approval to the Committee on 27 March 2020, from your supervisor Prof Nic Bury, about the modification to your research project (including all amended documents from you on 21 April 2020) the University of Suffolk Research Ethics Committee have reviewed your application to conduct the above mentioned study with yourself as the Principal Investigator.

The Committee considered the application with all the modifications and agreed there were no ethical concerns and therefore I am happy to approve this via Chair's action.

As principal investigator, your responsibilities include:

- ensuring that (where applicable) all the necessary legal and regulatory requirements in order to conduct the research are met, and the necessary licenses and approvals have been obtained;
- approval by the University Research Ethics Committee should not be taken as evidence that the study is compliant with GDPR and the Data Protection Act 2018. You are expected to have completed the GDPR training and follow the guidance from https://www.ukri.org/files/about/policy/ukri-gdpr-faqs-pdf/. Final responsibility for GDPR compliance remains with you;
- reporting any ethics-related issues that occur during the course of the research or arising from the research to the University of Suffolk Research Ethics Committee to the Committee Secretary, Sue at s.raychaudhuri@uos.ac.uk (eg. unforeseen ethical issues, complaints about the conduct of the research, adverse reactions such as extreme distress);
- submitting details of proposed substantive amendments to the protocol/proposal to the University of Suffolk Research Ethics Committee for further approval.

Yours sincerely

Emma Bond

Professor Emma Bond
Director of Research and Chair of the University Research Ethics Committee
University of Suffolk