UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND PHYSICAL SCIENCES

Chemical Education

The role of subject matter knowledge in teaching A level chemistry

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Thesis for the Degree of Doctor of Philosophy

November 2021

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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THE ROLE OF SUBJECT MATTER KNOWLEDGE IN TEACHING A LEVEL CHEMISTRY

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Students may develop misconceptions when studying chemistry, either due to their own personal experiences and beliefs or due to their instruction. Specialist and non-specialist chemistry teachers have also been observed to possess chemical misconceptions and may pass these on when teaching. It can be said that a teacher's subject matter knowledge (SMK) is an important aspect of their teaching, influencing their pedagogical practice, and that enhancing their SMK can improve their teaching. Although the importance of SMK in chemistry teaching has been noted, it is unclear what the extent of a chemistry teacher's knowledge should be, and which topics are of most concern.

To investigate teachers' beliefs regarding the role of SMK in A level chemistry teaching, an exploratory study was undertaken to identify topics of low confidence, the impact of undergraduate degrees and initial teacher training (ITT) on SMK development, and teachers' beliefs regarding the limitations of models and analogies, specifically the octet rule and Le Chatelier's principle. This was undertaken through use of a semi-structured interview with eleven A level chemistry teachers, with the outcomes informing the development of a nationwide survey.

The study found that transition metal chemistry and electrochemistry were topics of low confidence for A level chemistry teachers. Teachers reported differences between their approaches to teaching high and low confidence topics. Most teachers felt that an undergraduate degree is necessary for teaching chemistry, though reported that ITT did little to develop their SMK. Teachers also felt that it is an issue if a teacher's SMK is limited to the specification they teach. Most teachers identified the limitations of the octet rule, whilst fewer identified limitations of Le Chatelier's principle, indicating weaker SMK in this area. Following these results, the development of resources to enhance teachers' SMK in electrochemistry and further investigation of confidence is recommended.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DECLARATION OF AUTHORSHIP

I, Stephen Michael Barnes, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

The role of subject matter knowledge in teaching A level chemistry

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Either none of this work has been published before submission, or parts of this work have been published as: N/A

Signed: …………………………………………………

Date: ……………………………………………………

ACKNOWLEDGEMENTS

I would like to express thanks to my supervisor, Prof. David Read, for his expertise, assistance, and support through the duration of this project. Thank you for your continued feedback and for providing me with the opportunity to undertake this research. I am also grateful for the opportunity to hone my teaching skills working on the science foundation year for the past few years, and to the students for their encouragement and humour. I will look back on Fridays very fondly.

I also extend my thanks to the teachers who participated in this project; without their engagement, this study would not have been possible. Thank you for giving up your time and for sharing your insightful experiences and opinions.

I would like to thank my former colleagues Iveta, Wilson, and Rachel for their technical insights in the early stages of my research career, and for glancing a critical eye over my decisions.

Iain, thank you for putting up with me for three years and for listening to my outbursts. The emotional and professional support that you have provided as a housemate is appreciated immensely. You will be an immensely tough act to follow when I start teaching this year.

Thank you to all of Southampton's Quiz Society, which I have seen grow immensely over the last five years. You have strengthened my love of quizzing and provided me with many laughs and competitive evenings, bringing me a huge amount of joy in the process.

Ollie, thank you for keeping me caffeinated for the last few years and for undertaking the laborious job of transcription. I am grateful for your advice and for your insights, and for your efforts proofreading sections of this work. Although we never reached Diamond, we make a pretty good team, and I hope that continues. My thanks extend to Steven Jupien, OG, Terry, and the rest of the gang.

Mum, Dad, Jon, and Charlotte, thank you for your everlasting love and support, and for your continued encouragement throughout the project. There is no way I would have persevered without your reassurance and inspirational quotes. Thank you for always being there and for your belief in me.

Finally, I would like to thank Lorna. It has been a privilege and a pleasure to share the last few years with you and I look forward to many more. Thank you for taking the time to proofread sections of this work and for your criticism and discussion of ideas central to this thesis, and of course for keeping me well fed throughout. I am so grateful for your support, in all senses of the word.

It has been a journey getting to this stage and undertaking this project has certainly been an extremely formative experience. The road has been full of positives but has also been full of challenges, which would have proven far more difficult without the network of incredible people around me. For all of them, I am extremely grateful. Thank you.

TABLE OF ABBREVIATIONS

Abbreviation	Meaning
CoRe	*Content representation*
CPD	*Continued professional development*
GTP	*Graduate Teacher Programme*
ITT	*Initial teacher training*
PaP-eRs	*Pedagogical and Professional Experience Repertoires*
PCK	*Pedagogical content knowledge*
PCK&S	*Pedagogical content knowledge and skill*
PGCE	*Postgraduate Certificate in Education*
QTS	*Qualified teacher status*
SKE	*Subject knowledge enhancement*
SMK	*Subject matter knowledge*
TMS	*Talking mark scheme*
TPK&S	*Teacher professional knowledge and skill*
VSEPR	*Valence shell electron pair repulsion*

CHAPTER ONE

~ Introduction ~

1.1 Chemical misconceptions

It is widely recognised that chemistry can be a challenging subject for those who choose to study it. The abstract nature of fundamental concepts within chemistry can lead to misunderstandings amongst students and can hamper their progress (Zoller, 1990). As these concepts are crucial in developing a meaningful understanding of chemistry, as well as other sciences (Taber, 2002), it is imperative that they are well understood by students. If they are not, then this can lead to the development of misconceptions.

A misconception, sometimes called an alternate or alternative conception, is defined by Nakhleh (1992) as any concept that differs from the commonly accepted scientific understanding of the term. Misconceptions can be a prominent issue in student learning, as it is believed that once they are possessed, they become deep-rooted and instruction-resistant, preventing further learning of scientific concepts (Lawson, 1988). Numerous studies have been undertaken to investigate student misconceptions within particular areas of chemistry, including reactivity (e.g. Rushton et al., 2008), organic mechanisms (e.g. Bhattacharyya and Bodner, 2005; Ferguson and Bodner, 2008; Graulich, 2015), and chemical equilibrium (e.g. Wheeler and Kass, 1978; Hackling and Garnett, 1985).

Studies have been undertaken to investigate how misconceptions can arise amongst students. Skelly (1993) suggests that misconceptions can be placed into two categories, namely 'experiential' and 'instructional'. Experiential misconceptions develop through exposure and interaction with the real world through "everyday experience", and can develop in phenomena including motion, energy, and gravity. Conversely, instructional misconceptions develop through instructional experiences, including classroom teaching and self-learning. Studies have shown that students, including those studying at university, learn science with numerous preconceived ideas (Taber, 1997; Kind, 2009a), which may differ from accepted scientific knowledge. Furthermore, students' misconceptions are considered not to exist in isolation, existing within the subject's context and set firmly within students' beliefs (Settlage and Southerland, 2007).

Taber and Tan (2011) state that to approximate what may cause the development of misconceptions, attention must be paid to the broad, central sources of students' ideas. These include but are not limited to learner intuition (diSessa, 1993), language (Gold and Gold, 1985; Schmidt, 1991), and 'creative acts of analogy' (Taber and Tan, 2011).

The use of analogy is widespread in science teaching, in order for abstract concepts to be explained in a manner that provides relevance to the students learning them (Thiele and Treagust, 1994; Tibell and Rundgren, 2010; Orgill et al., 2015). There is, however, a danger associated with the use of analogies in science teaching. Learners have been seen to lack an appreciation of the reasons why models are used to explain particular aspects within a specific context (Driver et al., 1996). Similarly, the use of anthropomorphic language in the description of chemical concepts may also contribute to misconceptions. The discussion of chemical reactions in terms of what atoms 'need' or 'want' causes students to solely consider *why* atoms 'want' to react, rather than the chemical and physical processes that are occurring (Taber, 2000; 2002).

To avoid these potential misconceptions, there are three key points that should be considered when teaching with analogies (Taber, 2001). These are:

1. The analogy must directly map onto the fundamental aspects of the concept that is being explained.

2. Both the advantages and limitations of using the analogy should be discussed, and learners should develop an appreciation for both.

3. The analogy must be more familiar to learners than the target concept; if this is not the case, time will need to be spent teaching about the analogy before it can be implemented.

The use of analogies is therefore not always appropriate in science teaching. Some schoolteachers may use them in their practice when they are unsuitable or may not always discuss their limitations. Skelly (1993) infers that because chemical concepts are typically abstract in nature, such as atomic structure and chemical bonding, misconceptions possessed by students in chemistry are more likely to be instructional, as such abstract concepts are not typically encountered through everyday experience. The use of analogies in chemistry teaching may therefore contribute to the development of instructional misconceptions. It has also been suggested that misconceptions are linked to so-called "hard-core commitments", with graduates retaining their misconceptions as they enter professional roles within science and technology, including those choosing to enter the teaching profession (Taber and Tan, 2011).

Preservice teachers have been observed to hold misconceptions in numerous scientific topics, including astronomy (Trumper, 2001), conservation of matter (Haidar, 1997), earth science (Dahl et al., 2005), and the greenhouse effect (Dove, 1996). A significant number of studies have been undertaken into preservice teachers' misconceptions in specific chemistry topics. Notable examples include chemical equilibrium (Azizoglu et al., 2006; Cheung, 2009), acid-base chemistry (Bradley and Mosimege, 1998), chemical kinetics (Sözbilir et al., 2010; Çam et al., 2015), orbital theory (Nakiboglu, 2003), and electrochemistry (Özkaya, 2002). In one instance, misconceptions regarding the stability of shells and sub-shells were seen to be more common amongst preservice teachers than high school students (Taber and Tan, 2011).

This phenomenon is not restricted to those who are training to teach. Kolomuç and Tekin (2011) found that experienced teachers held misconceptions on chemical kinetics, whilst Lin et al. (2000) observed misconceptions regarding gas laws. Banerjee (1991) noted that misconceptions in chemical equilibrium were prevalent amongst both schoolteachers and undergraduate students, whilst Quílez-Pardo and Solaz-Portolés (1995) reported that teachers have been seen to misapply Le Chatelier's principle in addition to using algorithmic procedures to solve chemical equilibrium problems. Furthermore, the findings of the latter study indicated that teachers' problem-solving methodology focused primarily on the transmission of knowledge rather than on ensuring student understanding of the subject, therefore indicating that teacher conceptions and misconceptions had a significant influence on the problem-solving strategies of their students. This in turn may result in failure to develop student understanding of key concepts (Quílez-Pardo and Solaz-Portolés, 1995).

A study of preservice science teachers in Turkey found that most participants held misconceptions regarding fundamental scientific concepts (Tekkaya et al., 2004). Despite this, the participants generally felt confident teaching these concepts. Alongside the misuse of chemical models and analogies, if schoolteachers themselves hold misconceptions regarding fundamental chemical concepts, then it can be said that there is a high probability that this will influence their students' learning and hence their understanding of chemistry. Special attention must therefore be paid to the subject matter knowledge, or SMK, of chemistry teachers and its role in chemistry teaching.

1.2 Subject matter knowledge and teaching

A report published in 2014 cites six components that are necessary for great teaching, with great teaching defined as "that which leads to improved student achievement using outcomes that matter to their future success" (Coe et al., 2014). The first of the components listed is "(pedagogical) content knowledge", as there is robust evidence to suggest that this has an impact on student outcomes (Hill et al., 2005; Sadler et al., 2013). The Royal Society of Chemistry also argue that good SMK is essential in good teaching:

> *"The best teachers are those who have specialist subject knowledge and a real passion and enthusiasm for the subject they teach…the Royal Society of Chemistry believes that young people deserve to be taught the sciences by subject specialists" (RSC, 2004, quoted in Kind, 2009b, p.169).*

It is crucial that science teachers understand the subject matter that they teach (Abell 2007; Van Driel et al., 2014), to ensure that their students can comprehend it (McConnell et al., 2013).

In line with the constructivist theory of learning, teachers should consider and be aware of the pre-existing knowledge and beliefs of their students, as well as their misconceptions (Sewell, 2002). However, despite having an awareness of student misconceptions, schoolteachers may not always understand how they develop, or how they may impact on instruction (Gomez-Zwiep, 2008). Additionally, on an individual basis, high-school physics teachers have been observed to identify few student misconceptions, but as a group were able to identify nearly all of them in a set of responses (Berg and Brouwer, 1991). Experienced science teachers use their students' prior knowledge to great effect in their teaching, whereas novices lack an awareness of this prior knowledge, and therefore are not necessarily able to implement constructivist teaching (Meyer, 2004).

It is expected that with greater teaching experience a teacher's SMK will improve, due to their extended exposure to both the subject matter and the curriculum that they teach. Novice teachers have been observed to misapply their knowledge of chemistry in teaching, while experienced teachers have been observed to be more accurate and confident in their explanations of concepts (Clermont et al., 1994). Experienced teachers of chemistry also rely less on materials such as textbooks (Lantz and Kass, 1987). However, one finding suggests that the content knowledge of mathematics teachers either largely remains the same or decreases as they become more experienced (Kleickmann et al., 2013).

Issues regarding SMK are of increased relevance at present. In March 2018, an Ofsted boss was quoted as saying that teachers should have to prove that their subject knowledge is of an adequate level at regular intervals to maintain their qualified status (Staufenberg, 2018). In 2015, the major A level chemistry specifications in the United Kingdom were changed in line with new reforms, with concepts including the Arrhenius equation and K_p introduced (or reintroduced) to the syllabus (OCR, 2014a; OCR, 2014b; AQA, 2015; Pearson, 2016). The inclusion of new content could pose problems for those teachers with limited SMK, or for those who did not study chemistry as their undergraduate degree.

In recent years, a significant number of new science teachers have been assigned to teach science subjects that they have not been sufficiently prepared for (Banilower et al., 2015). In 2019, only 59.5% of chemistry teachers in England held at least a degree level qualification in chemistry, whilst 26.4% did not have a relevant post-A level qualification (DfE, 2020). In 2016, these numbers were 61.7% and 25.1% respectively, indicating a small shift over the last few years towards a greater number of non-specialist chemistry teachers (DfE, 2017). This issue is coupled with concerns that a significant proportion of the teaching population comprises newly qualified science teachers, in both the United States (Ingersoll et al., 2018) and England (DfE, 2020).

Evidence suggests that the SMK of chemistry teachers is influenced both by the amount of classroom experience that they have and by holding a degree in the subject area that they teach. Kind (2014) observed that the SMK of non-specialist chemistry teachers was insufficient for teaching chemistry concepts at high school level. Furthermore, chemistry teachers who possessed a chemistry degree were seen to have more coherent and focused SMK than those who did not (Nixon et al., 2016). Classroom experience is considered important as it allows for the development of pedagogical content knowledge, or PCK.

1.3 Improving teacher knowledge

PCK is an aspect of teacher knowledge first described by Shulman (1986) as one of three categories of content knowledge, alongside SMK and curricular knowledge, and is described as the overlap between a teacher's SMK and their pedagogical knowledge (i.e. their knowledge of *how* to teach). Shulman (1987) later redefined these three categories into seven knowledge bases required for good teaching (Figure 1.1). In this new model, PCK is described as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p.8); in essence, it can be said that a teacher's PCK is dependent on the other six knowledge bases. Magnusson et al. (1999) comment that PCK is the "transformation of several types of knowledge for teaching" (p.85).

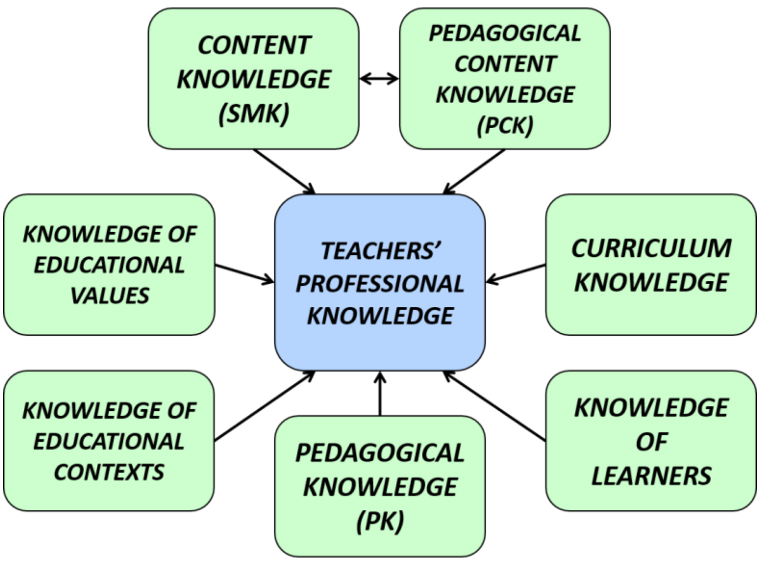

Figure 1.1 The seven knowledge bases that a teacher should possess, as described by Shulman (1987). Studies suggest that SMK and PCK are intrinsically linked.

Research into the PCK of science instructors has been of particular interest in recent years due to its influence on the quality of teaching (Shulman, 1987), with numerous approaches devised to display or quantify the PCK of teachers (e.g. Van Driel et al., 2002; Loughran et al., 2004). In cases where the PCK of science teachers is measured, it is considered within specific concepts, for example in chemical equilibrium (Van Driel et al., 1998; Rollnick et al., 2008) and the use of particle models (Jong et al., 2005).

Studies have been undertaken to investigate the relationship between teachers' SMK and their PCK. Though a handful of studies have found only moderate to low correlation between the two (Kleickmann et al., 2013; Großschedl et al., 2014), others show that the impact of SMK on PCK is significant (Rollnick et al., 2008; Van Driel et al., 2014). Van Driel et al. comment that SMK is a necessary but not sufficient condition for PCK, whilst Kind (2009a) discusses that good SMK can support a teacher in the planning and development of appropriate PCK. Though it is not necessarily clear whether SMK is an implicit component of PCK, it can be said that having a high level of SMK can assist with the development of a teacher's PCK, and as a result attention should be given to the improvement of teacher SMK.

The Ofsted chief referenced in Chapter 1.2 suggests that a professional development programme for each subject should be developed in order to ensure that teachers are up-to-date with their knowledge of the latest research in their own subject area (Staufenberg, 2018). Some studies support this idea, with outcomes indicating that the SMK of science teachers improves through interaction with the curriculum and engagement with professional development courses (Arzi and White, 2008; Diamond et al., 2014). Additionally, intervention sessions have been observed to assist with the development of preservice chemistry teachers' SMK, in addition to their confidence in their SMK (Wheeldon, 2017).

Although the importance of good SMK in science teaching has been noted, there is another question that should be asked; at what level should a chemistry teacher's SMK be? In other words, how much do we expect chemistry teachers to know about their subject? A report published in 2015 recommends that science teacher-training courses should provide for the development of knowledge such that it is "at a level well above that which they will teach" (SCORE, 2015, p.2). With respect to the A level in the

United Kingdom, this would imply that chemistry teachers should know their subject at least to undergraduate level within all areas of their subject. As discussed in Chapter 1.2, with many UK-based chemistry teachers being non-specialists, this will not always be the case.

1.4 Rationale for the study

Many questions remain as to exactly what makes a good teacher, but it has become evident that a key component in good teaching is a teacher's PCK, and in influencing that, a teacher's SMK. If a teacher's knowledge of chemical concepts is underpinned by deep-rooted misconceptions, then the information that they impart to their students will be fundamentally flawed. Although the use of analogy in chemistry teaching can assist student understanding, if used inappropriately it can also cause students to develop chemical misconceptions. Continued professional development (CPD) courses have been observed to make teachers aware of chemical misconceptions and provide a means of improving their SMK.

It can be argued that by improving the SMK of preservice and novice chemistry teachers, the development of their PCK can be accelerated. To assist with their understanding of chemistry, however, consideration must also be given to teacher confidence with respect to individual chemical concepts. Through elucidating the topics that are of more concern to chemistry teachers, work can be undertaken to develop tools and CPD with the intention of improving teachers' SMK, and their confidence in it. The opinions of current A level chemistry teachers in the UK are important to consider in the development of such resources as they are the intended users. This fundamental point provides the basis that this research project is built upon.

This exploratory study seeks to investigate chemistry teachers' general beliefs regarding their SMK and the role it plays in their own teaching, whilst also launching preliminary investigation into where teachers' misconceptions may arise. Additionally, chemistry teachers' views regarding assessment and the use of analogies in their teaching are investigated as part of this study. The outcomes of this project will provide a foundation for the creation of new resources and CPD to assist preservice teachers in the preliminary years of their career, with the aim of improving their instruction as a result. Finally, the beliefs and attitudes of current chemistry teachers hold great value in beginning to answer the pivotal questions: what makes a good chemistry teacher? And what can be done to help enhance their teaching?

1.5 Research questions and outline of the thesis

This research project is split into three phases. The first of these phases, described in Chapter 2, sought to investigate the aspects of a particular area of chemistry (chemical equilibrium) that were problematic, and to identify any prevalent misconceptions in this topic amongst A level chemistry teachers. This phase of the project was guided by the two research questions given below.

Is there evidence to suggest that A level chemistry teachers hold misconceptions related to chemical equilibrium, and if so, what is the nature of these misconceptions? (RQ1)

How confident do A level chemistry teachers perceive themselves to be in their (a) understanding of and (b) ability to teach chemical equilibrium? (RQ2)

Preliminary insights into A level chemistry teachers' views regarding chemical equilibrium were gauged using focus group sessions, where the intended outcome was for the findings to guide the development of a resource designed to improve the PCK of A level chemistry teachers in this topic. However, following this phase of the project, the data collected led to the development of a new set of research questions, based on the findings regarding confidence in SMK. The development of these new research questions is detailed in Chapter 3.

The second phase of the research project was guided by two overarching research questions, each with three supporting sub-questions that would assist in the collection of data. These are listed below, with the over-arching research questions in bold.

How do A level chemistry teachers perceive the influence of their education on their chemistry subject matter knowledge and their confidence in it? (RQ3)

What are the perceptions of A level chemistry teachers regarding the impact of their undergraduate degree on their subject matter knowledge? (SQ3.1)

How do A level chemistry teachers perceive their confidence in their chemistry subject matter knowledge to change during their initial teacher training? (SQ3.2)

Which methods do A level chemistry teachers use, during their initial teacher training, to enhance their chemistry subject matter knowledge? (SQ3.3)

Are there differences in the ways that A level chemistry teachers approach teaching topics where they are confident in their SMK compared to those topics where they are not? (RQ4)

Are there particular topics within the A level chemistry syllabus that A level chemistry teachers are generally less confident with their knowledge of? (SQ4.1)

Do teachers of A level chemistry believe it is a problem if the subject matter knowledge of teachers is limited to the A level specification? (SQ4.2)

Are A level chemistry teachers aware of their usage of models and analogies in particular topics within the A level specification, and are they aware of the limitations of such models? (SQ4.3)

Preliminary insights into teachers' opinions of chemistry SMK in the second phase of the project were gauged using semi-structured interviews, the methodology and findings of which are detailed in Chapter 4. The responses provided at interview were then used to guide the third phase of the project, a nationwide survey designed to investigate whether the views held by the interviewees were held by a larger population of A level chemistry teachers. As a result, this phase of the project was guided by the research question below.

Are the results obtained from the participants in the interview phase of the study indicative of the wider population of A level chemistry teachers? (RQ5)

The methodology and results of this third and final phase of the project are detailed in Chapter 5. The conclusions and implications of the study are discussed and summarised in Chapter 6.

It should be noted that whilst the aim of this project is to gain insight into the role of a chemistry teacher's SMK in their teaching, no investigation into measuring or quantifying a teacher's SMK has been undertaken. The development of a tool allowing for these measurements to be made requires a significant amount of validity testing and piloting, and due to the time constraints of this project undertaking such a task is unfeasible. Further investigation comparing the responses provided by teachers to a quantitative measure of their SMK would produce insightful data, and therefore such a study should be considered in the future.

The responses given in the interview and survey phases of the project will provide important information regarding SMK development in the initial stages of teaching and will allow for identification of those areas of initial teacher training (ITT) which were of most use to preservice chemistry teachers. Though not an explicit research question, some comparison between the responses of novice and experienced teachers will be made, to ascertain whether there are any considerable similarities or differences in belief between the two groups. Comparisons will also be drawn between the responses of specialist and non-specialist teachers, to investigate whether alternative study backgrounds result in different perceptions of SMK and its role in chemistry teaching.

CHAPTER TWO

~ From Pedagogical Content Knowledge to Subject Matter Knowledge ~

As with many research projects, the nature and aims of this study changed over its duration. Initially, the role of subject matter knowledge (SMK) in chemistry teaching was not the primary focus; instead, teacher pedagogical content knowledge (PCK) in a specific chemical concept was to be considered, with the intention of designing and evaluating a resource aimed at enhancing teachers' PCK.

This chapter provides a literature-based discussion of the original scoping work of this study, discussing and reviewing how PCK fits into a teacher's professional knowledge and how it can be evaluated or assessed. This is followed by a discussion of the project's original research questions, before proceeding into a presentation of the methodology and results obtained during this early phase of the project. Following discussion of these results, this chapter concludes with a short discussion of the reasoning behind changing the focus of the project.

2.1 Defining and conceptualising pedagogical content knowledge

As discussed briefly in Chapter 1.3, PCK was originally defined by Shulman (1986, 1987) as the specific area of a teacher's knowledge that brings together the other areas of their knowledge, i.e. SMK, pedagogical knowledge, and curricular knowledge, that allows for the successful transmission of information to their students. Despite PCK comprising of a contribution from numerous areas of knowledge, it is a distinct body of knowledge that can be considered separately from the others; Baxter and Lederman (1999) describe it as "both an internal and external construct, as it is constituted by what a teacher knows, what a teacher does, and the reasons for the teacher's actions" (p.158). Since Shulman proposed the idea of PCK, it has been of keen interest to educational researchers in all disciplines, with many definitions and conceptualisations of it surfacing in the literature.

Geddis et al. (1993) define PCK as the knowledge that contributes to making SMK accessible to students, while Carter (1990) perceived PCK as what teachers know about their subject matter and the methods they employ to create classroom curricular events using that knowledge. Fernandez-Balboa and Stiehl (1995) discuss the importance of context in PCK, whilst Lee et al. (2007) add that PCK also encapsulates the encouragement of students' scientific enquiries. Some suggest that the definition of PCK should also include knowledge of assessment (Tamir, 1988; Magnusson et al., 1999). Despite the large quantity of definitions that have been proposed, it is clear in all cases that the fundamental basis of PCK is the transformation of SMK for the purpose of teaching, alongside an awareness of student learning and instructional strategies. With reference to the teaching of science, this infers that without a high level of science SMK, the development of PCK would be severely hindered.

PCK is widely perceived as a knowledge base that develops with classroom experience (Grossman, 1990; Magnusson et al., 1999; Van Driel et al., 2001). It can be said that preservice and novice teachers typically have a lower level of PCK in comparison to those more experienced than them, with experienced teachers exhibiting an advanced understanding of ideas attributed to PCK (Lee et al., 2007). Gess-Newsome (1999) developed two models for PCK to address this, named the integrative model and the transformative model.

In the integrative model of PCK, the different knowledge domains of SMK, pedagogical knowledge, and context exist separately from one another, and individually contribute to a teacher's PCK. It has been suggested that improvement of the knowledge within the individual domains directly contributes to the development of a teacher's PCK (Fernandez-Balboa and Stiehl, 1995). Alternatively, the transformative model indicates a constructed knowledge base specifically for teaching, where SMK, pedagogy, and context are amalgamated and then utilised in teaching practice. The model discussed by Marks (1990) bears great resemblance to the transformative model and stated that PCK could not be distinguished from the other knowledge bases. Grossman (1990) and Ball & Bass (2000) suggest that novice teachers do not elicit knowledge from all knowledge domains when teaching but rather rely mostly on one particular knowledge base. This, in turn, indicates that the integrative model maps a novice teacher's PCK, whilst the transformative model provides a basis for the PCK of experienced teachers.

Building upon the work of Tamir (1988) and Grossman (1990), Magnusson et al. (1999) identify five components of PCK specifically for science teaching. Brief summaries of these are provided below.

1. ***Orientations towards teaching science***

   This component of PCK refers to teachers' beliefs regarding the purposes and aims for teaching science at different levels (Grossman, 1990) and influences the development of PCK through informing instructional choices. These include the use of particular curricular materials and the assessment of student learning (Borko and Putnam, 1996).

2. ***Knowledge and beliefs about science curriculum***

   In addition to the knowledge of the science curriculum itself, this component also includes the awareness of curriculum materials available for teaching specific concepts (Grossman, 1990). Although Shulman (1986, 1987) originally presented curricular knowledge as a separate knowledge domain, it has been included as a component of PCK by Magnusson et al. (1999) as it characterises knowledge that "distinguishes content specialists from the pedagogue" (p.103).

3. ***Knowledge and beliefs about students' understanding of science***

   This component refers to the awareness that teachers must have of their students, allowing for the development of specific scientific knowledge. It comprises two distinct categories of knowledge: knowledge of the requirements for learning specific scientific concepts, and an appreciation of the particular science topics that students regard as difficult. This maps directly onto Ausubel's (1968) belief that teachers should be aware of what their students know to ensure that further learning and understanding can occur.

4. ***Knowledge and beliefs about assessment in science***

   Originally proposed by Tamir (1988), this component of PCK highlights two particular categories of knowledge that teachers are expected to have. The first of these is the awareness of the aspects of science learning that are important to assess, whilst the second is the knowledge of the methods that can be used to assess these aspects, including an understanding of approaches, instruments, and resources used for this purpose.

5. ***Knowledge and beliefs about instructional strategies***
   Subject-specific strategies and topic-specific strategies are the two categories that underpin a teacher's knowledge regarding instructional strategies. Subject-specific strategies refer to the general subject that is being taught, i.e. science, indicating that the methods employed in instruction of content that are important within that subject. Topic-specific strategies take this notion a step further and refer to the methods employed in teaching particular topics within the scientific domain.

Park and Oliver (2008) expanded upon this model of PCK by adding a sixth component, with consideration of teacher efficacy. Teacher efficacy was included in their model as it was found to play a significant role in defining problems in addition to rationalising strategies to solve those problems.

Through discussion of the five components, Magnusson et al. (1999) indicate two key ideas regarding PCK. The first of these is that there are different types of subject-specific pedagogical knowledge that are used in science teaching. Effective teachers are those who develop knowledge within all components of PCK, in addition to developing knowledge for all topics they teach. The second is that these five components, although independent of one another, all function as parts of a teacher's overall PCK, and hence a lack of coherence between components can prevent a teacher from developing and using their PCK. It is clear from these conclusions that the links between the individual components are important to consider when investigating PCK. However, though it is built upon these individual components, it has been suggested that there are different types of PCK that also need to be considered.

Veal and MaKinster (1999) propose a general taxonomy of PCK, organised hierarchically. The model proposed indicates that the foundations of all PCK lay in general teaching skills that should be developed by all teachers, regardless of the subject that they teach. The authors propose then that there are three levels of PCK, named general PCK, domain-specific PCK, and topic-specific PCK (Figure 2.1).

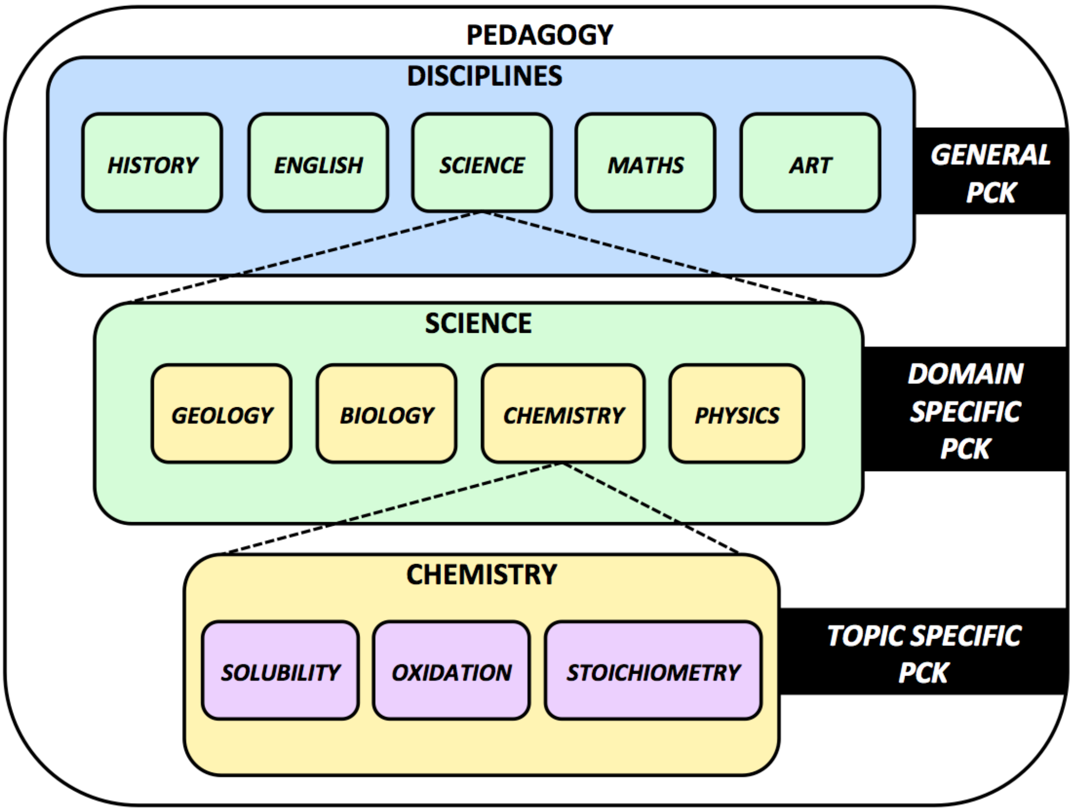

Figure 2.1 The General Taxonomy of PCK, proposed by Veal and MaKinster (1999).

General PCK is the PCK related to the teaching of a general subject, such as science or art. Magnusson et al. (1999) refer to this as subject-specific PCK. Although teaching strategies may be similar between two subjects, for example the use of critical analysis or guided inquiry in both art and science, these teaching strategies are specific to their discipline in terms of what is being taught. Domain-specific PCK goes a step further than general PCK, in that it regards the different domains within a subject discipline. The example given by Veal and MaKinster refers specifically to the teaching of chemistry. Chemistry is a domain within science, and so teacher's understanding of how to teach it can be regarded as domain-specific PCK. Topic-specific PCK is the most specific level of the taxonomy of PCK. Each subject domain consists of a large number of concepts and specialist terms, which a teacher must be able to effectively convey if they are to be successful. Topic-specific PCK refers to the teaching of these individual ideas. Veal and MaKinster argue that if a teacher's topic-specific PCK is well developed, then their skills within the other levels should theoretically also be at a high standard.

The authors suggest in their conclusions and implications that an important area for research is the identification and classification of the types of PCK employed by teachers in the classroom, allowing for the development of PCK to be monitored over a teacher's career. Based on the research presented in this section, however, PCK is a particularly dynamic component of a teacher's knowledge base, which is influenced by many other knowledge bases and beliefs. As a result, numerous factors must be considered if a teacher's PCK is to be monitored or measured.

2.2 Assessing pedagogical content knowledge

Numerous studies have discussed the assessment of teacher PCK, in a wide range of disciplines. The evaluation of PCK is a complex task that demands a combination of approaches to allow for an understanding of its individual components to be developed. As a result, researchers choosing to investigate teacher PCK commonly adopt mixed-method approaches. Comparison of data from each source in a mixed-methods study also increases the validity of the results obtained (Patton, 2002; Cohen et al., 2011).

Semi-structured interviews are one of the most common methods used in the study of teacher PCK. The use of interviews allows for the researcher to gain an insight into the teacher's beliefs regarding the components of PCK as well as their knowledge of such components. Some interviews have incorporated other activities, such as card sort tasks, concept maps, and the construction of diagrams (Baxter and Lederman, 1999; Meis Friedrichsen and Dana, 2005; Lee and Luft, 2008). In addition to interviews, surveys have also been used to collect data regarding PCK (Halim and Meerah, 2002). It should be noted, however, that there is a danger to using surveys in quantifying PCK, especially if respondents are asked to indicate how they would teach a particular topic to a student. A response to a survey is more akin to responding to an examiner rather than to a student, and as such the data obtained may not necessarily be accurate.

To avoid this problem, classroom observations are often undertaken, as they can allow for researchers to gain a better understanding of teachers' own practice and observe the context that they teach in (Bogdan and Biklen, 1992). Observations are frequently used in conjunction with semi-structured interviews, as they can lead to the development of further questions. Probing these specific points regarding aspects of a teacher's practice, in addition to the reasons why they have been adopted, can allow for further analysis to be undertaken (Patton, 2002; Lee and Luft, 2008). As well as semi-structured interviews and classroom observations, studies have also used lesson plans (Lee and Luft, 2008;

Faikhamta et al., 2009) and other classroom resources, such as worksheets (Faikhamta et al., 2009), to provide insight into teacher PCK.

In addition to the more traditional data collection methods described previously, novel methods have been developed to evaluate teacher PCK. One such method is the use of CoRes and PaP-eRs (Loughran et al., 2004). A CoRe is a 'content representation', in which science teachers demonstrate their understanding of specific aspects of PCK, including but not limited to:

- An overview of the main ideas
- Knowledge of misconceptions
- Insightful methods of testing for student understanding
- Known areas of confusion
- Effective sequencing
- Important approaches to the framing of ideas

These are laid out in the form of a table, where teachers are required to answer questions relating to a singular concept (e.g. particle theory). These can then be related to Pedagogical and Professional Experience Repertoires (PaP-eRs).

PaP-eRs relate to the CoRe in that the CoRe is the explanation of the "Big Ideas" of a certain content area, and the PaP-eRs provide insight into these ideas through representation in different forms (e.g. descriptions of classroom observations, teaching procedures, curriculum issues, students' misconceptions, etc.). This method of examining PCK has also been used in other studies (Aydin and Boz, 2013).

The assessment of PCK is considered important in research as it can allow for the investigation into the effectiveness of interventions designed to develop teacher PCK. Veal and Kubasko (2003) explored the topic-specific nature of PCK with secondary teachers of both biology and geology and concluded that SMK made a difference in how teachers taught particular topics. It was also observed that novice and experienced teachers held different levels of complexity in their topic-specific PCK, once again indicating the importance of classroom experience in improving teacher knowledge. Park and Oliver (2008) developed teachers' general PCK through encouraging them to use reflective methods within instructional contexts. These methods involved the teachers reflecting on their practice during instruction and then reflecting upon their practice again after the lesson they had taught. The findings of this study also indicated the importance of students in developing teacher PCK, with respect to their knowledge and their misconceptions, further supporting the model proposed by Magnusson et al. (1999).

Veal and MaKinster (1999) suggested that secondary science education programs could focus on developing topic-specific PCK in teachers. One such program has been trialled by Mavhunga and Rollnick (2013), who developed twelve sessions of 100 minutes each designed to focus on five topic-specific concepts of PCK in chemical equilibrium, with teacher PCK monitored through a mixed-methods analysis. Particular emphasis was placed on understanding the transformation of SMK into knowledge that can be taught to students. Sixteen preservice teachers in South Africa took part in the study. The findings of the study indicated that the topic-specific PCK of the participants improved as a result of the sessions, with teachers displaying an increased awareness in the targeted concepts. The focus of this literature review will now turn to the concept of chemical equilibrium, its position within chemistry education, and the misconceptions associated with it.

2.3 Chemical equilibrium and Le Chatelier's principle

Chemical equilibrium is an important concept in chemistry as it is fundamental to the understanding of more advanced ideas, including (but not limited to) solubility, phase changes, and oxidation/reduction processes (Voska and Heikkinen, 2000). It is therefore essential for students to have a solid understanding of the subject before approaching these more advanced topics later in their studies. However, the underpinning theory of chemical equilibrium itself is not easy to understand. To improve student understanding of the topic, the teaching and learning of chemical equilibrium have been widely researched at both pre-university level and undergraduate level on a global scale.

Numerous misconceptions in chemical equilibrium have been found to plague students of all levels. Wheeler and Kass (1978) found that twelfth-grade high school students in Canada often do not (or cannot) discriminate between reactions that are reversible and reactions that go to completion. This particular misconception likely stems from the introduction of chemical reactions in secondary science lessons. The reactions introduced at this level always go to completion, and so when reversible reactions are eventually introduced, students must make an alteration to their previous knowledge of chemical reactions, which not all students will do successfully (Andersson, 1990).

In A level qualifications in the United Kingdom, students are required to be able to define the term 'dynamic equilibrium'. If a reaction is at dynamic equilibrium, then the rates of the forward and backward reactions are identical. In a study of secondary science students in the Netherlands, Van Driel and Gräber (2003) noted that some students assume that the forward reaction must be complete before the reverse reaction occurs, whilst in other studies researchers have noted that some students assume that when equilibrium is reached, the reaction is no longer occurring (Gorodetsky and Gussarsky, 1986; Maskill and Cachapuz, 1989; Thomas and Schwenz, 1998). In similar studies, Bilgin & Geban (2006) and Kırık & Boz (2012) found that some students believe the rate of the forward and backward reactions at equilibrium to be equal to zero.

These difficulties may arise because on the macroscopic scale, reversible reactions are difficult to observe. For example, in the equilibrium between the two cobalt complexes $[Co(H_2O)_6]^{2+}$ and $[CoCl_4]^{2-}$, colour changes can be seen when the concentration of each individual species are changed; at dynamic equilibrium, the solution remains one colour, and hence no reaction can be directly observed with the naked eye at this point.

This may be partly related to the triangular nature of chemistry (Johnstone, 1982) and the problems faced by students in switching between the three levels of representation (Johnstone, 1991). These three levels of representation are the macroscopic (what can be observed with the naked eye), the sub-microscopic (what cannot be observed with the naked eye, i.e. molecules, atoms, etc.), and the symbolic (how the other levels are represented). On pre-university qualifications, equilibrium is rarely discussed on the sub-microscopic level, and so this may cause misconceptions to arise. In addition, students also converge their ideas of kinetics and thermodynamics, sometimes using one to erroneously explain concepts in the other (Voska and Heikkinen, 2000; Kousathana and Tsaparlis, 2002; Çakmakci and Leach, 2005; Çakmakci, 2010; Sözbilir et al., 2010; Çakmakci and Aydogdu, 2011; Turányi and Tóth, 2013).

Great emphasis is placed on equilibrium 'shifts' at pre-university level in the United Kingdom, and the effects that changing concentration, pressure, and temperature have on the position of equilibrium. This can be considered either on a qualitative or quantitative basis, through use of Le Chatelier's principle or the equilibrium law. Misconceptions related to these equilibrium shifts have also been seen to arise amongst students. Studies have found that students rely on qualitative explanations when explaining the effects of addition or removal of a reactive gas to an equilibrium system at constant temperature and pressure (Katz, 1961; Quílez-Pardo and Solaz-Portolés, 1995; Quílez, 2006).

These misconceptions do not just exist amongst students, but amongst teachers as well. Studies undertaken by Banerjee (1991) and Quílez-Pardo and Solaz-Portolés (1995) have highlighted that the issues students struggle with are also prevalent amongst their instructors. The concept of equilibrium has gained notoriety amongst secondary science teachers, and many believe the subject to be difficult to teach (Johnstone et al., 1977). This may partly be due to the oversimplification of the concept using Le Chatelier's principle.

Henri Louis Le Chatelier first published his namesake principle in 1884 (Le Chatelier, 1884), describing it as very simple and placing a large emphasis on the fact that the law was experimental. His original portrayal of the principle is depicted below.

> *"Any system in stable chemical equilibrium, when subjected to the influence of an external cause which tends to change either its temperature or condensation (pressure, concentration, number of molecules in unit volume) throughout or in only some of its parts, can undergo only such internal modifications which, if they occurred on their own, would bring about a change of a sign contrary to that resulting from the external cause."*
>
> \- Henri Louis Le Chatelier, 1884.

Its depiction in chemistry textbooks has been seen to cause confusion amongst both pre-university and undergraduate students. Pedrosa and Dias (2000) found that the terminology used in chemistry textbooks in Portugal could be one of the primary causes for the presence of misconceptions. Gold and Gold (1985) discussed the restatements of the principle in textbooks and how the changing of a singular word can bring about a different meaning. Words such as 'relieve' and 'minimise' are used in some depictions of the principle, whereas 'counteract' and 'oppose' are used in others, giving rise to different definitions of the principle, and potentially causing confusion.

Despite its prominence, distinguished members of the scientific community were critical of the principle and believed it to be unreliable in predicting equilibrium shifts, citing a lack of clarity and precision and an overall sense of ambiguity (Ehrenfest, 1911; Planck, 1934). Some researchers have called for the removal of Le Chatelier's principle from teaching, stating that it is a 'redundant principle' (Allsop and George, 1984). These concerns are not new to the field; Benedicks (1922) discussed the conceptual problems that may arise as a result of teaching with the principle nearly one hundred years ago. With misconceptions in equilibrium at pre-university level still widespread, questions should be asked of whether the principle should be included at this level, or indeed at any level of teaching.

Numerous approaches have been taken to try and reduce the number of misconceptions in chemical equilibrium. One such example is the method proposed by Ghirardi et al. (2015). They propose that the teaching of equilibrium at secondary school level should be sequential and should not include consideration of the kinetic derivation of the equilibrium expression, instead establishing the expression for K_{eq} through a trial-and-error approach. The approach was tested on 54 students, and their participation indicated that this method might promote discussion and active learning.

Van Driel et al. (1998) suggest the use of discussions to introduce the concept of reversible reactions and incomplete chemical conversions. These discussions would be influenced by undertaking practical work and observing whether a reaction goes to completion before having the theory explained to them. This was found to improve student understanding of the topic, and students reacted favourably to this method of teaching. In a different study, Rogers et al. (2000) described a series of card games to simulate the behaviour of equilibrium systems as these are subjected to changes, in order to assist with the explanation of Le Chatelier's principle. Twelfth-grade and first year undergraduate students in South Africa were required to plot graphs showing reaction rates and the amount of substances against time. The study found that this was a useful method for teaching the higher ability students, however lower ability students with a poor understanding of the concept did not benefit from participating. Furthermore, Kaya (2013) suggests that preservice teachers should be taught about equilibrium through argumentation practices. The study found that the conceptual understanding of those who took part in the argumentation practices was better than those who did not participate in this method.

Although numerous studies suggest methods of improving student understanding of chemical equilibrium, there are fewer that indicate methods of improving the understanding of experienced secondary-level teachers in the topic. Furthermore, there is limited research surrounding the development of methods for improving teacher PCK in chemical equilibrium. This led to the development of the research question below:

Can the introduction of a continued professional development (CPD) intervention improve A level teachers' pedagogical content knowledge (PCK) and perceived understanding of chemical equilibrium?

Rather than addressing the PCK of secondary-level science teachers, it was decided to explicitly focus on the PCK of A level teachers. In the United Kingdom, though chemical equilibrium is introduced at GCSE level (age 14-16), the mathematical side of it is not introduced until post-16 chemistry qualifications are studied. Given the more developed nature of the concept at A level, and provided that a higher degree of subject specialism is required to teach a post-16 chemistry qualification than the chemistry or combined science GCSE, it was considered more appropriate to focus on those individuals required to teach it to a higher level.

This research question guided the preliminary stages of the project. To begin answering this question, necessary scoping work would have to be undertaken, to ascertain the aspects of teacher knowledge regarding chemical equilibrium that were the most problematic, and to identify which misconceptions (if any) were the most pertinent. As a result, the preliminary phase of the project sought to answer the research question shown overleaf.

Is there evidence to suggest that A level chemistry teachers hold misconceptions related to chemical equilibrium, and if so, what is the nature of these misconceptions? (RQ1)

In addition to the above question, it was considered important to ascertain teachers' confidence in their understanding of and ability to teach chemical equilibrium, as this is intrinsically linked to their topic-specific PCK. This led to the development of the below research question:

How confident do A level chemistry teachers perceive themselves to be in their (a) understanding of and (b) ability to teach chemical equilibrium? (RQ2)

The methodology used to answer these research questions is detailed in Chapter 2.4.

2.4 Challenging teachers' knowledge of chemical equilibrium

2.4.1 Methodology

Misconceptions with equilibrium can be commonplace amongst students, but these misconceptions do not arise automatically. As has been discussed previously, there are issues with student study practices (e.g. rote learning) that may give rise to these misunderstandings. In the topic of organic chemistry, Grove and Bretz (2012) noted that students can sit in different positions between meaningful learning and rote memorisation on a continuum of learning, which can explain their relative performance in the first year of their undergraduate degree. However, as noted by Skelly (1993), misconceptions in abstract topics, such as chemical equilibrium, are likely caused through instruction. Based on this, it can be inferred that it is possible and highly likely that some student misconceptions arise due to the knowledge and instructional practices of their teachers.

To determine whether teachers of A level chemistry possessed these misconceptions, a focus group-style workshop session was run at a conference for post-16 educators. The content of the workshop was based heavily on the work of Quílez-Pardo and Solaz-Portolés (1995). In this study, the misapplication of Le Chatelier's principle was investigated amongst both students and teachers of a first-year university chemistry course in Spain, similar in content and level to the A level in the United Kingdom. Students were asked a set of five questions relating to the concept of equilibrium, and their answers were analysed based on a devised set of criteria relating to both qualitative and quantitative measures of equilibrium. In contrast, teachers were given a problem and required to suggest a 'proper approach for solving this problem in the classroom'.

In the focus group session, rather than suggesting an approach to solving a problem, the teachers present were required to answer the problems that were given to the students in the initial study individually, writing them on post-it notes and sticking them on a piece of A3 paper depicting the question. After doing so, the teachers were encouraged to discuss the answers they provided to the problem with one other person for two minutes, in an approach similar to peer instruction. Peer instruction is a participant-led method that involves the partial flipping of the classroom (Mazur, 1997), in which participants are required to answer a question individually, discuss their answers and the thinking behind it with their peers, and then finally answer the original question again. The method has been shown to improve student performance in scientific disciplines (Smith et al., 2009).

This approach was chosen to observe teachers' initial ideas relating to equilibrium, and whether their peers, through discussion of the topic, influence them. Another result that will be observed is whether it is the misconceptions or the correct theory that has the greater degree of influence in the teachers' answers. In addition to investigating whether teachers hold initial misconceptions related to equilibrium, this approach will hopefully allow for teachers to gain a greater understanding of the topic from fellow instructors. The session hence both allows for preliminary data collection for this research project as well as continued professional development (CPD) for the teachers, providing benefit to both parties.

The questions used were lifted directly from the Quílez-Pardo and Solaz-Portolés (1995) study. Due to the session length being only 40 minutes, three of the five questions from the study were asked to the teachers. The questions used are given below:

1. $CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$
   - What will be the effect of adding water to the system on the position of equilibrium, under constant temperature and pressure?
   - What will be the effect of adding water to the system on the pH of the solution, under constant temperature and pressure?

2. $PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}$
   - What will be the effect of adding $Ne_{(g)}$ (an inert gas), at constant temperature and pressure, on the equilibrium position?

3. $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$
   - We start with a gaseous mixture containing 1.0 mol of N_2 molecules and 1.0 mol of H_2 molecules that is allowed to reach equilibrium at a given temperature and pressure. Can you predict any equilibrium shift if 0.5 mol of N_2 is added to the equilibrium mixture, at constant temperature and pressure?

These questions were chosen because each of them relied on different thought processes in order to obtain the correct answer, and total reliance on Le Chatelier's principle would result in obtaining only a partially correct or incorrect answer.

As well as being asked these questions, at the beginning and end of the focus group session the participating teachers were required to answer questions based around their confidence in their understanding of equilibrium, their teaching of the concept at A level, their students' understanding of equilibrium, and their students' ability to answer an equilibrium-based A level exam question.

2.4.2 Outcomes of the focus group session

In total, 44 teachers attended the focus group session. The first question they were required to answer in the session is given below.

$$CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$$

What will be the effect of adding water to the system on the position of equilibrium, under constant temperature and pressure?

What will be the effect of adding water to the system on the pH of the solution, under constant temperature and pressure?

The correct answer to this problem is that the equilibrium will initially shift to the right, although this outcome contradicts what may be instinctively suggested (Gordus, 1991). The participants' responses to the first part of this question are shown in Figure 2.2. It can be seen that initially the most popular answer was that there would be no shift in the equilibrium (n = 22). After discussing the problem, however, a higher proportion (n = 23) believed that the equilibrium would shift to the right, with some of those who initially opted for the 'Left Shift' and 'No Shift' options changing their answers. It is positive to see that the majority of respondents answered the question correctly, although this majority is perhaps not as significant as would be desired, with a significant proportion of respondents still opting for alternative answers.

Analysis of the written responses provides insight into some of the reasons the participants gave incorrect answers. The majority of incorrect responses considered only the dilution and not the increased amount of ionisation of acid, thus explaining why a large number of participants responded with 'No Shift' as their answer. Others choosing 'No Shift' as their answer believed that the addition of water would have no effect as it was in excess anyway. Typically, those who responded with 'Left Shift' assumed that the addition of water would cause an increase in the concentration of H^+ ions, due to the dissociation of water given by $H_2O_{(l)} \rightleftharpoons H^+_{(aq)} + OH^-_{(aq)}$. One response suggested that the water would react with the products, causing the equilibrium to shift to the left.

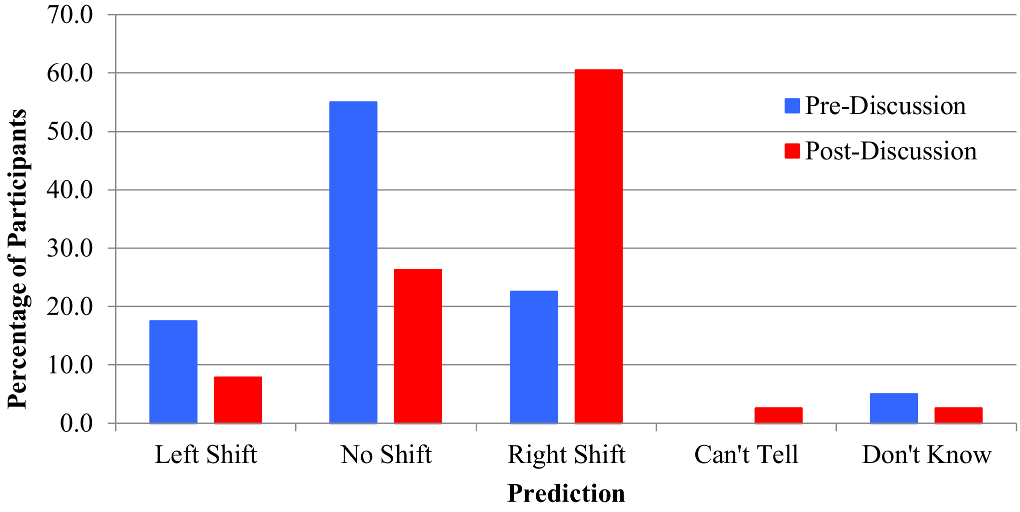

Figure 2.2 Responses to the question "$CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$ What will be the effect of adding water to the system on the position of equilibrium, under constant temperature and pressure?" before and after discussion of the question with peers (*N* = 40).

These answers give a small degree of indication that teachers may have some degree of misunderstanding surrounding the concept of equilibrium. It is also interesting to note that fewer than half of the respondents considered the equilibrium expression for K_c in their answers. These findings are very similar to those of Quílez-Pardo and Solaz-Portolés (1995), with the reasons given behind each answer being identical to those given in the focus group, and with a very small number of participants utilising the K_c expression in their answer.

The participants' responses to the second part of this question are shown in Figure 2.3. In comparison to the results seen for the first part of the question, there is much more consistency between the pre-discussion and post-discussion responses for the second part of the question. The majority of participants (pre: n = 24; post: n = 25) answered the question correctly, indicating that the pH of the solution would increase. Again, although the majority answered the question correctly, the proportion of participants who answered incorrectly is higher than expected. It could be argued that had equilibrium shifts not been mentioned and had the participants been asked what happens to the pH of the system upon addition of water, the proportion answering this question correctly would be greater.

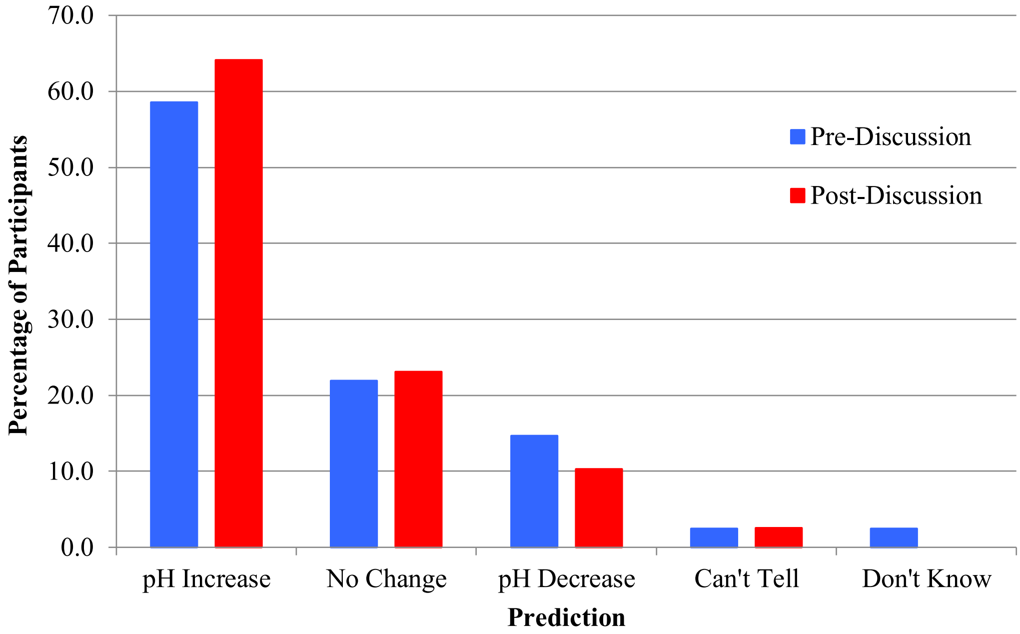

Figure 2.3 Responses to the question "$CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$ What will be the effect of adding water to the system on the pH of the solution, under constant temperature and pressure?" before and after discussion of the question with peers (N = 41).

Analysis of the written answers indicates that some of those who suggested that the equilibrium would initially shift to the right considered only this factor in their response and did not consider dilution, indicating an increase in the H^+ concentration and therefore a decrease in pH. Initially, one participant gave their answer as 'Can't Tell'. Their written answer is given below.

> *"Dilution shifts equilibrium to right increasing [H+] BUT adding water reduces [H+] - which effect greater?"*

It is surprising that only one participant considers this in their response, though two participants suggested that because the solution was already dilute, the addition of water would have no effect on the pH. These respondents have assumed that there is a very large amount of water in the solution. This is a fair assumption to make, as when writing the K_c expression the concentration of water is omitted, due to its high value and the fact that it does not change much. However, it must be noted that without numerical data, the effects on equilibrium shift and pH change are difficult to predict, and as such greater consideration of the point presented in the above quote was expected amongst the participants. It must be noted, however, that the amount of time given to participants to answer questions was limited due to the nature of the session, and as such this time pressure (in addition to the fact that responses were written on post-it notes) could have restricted the depth of responses obtained.

The second question given to participants is displayed below.

$$PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}$$

What will be the effect of adding $Ne_{(g)}$ (an inert gas), at constant temperature and pressure, on the equilibrium position?

The correct response to this question is that the equilibrium will shift to the right, towards the products. The participants' responses to the question are shown in Figure 2.4. It can be seen that, like the first part of the previous question, there is a significant shift in the response from before to after the discussion. Initially, the majority of teachers (n = 22) believed that introducing an inert gas to the system under constant pressure would have no effect on the equilibrium position. After discussion, the majority of teachers (n = 22) thought that the position of equilibrium would shift to the right. It is pleasing to see that there is a move towards the correct answer after discussion, but again there are still a significant number of participants (n = 17) who answered the question incorrectly. It is therefore evident that some of the participating teachers have misconceptions in this area.

In order to elucidate the specific misconceptions that led the teachers to their responses, the text responses to this question were analysed. 58% of the participants who answered correctly initially referred to the equilibrium constant in their answer, with all but one of these responses citing that the partial pressures of PCl_3 and Cl_2 need to increase to restore the equilibrium. Those who described it on a purely qualitative basis drew parallels to the previous question by stating that the inert gas was effectively diluting the mixture and used this to explain their answer. In contrast, only 32% of those who initially believed there would be no shift in the equilibrium mentioned the equilibrium constant in their answer.

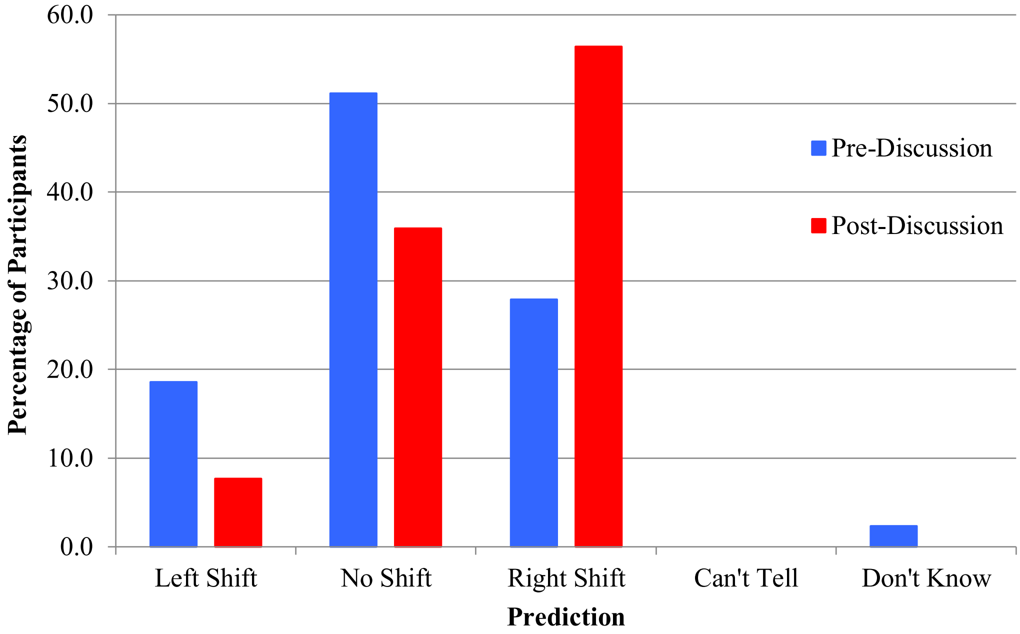

Figure 2.4 Responses to the question "$PCl_{5\,(g)} \rightleftharpoons PCl_{3\,(g)} + Cl_{2\,(g)}$ What will be the effect of adding $Ne_{(g)}$ (an inert gas), at constant temperature and pressure, on the equilibrium position?" before and after discussion of the question with peers ($N_{pre} = 43$; $N_{post} = 39$).

A common misconception that some participants displayed upon answering this question was the assumption that because Ne did not appear in the equilibrium expression, there was no effect on the equilibrium constant as a result. Based on this, and the fact that only a small number of participants used the equilibrium expression to arrive at their answer, it is likely that there is a heavy reliance on Le Chatelier's principle when answering questions of this type. This is unsurprising given its prominence on A level exam specifications and could be potentially detrimental to student understanding of the topic.

Some of the responses typical of those who answered 'No Shift' are given below.

"No reaction, will react with neither reactants or products"

"Volume increases but Kc will not change as concentration changes do not affect Kc (only changes in T or P)"

"Volume increases - but assuming pressure is constant, there should be no shift"

These quotations highlight three particular misconceptions. The first of these is the misconception that only alteration of the species involved in the reaction will have an effect on the equilibrium. The second quotation illustrates a common problem that has been previously noted by Pedrosa and Dias (2000), in that the vocabulary used in describing equilibrium can be ambiguous. K_c and the 'position of equilibrium' refer to different things. Discussion of the position of equilibrium refers to alterations in the concentration of the products and reactants, whereas K_c refers to the specific expression involving the species of the chemical reaction. In the instance of this question, it is evident that the respondent has confused the terms. In addition to this misconception, the respondent has also suggested that changes in pressure will affect the value of K_c, which is untrue; changes in pressure have no effect on the value of K_c.

The third of these statements highlights that although the respondent realised the volume increased but the pressure stayed constant, they did not take the resulting effect on partial pressures of the individual species into account. This was the most common misconception noted amongst participants. It is possible that many misinterpreted the question, in that they believed that though the system was under constant temperature and pressure initially, addition of Ne would disturb and hence alter the pressure.

All participants who answered with 'Left Shift' displayed a complete reliance on Le Chatelier's principle in the answering of the question, ultimately leading them to the incorrect answer. These participants misinterpreted the question, believing that upon addition of the inert gas the overall pressure of the system would increase, and as a result the 'equilibrium would shift to the side with fewer moles'. It is with this wording that the A level specifications describe the effect of changing pressure on the position of equilibrium using Le Chatelier's principle. Even if these participants had considered the equation for K_c or K_p, it cannot be said whether they would have arrived at the same answer. It is however positive to see that a small majority of those who initially opted for 'Left Shift' altered their answer upon discussion with their peers ($n_{pre} = 8$; $n_{post} = 3$), with two changing their answer to 'No Shift' and three to 'Right Shift'. These findings almost map directly to those found by Quílez-Pardo and Solaz-Portolés (1995). The majority of participants in their study gave a 'no reaction' explanation and suggested that there would be no shift in the position of equilibrium, with very few using the equilibrium expression in their answers.

The final question given to participants is displayed below.

$$N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_{3\,(g)}$$

We start with a gaseous mixture containing 1.0 mol of N_2 molecules and 1.0 mol of H_2 molecules that is allowed to reach equilibrium at a given temperature and pressure.

Can you predict any equilibrium shift if 0.5 mol of N_2 is added to the equilibrium mixture, at constant temperature and pressure?

Of the questions asked, this was considered to be the most difficult. With the data that has been given, there is no way to predict which way (if any) the position of equilibrium will shift. Addition of more nitrogen gas under constant temperature and pressure results in an increase in the partial pressure of nitrogen gas, and therefore the partial pressures of hydrogen and ammonia must decrease. Without numerical data for the equilibrium amounts/concentrations for species, it is impossible to tell which way the equilibrium will shift, as it is unknown whether the decreasing partial pressure of hydrogen or ammonia will have the greater effect.

The participants' responses to the question are shown in Figure 2.5. Of the questions asked, this was the most poorly answered with only 21% of participants (n = 7) answering the question correctly after discussion with peers. The majority of participants believed that the equilibrium position would shift to the right. This result is unsurprising, given how the theory is portrayed at A level. These participants have anticipated the increase in concentration/partial pressure of nitrogen gas and have assumed that to counteract the change the equilibrium has shifted to the right. There has been little to no consideration of the fact that the overall pressure of the system has remained constant.

The written responses given by teachers provide further insight into the results. Many responses mentioned rates of reaction and explained that the equilibrium would shift to the right because increasing the amount of N_2 will increase the number of collisions and hence increase the rate of the forward reaction. However, this explanation relies on the assumption that the rate equation for the forward reaction involves the nitrogen species. With the data that has been provided, there is no way of knowing this. For the participants who opted for 'Left Shift', there do not appear to be any clear misconceptions, but instead there are simple errors in logic, e.g. "N_2 is in excess, so equilibrium shifts left".

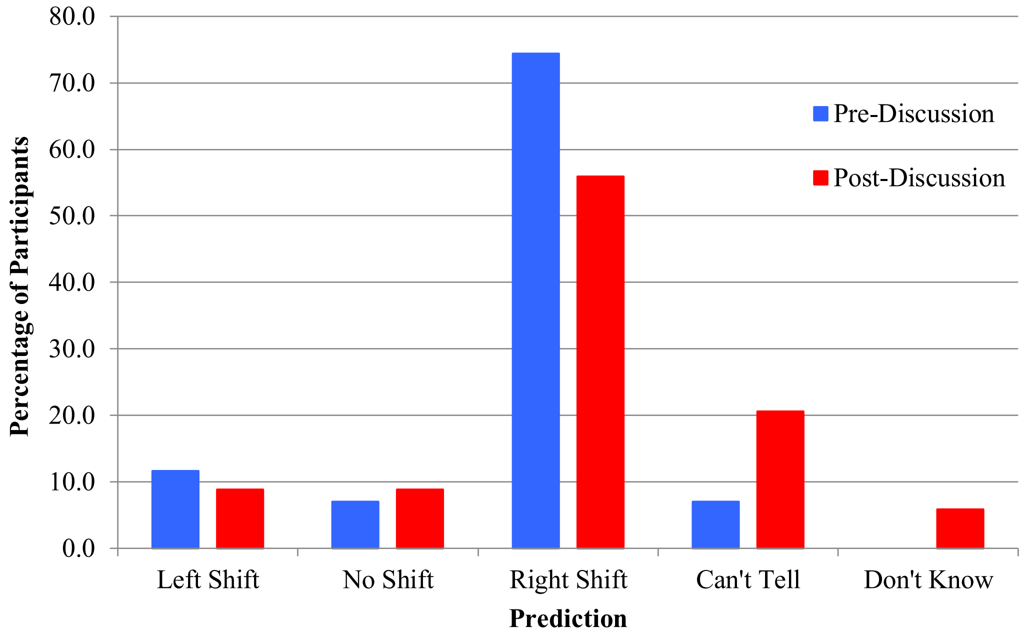

Figure 2.5 Responses to the question "$N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_{3\,(g)}$: Can you predict any equilibrium shift if 0.5 mol of N_2 is added to the equilibrium mixture, at constant temperature and pressure?" before and after discussion of the question with peers (N_{pre} = 43; N_{post} = 34).

As was the case in the previous examples, very few participants (n = 11, 26%) considered either the equilibrium constant or expression in their response and relied on Le Chatelier's principle and qualitative explanations. Writing out the expression for K_c could have allowed for them to notice that a prediction cannot be made with the data provided. The participating teachers should not be criticised for this, however; this is a question that goes above the scope of the content that they are teaching, and as such the methods that they have been using throughout their teaching career are not as appropriate as others for the problem at hand. The issue that this raises, however, is that misconceptions regarding chemical equilibrium are present amongst A level teachers, and it can only be assumed that some of these will be passed on to their students.

The issue is not with the teachers but is primarily with the content appearing on the A level specifications. The reliance on Le Chatelier's principle creates problems when answering questions on more complicated equilibrium systems. If a student opts to take chemistry to a higher level, and they are in possession of misconceptions in their fundamental knowledge of the concept of equilibrium, then this could cause numerous problems throughout their study given how integral a concept it is. The findings presented here suggest that the same issues that beset instructors in the mid-1990s are still widespread now, over twenty years on. It can hence be said that there is scope for developing a resource or CPD course designed to enhance teacher SMK of equilibrium and help reduce the prevalence of misconceptions in this topic.

At the beginning and end of the focus group sessions, the participating teachers were asked questions regarding their confidence. The responses to the first two of these questions are reported in Figures 2.6 and 2.7. Before the focus group session, the majority of participants were at least moderately confident in their own knowledge of chemical equilibrium, with only two participants rating their confidence at either 4 or 5. After the session, it can be seen that a significant number of participants' confidence decreased. This is an unsurprising result, as the questions presented to them were chosen to be challenging and highlight any misconceptions present between them. This was proved correct, with the success rate no higher than 65% on any of the questions given. It is likely that the lack of familiarity with the questions would also have contributed to this feeling of decreased confidence amongst the teachers. The questions that have appeared on A level papers in recent years are highly formulaic and follow the same style, a style much unlike those presented to them in the focus group session.

The session also appears to have caused teachers' confidence in their teaching to decrease. Based on the previous discussion, this is also unsurprising, as the session has caused the participants to doubt their knowledge of the subject. In contrast to the response of the first question, most participants responding to this question were still mostly positive about their confidence after the session. It is likely that this is because teaching the subject at A level does not necessarily require the higher-level problem-solving skills needed to answer the questions presented in the focus group and that they still feel comfortable with the content on the specification.

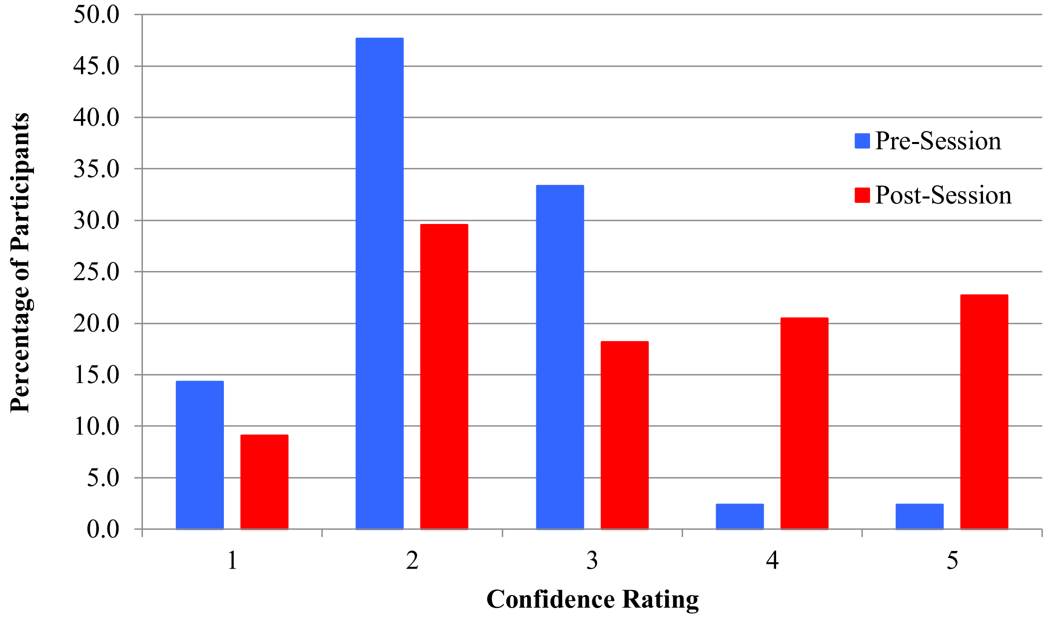

Figure 2.6 Responses to the question 'Please rate your confidence in your subject knowledge of chemical equilibrium." before and after the focus group session (*N* = 42). A rating of 1 indicates a high level of confidence, whereas 5 indicates a low level of confidence.

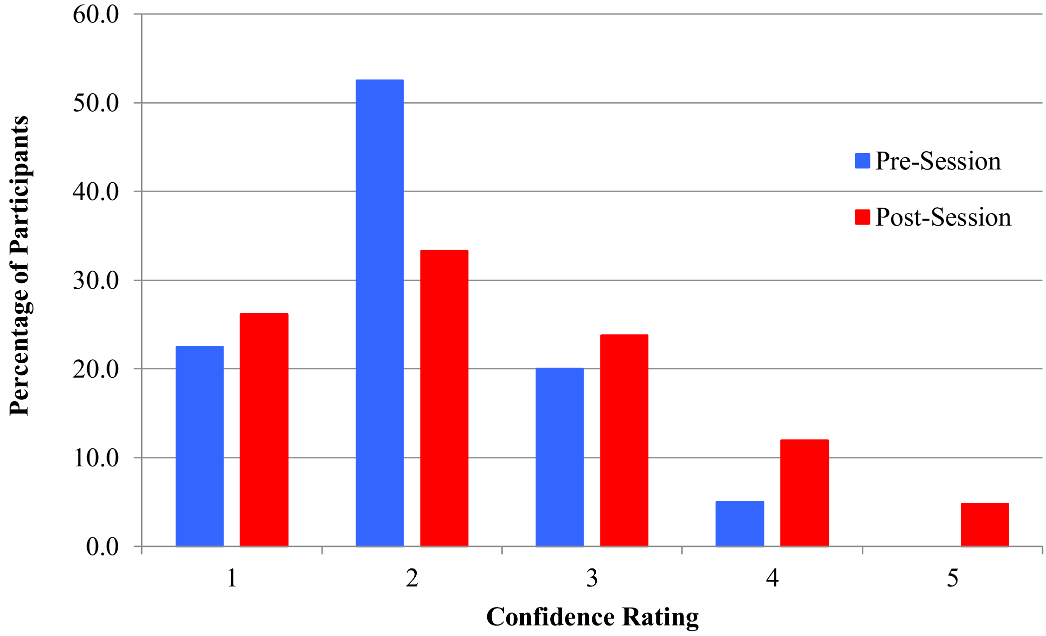

Figure 2.7 Responses to the question "Please rate your confidence in teaching chemical equilibrium at A level." before and after the focus group session (*N* = 40). A rating of 1 indicates a high level of confidence, whereas 5 indicates a low level of confidence.

Figure 2.8 depicts the response to the question regarding the teachers' confidence in their students' understanding of chemical equilibrium.

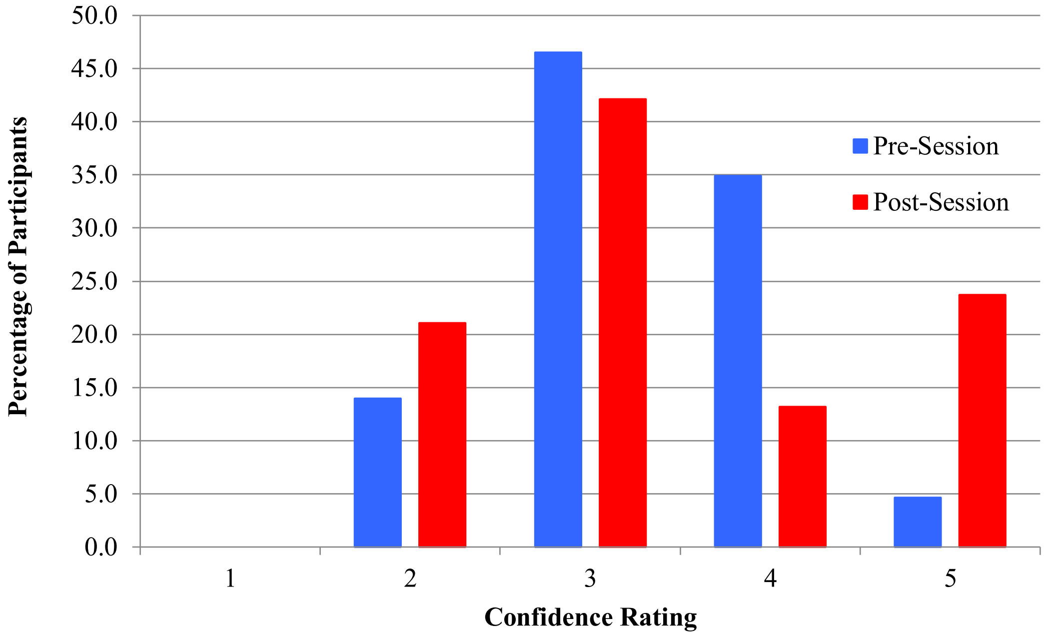

Figure 2.8 Responses to the question "Please rate your confidence in your students' understanding of chemical equilibrium." before and after the focus group session (*N* = 38). A rating of 1 indicates a high level of confidence, whereas 5 indicates a low level of confidence.

It can be seen again that there is a distinct shift towards the lower end of the confidence scale, with more teachers selecting the '5' option after participating in the focus group session. Interestingly, the number of teachers selecting '2' also increases after the session, indicating that some of the participants' confidence in their students' understanding increased as a result of the session. The responses from the teachers to the earlier questions may indicate that in their belief, their lack of confidence in their own ability has therefore decreased their confidence in their students. Those who gained an increase in their confidence in their students possibly did so because the highlighting of the issues surrounding the problems has allowed for them to become aware of their own misunderstandings, and hence they are better equipped to spot them amongst their students.

Though decreases in the teachers' confidence with respect to these areas may appear to be a negative outcome, this decrease in confidence likely arises due to the participants' realisation that their knowledge of the subject is not as good as they first believed it to be. This, however, will allow for the participating teachers to reflect on the session and has allowed for them to pinpoint the particular concepts surrounding chemical equilibrium that they do not understand as well, and hence will allow for them to focus on these areas more in the future in their teaching.

The findings of the focus group sessions are not conclusive. These sessions were undertaken to gauge the misconceptions that teachers of A level chemistry may possess, and to inform the next steps of the research project. The main limitation of the data obtained in this session is that the time available to ask the questions, allow for peer discussion, as well as to discuss the answers to the problems was severely restricted. Ideally, a session like this would have lasted closer to two hours than the 40 minutes that were available. This means that the data primarily consists of moment-in-time 'snapshots' of the teachers' workings written on the post-it notes, rather than 'exam-style' answers to the problems. Given the nature of the session as a scoping exercise, this is not too significant an issue, and provides plenty of useful data to allow for the development of resources to minimise misconceptions in this area of chemistry.

2.5 Conclusions drawn from the scoping work

The findings of this preliminary session suggested that although teachers' confidence in their SMK of chemical equilibrium was high, upon being asked questions that challenged their knowledge their confidence dropped significantly. Additionally, some responses highlighted misconceptions in the topic that have been observed in previous research, as well as an overreliance on Le Chatelier's principle. Before undertaking this phase of the project, there was a clear aim in mind of improving teachers' topic-specific PCK for chemical equilibrium. However, the outcomes of this session suggested that this was not necessarily the best direction for the project.

As noted by Shulman (1986, 1987), Tamir (1988), Magnusson et al. (1999), and many others, one of the major influencing factors in strong PCK is a high level of SMK in the topic being taught. The outcomes from this session suggest that there are areas of weakness in teacher SMK within the topic of chemical equilibrium, and for some teachers there is a general lack of confidence in their knowledge and teaching of the subject. As a direct result of this session, it was decided that emphasis should no longer be placed specifically on PCK, but instead investigation should be launched into the importance of SMK in the instruction of A level chemistry, and how this in turn can be used to strengthen teachers' PCK in the future.

In doing so, it was also decided to move the specific focus of the project away from the topic of chemical equilibrium. This decision was made so that the next stages of the project would follow a more inductive approach, allowing for topics of significant concern to be raised by in-service teachers themselves, to allow for recommendations to be made in developing relevant CPD and SMK development resources. Although chemical equilibrium was identified to be a problematic topic, it was deemed important to determine whether any other topics were of greater concern. As a result, the focus of the project was moved towards the opinions of currently practising teachers to ensure that the outcomes of the project were relevant to A level chemistry today.

CHAPTER THREE

~ Literature Review ~

This chapter presents a review of the literature regarding subject matter knowledge (SMK) and its links with pedagogical content knowledge (PCK) in the teaching of science. The literature review begins with a general overview of SMK before focusing further on the role of a teacher's SMK in the classroom and how it links to other knowledge bases. The literature review then turns to the relationship between a teacher's SMK and their confidence, before leading into a discussion of how SMK develops through the first few years of a teacher's career. Finally, this chapter finishes with a discussion of the new research questions for the project, how they were developed, and the methods by which they will be answered across the study.

Although the A level curriculum of England and Wales make up the landscape in which the research in this study was conducted, it was deemed necessary to include research from other schooling backgrounds around the world in this literature review. This decision was taken for two primary reasons. The first of these is that there has been limited research conducted in SMK in science teaching in recent years within England and Wales, meaning that to broaden the scope of the review it was necessary to look elsewhere. Secondly, it was considered important to review research undertaken at different educational levels, from primary up to degree level, to expand the scope of the review.

3.1 What is subject matter knowledge?

As has been discussed previously, SMK corresponds to the quantity of knowledge in the mind of a teacher and how it is organised there (Shulman, 1986). In his initial discussions of PCK, Shulman (1986) refers to this domain of knowledge as 'content knowledge'. When considering different aspects of SMK, it is not enough to simply consider an awareness of facts or concepts; SMK also encapsulates understanding subject matter, as well as understanding how concepts are structured and how they are linked together (Schwab, 1978). In Shulman's writing, he identifies that much of previous research into teaching considered pedagogy without reference to SMK, which he argues is of great importance in teaching.

The role of SMK in teaching any subject was expanded upon by Grossman et al. (1989), who suggested that a teacher's SMK can be categorised into four dimensions. These are:

1. **Content knowledge**
   Content knowledge encapsulates the factual information, principles, and underlying concepts in a subject. Knowledge within this dimension allows for teachers to identify the links between concepts both within and beyond their subject.

2. **Substantive knowledge**
   A teacher's substantive knowledge consists of an awareness of frameworks and paradigms that are used to guide inquiry and experiment, as well as to interpret data.

3. **Syntactic knowledge**
   This dimension of SMK accounts for the awareness of methods that allow for new knowledge to be generated, examined, and evaluated. Essentially, it accounts for a knowledge of research processes.

4. **Teachers' beliefs about subject matter**
   This accounts for what teachers believe about their SMK, influencing the aspects that teachers choose to teach and the methods they use to do so.

These dimensions of SMK highlight the importance of SMK in teaching. A strong level of SMK concerns more than just the memorisation of facts. When teaching concepts of higher complexity, an understanding of the underpinning principles is essential to ensure that students do not develop misconceptions in the subject matter (see Chapter 1.1). The influence of a teacher's beliefs in how they convey SMK to their students is also of great significance, as teachers must be able to use their knowledge of the curriculum, their students, and how the subject matter can be applied in real-world contexts to communicate information effectively.

These comments are supported by Hashweh (1987), who conducted a study with six experienced American high school (age 11-18) science teachers, describing their knowledge of science topics both within and beyond their specialism as well as determining the effects of this knowledge on their planning for teaching. His findings showed that teachers with stronger SMK possessed more comprehensive knowledge of the particular topic being taught, as well as a wider knowledge within the subject. He also noted that more knowledgeable teachers were able to relate topics to other areas within the subject more easily and displayed more traits considered essential in good science teaching. Those with a lower level of SMK were observed to rely more heavily on textbooks in their teaching, whilst also posing less cognitively demanding questions to their students (i.e. fact recall). This is further supported by Loucks-Horsley et al. (2010), who suggest that the SMK of American high school (age 11-18) mathematics and science teachers influences how they choose to engage their students in the subject matter they are teaching, as well as how they evaluate, select, and use instructional materials.

Similarly, Hill et al. (2005) observed in a longitudinal study of over 300 elementary school (age 5-11) mathematics teachers in the United States that there was a significant relationship between teachers' mathematical knowledge and student achievement gains. Measures of student achievement and teachers' SMK were made over a three-year period using a mixed-model methodology. The study found that teachers' SMK for teaching could be used as a predictor for the students' achievement gains between the first grade (age 5-6) and the third grade (age 7-8), with a positive relationship observed between the two.

The observations noted in the studies of Hashweh (1987) and Hill et al. (2005) are of particular importance to the discussion of the role of the teacher's SMK in instruction. It is worth noting that in Hashweh's study, the measure of the teacher's SMK is related to how they are teaching, whereas the findings of Hill et al. are directly related to the students' own achievements. Both metrics are important to consider when investigating the role of SMK in teaching, and it is evident that they are both impacted by the teacher's SMK.

It is also important to consider the ages of the students in these studies. It could be argued that studies involving primary school teachers (age 4-11) cannot be compared to studies involving secondary school teachers (age 11-18) due to the differences in educational setting. However, the findings of Hill et al. (2005) highlight the significant role that a teacher's SMK can play at the fundamental level in mathematics, even though their SMK will most likely go beyond that of the US elementary school course. Hashweh's (1987) findings potentially provide an explanation for this observation, lying within the methods by which teachers deliver content and assess student understanding, and highlighting the effect that appropriate planning can have on the learning that students achieve. Given the similarities between mathematics and science, it could be inferred that the same holds true in both subjects.

Even though stronger SMK has been associated with more effective teaching, this cannot necessarily be correlated with a teacher's qualifications. In a large-scale study of elementary (age 8-10), middle (age 10-13), and high school (age 13-15) teachers in Florida, USA, Harris and Sass (2007) sought to investigate the effects of education and training on teachers' ability to promote student achievement. In their study, using numerous econometric models, they found that university-level qualifications were not a good indicator of a teacher's quality, finding that in some cases higher level qualifications were linked with a lower level of student attainment. Furthermore, they found that when teacher professional development opportunities focused on SMK, this had a positive impact on mathematics teaching and student achievement at both middle and high school level. This finding provides support for the conclusions of Hill et al. (2005).

Similarly, Kind (2014) probed the chemistry SMK of 265 UK-based preservice secondary (age 11-16) teachers using a set of diagnostic questions across five chemistry concept areas, comparing the SMK levels of biology, chemistry, and physics specialists. Kind observed that although preservice teachers exhibited similar SMK levels in the topics of "particle theory & changes in state" and "mass conservation", biology specialists exhibited significantly weaker understanding than chemistry and physics specialists in the topics of "chemical bonding", "mole calculations", and "combustion reactions", noting that possession of a "good" science degree is not necessarily enough for teaching chemical concepts in high school. Kind later suggests methods for remedying this, including the employment of diagnostic instruments to ensure that teachers are aware of their misunderstandings.

The findings of these studies indicate that although teachers generally possess high level qualifications, these are not necessarily an indicator of strong SMK in both mathematics and science teaching at numerous levels. This is especially true for non-specialists teaching science, which has become more pertinent in recent years (see Chapter 1.3). It is interesting to note the similarity in findings between these studies based on the demographics and setting, where it may have perhaps been expected to be different. In the case of UK science teaching, the fact that it is common for teachers to study a single science at undergraduate level prior to teaching multiple sciences at secondary level (age 11-16) could lead to the conclusion that teachers of secondary science will have more issues with their SMK across the secondary science curriculum.

However, this is less expected in mathematics teaching, where such a split does not exist in either the US or UK education systems.

Although the findings of the two studies are similar, there are limitations associated with each which must be regarded when considering their results. The study undertaken by Kind (2014) considered only preservice teachers at one institution surrounding a small range of chemistry topics, whilst the study undertaken by Harris and Sass (2007) considered most of the teacher population in Florida. Additionally, the results obtained by Harris and Sass related to the test scores achieved by students being taught by in-service teachers, whilst Kind investigated the scores of preservice teachers on a diagnostic test, making it difficult to compare the outcomes.

Despite this, based on these findings, methods should be outlined in order for preservice teachers to develop their SMK in the areas they feel less comfortable with, with these areas outlined at the earliest available opportunity. Additionally, based on the findings of Harris and Sass (2007), it can also be said that attention should be paid to enhancing teachers' ideas of how to convey their SMK effectively and the methods and resources that they can use to do this. It is important, therefore, that the link between SMK and PCK is also considered.

3.2 SMK and PCK: teachers' professional knowledge

Although Shulman's (1986; 1987) original description of PCK depicts it as the amalgam between SMK and pedagogical knowledge, the role played by SMK in a teacher's professional knowledge has been considered to be more complex, with numerous studies reconceptualising it in different situations. As was described in Chapter 2.1, PCK is considered to be a knowledge base that develops with classroom experience (Grossman, 1990; Magnusson et al., 1999; Van Driel et al., 2001). PCK can fundamentally be defined as the transformation of SMK for the purpose of teaching, with SMK being a necessary but not sufficient condition for strong PCK (Van Driel et al., 2014; Kind, 2017; Pitjeng-Mosabala and Rollnick, 2018; Kind and Chan, 2019). The findings of these studies further support the notion that weaker SMK results in a lower level of PCK.

Numerous models, discussed in detail in Chapter 2.1, have been proposed to provide a structure to PCK (Shulman, 1986; Grossman, 1990; Magnusson et al., 1999; Park and Oliver, 2008). These models, and other studies in PCK, were considered during a PCK summit held in 2012 to develop a so-called 'consensus model of PCK' (Gess-Newsome, 2015), unifying ideas in the field of study. The model developed at this summit is also referred to as a "model of teacher professional knowledge and skill (TPK&S)". In addition to the development of the consensus model, the summit also led to a newly proposed operational definition of PCK, stating that it is the "knowledge of, reasoning behind, and enactment of the teaching of particular topics in a particular way with particular students for particular reasons to enhance student outcomes" (Carlson et al., 2015, p. 24). From this definition, it can easily be seen that the concept of PCK is highly complicated.

In the consensus model of PCK, teachers are seen to have five professional knowledge bases. These are assessment knowledge, pedagogical knowledge, content knowledge (or SMK), knowledge of students, and curricular knowledge. These professional knowledge bases are directly linked to teachers' topic-specific professional knowledge, including knowledge of instructional strategies. These links are considered to be synergistic, in that they overlap and feed into each other.

Topic-specific professional knowledge itself has a synergistic relationship with what Gess-Newsome (2015) refers to as amplifiers and filters. This refers to how a teacher approaches their teaching. Teachers are themselves individuals with different beliefs and distinct orientations towards learning, each with their own prior experiences and present contexts. Based on these factors, teachers therefore may approach the learning of new knowledge and how it is applied in a classroom setting differently. Although orientations and beliefs about science lie within the five components of PCK in the model devised by Magnusson et al. (1999), they are considered as separate in this study, though with a strong influence on PCK. The reasoning behind this decision is that it lies in agreement with other studies on the orientations of science teachers (e.g. Friedrichsen et al., 2011), where it has been noted that the consideration of such orientations has not been consistent across previous research.

All the knowledge bases considered in the above two paragraphs have a synergistic link with a teacher's classroom practice. In the consensus model, PCK is an aspect of classroom practice, both when planning lessons and when delivering lessons. In this model, the nature of PCK as a teacher's awareness of the lessons they teach, in addition to how they can adjust them based on real-time events including student participation and student needs, is emphasised heavily.

The consensus model differentiates between two different types of PCK, namely personal PCK and personal PCK and skill (PCK&S). Personal PCK is considered to be the knowledge of what happens before a lesson. This entails the reasoning behind and planning of teaching a particular topic, using a particular method, to ensure that the teachers' students meet a set of outcomes. Conversely, personal PCK&S is what happens during a lesson, defined as the "act of teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (Gess-Newsome, 2015). It is further discussed that PCK varies greatly with different topics, as also discussed by Veal and MaKinster (1999), and therefore indicates that different PCK is required when teaching both within and beyond specialism.

As well as teacher amplifiers and filters, student amplifiers and filters are considered as part of the consensus model. Students themselves are important in the teaching and learning that happens in the classroom and can choose whether they engage with the learning process. However, their own success is not dictated solely by their teacher, and is dependent on a variety of factors, including but not limited to demographics, working memory, background knowledge (including misconceptions), and motivation. Moreover, students can influence the process that occur in the classroom, as their behaviour and engagement can both promote or subdue teacher motivation, practice, and ability. Finally, these are then linked to student outcomes, which in turn are synergistically linked to all the previously described knowledge bases.

The consensus model demonstrates the complexity of a teacher's professional knowledge, highlighting many factors that can influence a teacher's knowledge bases and their beliefs. Although SMK may seem to be a relatively small aspect of a teacher's professional knowledge, its impact is prevalent throughout the model. The model further highlights the importance of teachers developing an awareness of their students' beliefs and preconceived ideas. If these are unknown, it can be difficult to ameliorate these issues within the classroom, impacting student outcomes and teacher confidence as a direct result.

Alongside the development of models of PCK, numerous studies have been undertaken to try and determine the role that SMK plays in teacher development. Van Driel et al. (2002) investigated the development of PCK with twelve preservice pre-university level (age 16-18) chemistry teachers in the Netherlands, focusing on the relationship between observable phenomena and macroscopic properties and their interpretation on the microscopic level. They observed that a strong level of SMK assists preservice teachers in having an enhanced awareness of students' issues, including an awareness of student misconceptions and how to correct them. The findings of this study align with those models of PCK discussed previously, highlighting the links between a teacher's knowledge of learners, their SMK, and ultimately their PCK (Shulman, 1987; Magnusson et al., 1999; Gess-Newsome, 2015).

Further to this, Rollnick et al. (2008) investigated the role of teacher SMK in transforming content for teaching, considering the concepts of the mole and chemical equilibrium, in a South African secondary school (ages 14-16) with experienced science teachers. They observed that teachers with good SMK demonstrated a level of PCK in line with high-quality teaching, using topic-specific instructional strategies to deliver content. They also suggest that teachers with lower-level SMK demonstrate elements of PCK that are linked to theoretical assumptions, such as knowledge of students and context. Stender et al. (2017) observed similar results to Rollnick et al. (2008) in a study with 49 in-service secondary (age 11-18) physics teachers in Germany, identifying that those with stronger SMK were observed to make more informed decisions regarding lesson planning than those with weaker SMK.

While the findings of both studies align, their comparison must be considered carefully. The study undertaken by Rollnick et al. involved lesson observations, with interviews conducted before and after the lesson, whereas the study undertaken by Stender et al. considered only the lesson planning process of the participants. It would be interesting to note whether those informed decisions regarding planning translated directly into a classroom situation.

Although these studies suggest a positive link between SMK and PCK, they do not provide evidence to suggest a link between SMK and student understanding or achievement, as has been seen in those studies considered previously. The focus of these studies is based around how knowledge is implemented in a number of science teaching scenarios, providing further support for Hashweh's (1987) observations regarding how teachers use resources & questioning and the strength of their SMK. Additionally, there is limited discussion of teacher confidence in their SMK and how they perceive the role that their confidence plays in their teaching.

The outcomes of these studies highlight that it can be difficult to characterise a science teacher's SMK. In a more recent study, Nixon et al. (2019) set out the 'science knowledge for teaching' (SKT) model to better characterise science teachers' SMK. This model consists of three domains, namely core content knowledge, specialised content knowledge, and linked content knowledge. Secondary chemistry (age 11-16) teachers in South Africa and the United States were seen to draw on their knowledge from all three domains when discussing a specific teaching scenario, highlighting a further link between teacher SMK and how they are teaching a particular topic. This study is limited, however, by the fact that the methods used only involved approximated scenarios, to better focus solely on SMK.

Based on the findings of these studies, it can be said that there is a significant and noticeable correlation between stronger SMK and a higher level of PCK. As discussed earlier in this thesis, the original focus of the project was to develop a resource aimed at accelerating the development of teacher PCK in the topic of chemical equilibrium. The findings from the scoping work, where numerous experienced teachers were observed to display misconceptions or the misapplication of principles, highlight the presence of SMK deficiencies amongst A level chemistry teachers. Based on the literature discussed here, if the development of PCK is sought, then ensuring that teachers have strong and well-developed SMK is critical. These discussions support the decision to investigate the role of SMK in A level chemistry teaching, so that areas of self-reported weakness can be noted and targeted in future research in this field.

3.3 Teacher confidence in subject matter knowledge

In addition to considering the level of teachers' SMK and its position within teacher professional knowledge, it is also important to consider teachers' confidence in their SMK. Hoy and Spero (2005) investigated changes in American secondary (age 11-18) teachers' confidence (or efficacy) from their entry into an ITT programme, highlighting that when specialised support is provided to enhance teacher confidence that there is a positive influence on it. Although this study is centred on the general confidence of teachers rather than specifically confidence in SMK, this outcome should be considered a relevant and significant one.

In another study, Appleton (1995) observed amongst a sample of Australian elementary school teachers (age 5-11) that when they were seen to lack SMK in particular topics, in addition to the structure of the discipline, that this can cause teachers to possess lower levels of confidence in their teaching. Further to this study, Appleton and Kindt (1999) interviewed nine graduate Australian elementary school teachers during the first eighteen months of their teaching, investigating their perceptions of teaching science. The emergent themes from the interviews related to their perceived self-confidence and the influences on it within their school. The authors observed that those teachers with low levels of confidence in teaching science also had weak SMK, which was worsened significantly due to their belief that they needed to be competent enough to answer their students' questions about the subject.

It is important to consider the relevance of the studies discussed above (Appleton, 1995; Appleton and Kindt, 1999) to other studies of teacher SMK and confidence. The Australian elementary school setting is very similar to the primary school context in England & Wales, in that teachers mostly have degrees in education or primary education rather than a specialism in a particular subject. It is therefore difficult to compare these ratings of confidence in science SMK with that of a science specialist, as the views held will likely be very different. However, an increasing number of secondary science teachers in England & Wales are non-specialists, and therefore may lack confidence in their science SMK (or in their SMK of a particular science). Additionally, if teachers are required to teach A level (or an equivalent pre-university qualification) without a specialist degree in the subject, this may magnify their lack of confidence in the subject.

Youens and McCarthy (2007) observed that preservice secondary (age 11-16) science teachers in England found support from their colleagues to be of great help in improving their confidence in their SMK, which allowed for them to experiment more with their teaching through the use of new activities and different teaching strategies. These activities and strategies were seen to be appropriate for the content being delivered, aligning Hashweh's (1987) observations. This result demonstrates the importance that professional development can have in developing science teacher SMK.

In another study, Kind (2009a) investigated the sources used by 71 UK-based preservice secondary (age 11-16) science teachers to prepare for lessons both within and beyond their subject specialism (i.e. biology, chemistry, physics), as well as the effects on teacher confidence within those two domains. The findings of this study differ to those previously discussed, in that the transformation of SMK and selection of appropriate instructional strategies appeared to be more consistent with teachers who were teaching *outside* of their specialism, as they were observed to be using a greater variety of resources, including advice from experienced colleagues. As this study concerns preservice teachers, it may be that this finding is because preservice teachers teaching outside of their specialism will have more time to find and evaluate resources to use in their teaching, compared to experienced teachers with a greater teaching load.

Kind (2009a) also found that preservice teachers with low levels of confidence relied heavily on materials when teaching beyond their specialism, whilst those with a high level of confidence were observed to quickly realise the importance of both transforming SMK and selecting appropriate instructional strategies. The responses given by participants in this study were, however, self-reported, and were based on the participants' perceptions, so it does not necessarily translate that the reported views are indicative of the reality of the lessons delivered. While Kind's findings highlight the issue of confidence in teaching outside specialism in secondary teaching, they do not include teaching at the pre-university level (age 16-18), which could be considered a focus for future study.

Although Kind's findings may indicate that practices attributed to strong PCK were more notable amongst those teachers teaching outside of their specialism, this is not always the case. Sanders et al. (1993) investigated the similarities and differences between three experienced American secondary (age 11-16) science teachers' planning, teaching, and reflection when teaching both within and outside of their science specialism. They observed that these teachers were more likely to involve students in their lessons to a greater extent when teaching within their specialism, allowing them to talk more and ask more questions. The difference in observation between both Kind's study and the study conducted by Sanders et al. could be due to teacher experience, where experienced teachers are likely to be more confident in those topics of lower SMK simply because they have taught them more often than preservice teachers have.

Similarly, Childs and McNicholl (2007) investigated the perceptions of eighteen UK secondary (age 11-18) science teachers of varying experience regarding teaching outside of their science specialism through semi-structured interviews. Their findings were largely consistent with the research discussed above; teachers discussed that they often found it difficult to select suitable resources for teaching when teaching outside of specialism, as well as delivering "rigid and unimaginative" teaching due to a lower awareness of applications and context. Notably, the authors observed that their findings were largely the same regardless of how much experience teachers have, contrasting the findings of Kind (2009a). Given the similarities in context and methodology between the two studies, it is interesting to note the difference in these two outcomes. The results of both studies may have been different had they considered the use of other methods alongside semi-structured interviews and questionnaires. Based on these findings, it can be said that further investigation of the differences in teachers' confidence in their SMK between experienced and novice teachers is worthy of further study.

Many of the UK-based studies discussed in this chapter were published in a specific period, namely an approximately twenty-year period between the late 1980s and early 2010s, with fewer having been published in the last five to ten years. It is possible, and perhaps likely, that this stems from the introduction of the National Curriculum in England and Wales, as part of the Education Reform Act 1988.

One of the main aims of the National Curriculum is that it should provide students with the essential knowledge that they require to be educated citizens. The curriculum is structured into four key stages (1, age 5-7; 2, age 7-11; 3, age 11-14; and 4, age 14-16), each with its own programme of study that consists of a set of pre-defined topics that should be taught. This is the case in all subjects, including science. As a result, it is essential that teachers are aware of the National Curriculum and the content it sets out. This provides a background for much of the discussed research, demonstrating a need for both preservice and experienced teachers to have a strong level of SMK, and highlights why it may have become less pertinent since then. Given that there have been alterations to the curriculum as recently as 2014, there is still a need to investigate the role of SMK in science teaching further.

In recent years, few studies have focused on the development of secondary science teachers' SMK from their training through the first few years of their teaching career. One such study was conducted by Nixon et al. (2017), where fifteen novice secondary (age 11-18) science teachers in the United States were required to construct and organise concept maps, positioning and linking topics within a particular discipline (e.g. biology, chemistry) annually from the first year of their career until the fifth. These concept maps were scored based on the quality of knowledge demonstrated and how well the knowledge displayed had been linked together.

The study found that despite the fact the teachers were gaining more classroom experience, there was no significant change in their SMK based on their concept maps. This is a similar finding to that of Kleickmann et al. (2013), who observed that the SMK of secondary mathematics teachers in Germany (age 11-18) changes very little with experience, and in some cases was seen to decrease. Rather than an analysis of the quality of knowledge through concept maps, however, the study conducted by Kleickmann et al. focused on assessing knowledge in a test-based scenario, which may not demonstrate the participant's overall body of SMK in mathematics and how it links together. Although similar in their instruction, there are differences in the SMK and PCK required in mathematics and science teaching, so this comparison is limited.

These observations could be due to the nature of teaching, in that there is more to focus on than just SMK development. In a review of the challenges that new science teachers face, Davis et al. (2006) note that although understanding the content and disciplines of science is an important challenge for new secondary (age 11-18) science teachers in the United States, there are four other key areas related to the teacher knowledge bases that must also be understood. This is echoed by the Teacher Standards, published by the UK Government (DfE, 2021); though teachers in England are expected to demonstrate eight standards in their teaching, only one is directly linked to the teacher's SMK.

This is supported by the work of Mulholland and Wallace (2005), who followed the development of an Australian elementary (age 11-13) science teacher's PCK over the first ten years of her teaching career. They noted that in the early years of her career, her development was more noticeable in the areas of pedagogical knowledge and knowledge of learners, whilst her SMK development did not start to occur until later in her career. Based on these reports, it can certainly be assumed that science teachers in the first five years of their career will be facing many challenges and will be unable to devote a considerable amount of time to their SMK.

As noted in the models of teacher knowledge discussed previously (Shulman, 1986; Grossman, 1990; Magnusson et al., 1999; Park and Oliver, 2008; Gess-Newsome, 2015), a teacher's knowledge is complex and is many-faceted, so it is important to realise that there is more to it than simply their SMK. However, the fact that research demonstrates that SMK is often overlooked, or that there is little time available to enhance it, suggests that more work needs to be done to enhance the SMK of teachers.

This rationalisation is consistent with the fact that earlier studies of SMK development have also included teachers who were still in ITT (Gess-Newsome and Lederman, 1993), who are likely to have a lower teaching load and hence more time outside of the classroom to develop their SMK as opposed to those who have recently qualified. It can also be said that teachers on ITT courses may be receiving SMK development training as part of their course, which would also influence these results.

3.4 Scope of the present study

As has been mentioned previously, there have been few examples of research published within England and Wales in recent years based around the SMK of secondary science teachers. It is worth reiterating the context of the focus of this thesis, which was raised in Chapter 2, which is on teaching chemistry at pre-university level (A level) in the UK.

The A level chemistry curriculum, though it differs between specifications, contains a considerable amount more content than the National Curriculum outlines for key stages 3 and 4, which are expected to be taught by secondary science teachers. Although not all secondary science teachers will teach A level chemistry, they possess the qualifications required to do so, and so may take up this work at some point during their career. It can be argued, however, that teachers require a stronger SMK base if they are teaching A level chemistry compared to if they are only teaching up to key stage 4.

The lack of literature published that focuses on this level of teaching in England and Wales is of particular note. Pre-university courses act as a bridge between school learning and university learning, and as a result any misconceptions that students possess because of their secondary education could be deep-rooted when they come to university if they are not corrected beforehand. If an A level teacher does not possess the necessary SMK for teaching at this level, then this could have negative implications for their students' learning going forward. This also raises the question: what is the necessary SMK for teaching A level chemistry, and how does this differ to teaching secondary-level science? Further to this, the difference between a high level of SMK and a teacher's qualifications are also worth considering.

Additionally, the findings of the studies discussed throughout this literature review suggest that there is a positive correlation between a teacher's SMK and effectiveness of teaching and/or student achievement at both the primary (age 5-11) and secondary (age 11-16) levels. It would be of interest to investigate whether teachers of A level chemistry believe that the same is true for their level, and to see the extent to which it feeds into their other teaching knowledge bases. Based on the findings of their study, Nixon et al. (2017) recommended that future research should be undertaken on how secondary science teachers approach topics that are unfamiliar to them, in addition to their confidence in their understanding of science. Further to those mentioned above, this has also been deemed an important area to investigate, so that these approaches can be compared and discussed with novice teachers, in the hopes of accelerating their SMK and PCK development.

Based on the findings of the scoping work outlined in Chapter 2, and the literature discussed throughout Chapter 3, a new set of research questions were developed for the project, with sub-questions designed to guide towards answering the overarching research questions. The project was split into two main focuses: SMK in ITT and SMK & the A level curriculum. As a result, two overarching research questions for the project were developed. The first of these is given below.

How do A level chemistry teachers perceive the influence of their education on their chemistry subject matter knowledge and their confidence in it?
(RQ3)

Through asking this question, it allows for the investigation of how teachers perceive the development of their chemistry SMK over the first few years of their teaching career and could therefore provide important information that could contribute to the production of CPD and resources designed to enhance teacher SMK, ultimately leading to an enhancement in PCK as a result. To guide towards an answer to RQ3, a set of three sub-questions have also been developed. These, alongside their rationales for inclusion, are included below.

What are the perceptions of A level chemistry teachers regarding the impact of their undergraduate degree on their subject matter knowledge?
(SQ3.1)

The rationale for this sub-question was to allow for the investigation of the relationship between a teacher's SMK and the qualifications that they possess, and whether they believe that a specialist chemistry degree is necessary to teach A level chemistry. It was deemed important to consider how important teachers perceived their own study of chemistry in their SMK for teaching the subject, as prior literature has found little to no relationship between the two when considering primary and secondary teaching (Harris and Sass, 2007; Kind, 2014; Gaciu et al., 2017). These perceptions will be gauged through A level chemistry teachers' retrospective analysis of their undergraduate studies. Through investigating this sub-question, it will allow for this research to answer RQ3 by providing a baseline for the participants' SMK prior to ITT and their confidence in it, allowing for an analysis of any change in confidence to be undertaken. This leads on to the second sub-question, which is given overleaf.

How do A level chemistry teachers perceive their confidence in their chemistry subject matter knowledge to change during their initial teacher training? (SQ3.2)

Based on the findings of Nixon et al. (2017), as well as the scarcity of literature regarding confidence in SMK, it was considered important to investigate how the confidence of A level chemistry teachers in their SMK changes in the early stages of their teaching career. This sub-question also stemmed from the findings of this project reported in Chapter 2, where teachers' confidence in their SMK was seen to be impacted when they were given questions designed to investigate misconceptions in chemical equilibrium. The findings of this sub-question will follow those of SQ3.1 and will therefore contribute to the narrative of how teachers perceive their SMK to change as they become more experienced.

It is not only important to consider how the SMK of A level chemistry teachers develops during the ITT process, but also the action that they take to aid the development process. This consideration led to the development of sub-question 3.3, given below.

Which methods do A level chemistry teachers use, during their initial teacher training, to enhance their chemistry subject matter knowledge? (SQ3.3)

The findings in response to this question may provide insight into which resources A level chemistry teachers engage with to further their SMK and so could provide useful information on the style and nature of resources or CPD that could be developed in future to aid with SMK development. Equally, through investigating this, it will allow for some analysis of how effective particular resources were in enhancing SMK and confidence in SMK, and so will provide further evidence in answering RQ3.

The second of the newly developed overarching research questions is given below.

Are there differences in the ways that A level chemistry teachers approach teaching topics where they are confident in their SMK compared to those topics where they are not? (RQ4)

As was discussed previously, Nixon et al. (2017) suggested that research should be undertaken into how secondary science teachers approach topics that are not familiar to them. It can be argued that if a teacher has low familiarity with a topic, then they are likely to have low confidence in their SMK of that topic. As a result, it was considered important to research whether there were differences in approach between teachers' most confident and least confident topics, as well as to consider the effect of teacher experience on these perceptions. Identification of any differences in approaches, and their subsequent success or failure in the classroom, could allow provide data that are integral to the development of resources used for SMK enhancement.

A further set of three sub-questions were developed to guide towards an answer to RQ4. These, alongside their rationales for inclusion, are included below.

Are there particular topics within the A level chemistry syllabus that A level chemistry teachers are generally less confident with their knowledge of? (SQ4.1)

Given that this study aimed to investigate the differences in approach between topics where teachers possess high confidence in their SMK and topics where they possess lower confidence, it was considered essential to identify any topics that presented difficulties for a large number of A level chemistry teachers. If any such topics were to be identified, these would provide a focus for SMK enhancement resources that would be of wider appeal to practising teachers and would also have a positive outcome on their students. Through asking this question, the results of this study will also allow for investigation of approaches of high and low confidence in a number of different topics, which will provide valuable data in answering RQ4.

As was noted in Chapter 1.3, reports have recommended that science ITT courses should provide for the development of knowledge such that it is at a level higher than the level that teachers will teach (SCORE, 2015). With numerous non-specialists currently in the workforce (DfE, 2020), it was deemed to be valuable to investigate teachers' perceptions of whether it is an issue if teachers' SMK is limited to the level of the A level specification, as detailed in SQ4.2.

Do teachers of A level chemistry believe it is a problem if the subject matter knowledge of teachers is limited to the A level specification? (SQ4.2)

Through the investigation of SQ4.2, the data collected will highlight how A level chemistry teachers perceive what an appropriate level of SMK is, and as a result how this may impact on other factors in their teaching of it (for example, their confidence). Additionally, it can be argued that certain topics within the A level may be easier to understand and therefore explain if a teacher's knowledge lies beyond the specification. As a result, the findings from this sub-question will go some way to helping provide an answer to RQ4, as teachers' approaches may be different depending on their level of knowledge.

The A level chemistry specification is designed to give students an introduction to the key concepts in chemistry, allowing for them to be developed upon further at university level. As a result, this means that models are often used to describe complex chemical phenomena and allow for students to gain a preliminary understanding of the concepts involved. However, as has been noted previously, the use of models can cause the development of misconceptions if the limitations are not discussed effectively (Driver et al., 1996). Furthermore, teachers may use analogies in their teaching of complex concepts, in order to provide relevance to students learning them (Thiele and Treagust, 1994; Tibell and Rundgren, 2010; Orgill et al., 2015). Like models, analogies also pose a danger of facilitating the development of misconceptions amongst students (Taber and Tan, 2011). Based on this, it was deemed appropriate to investigate whether A level chemistry teachers are aware of the limitations in the models and analogies that they use in their teaching (SQ4.3).

Are A level chemistry teachers aware of their usage of models and analogies in particular topics within the A level specification, and are they aware of the limitations of such models? (SQ4.3)

Following the findings reported in Chapter 2, investigating the use of particular models was deemed to be of interest when speaking to A level chemistry teachers. The findings in response to this sub-question will help to illustrate whether there is a difference in the usage of analogies and models between topics of high and low confidence, further aiding the answering of RQ4.

To investigate the perceptions of A level teachers regarding the role of SMK in chemistry teaching, it was decided that a qualitative approach should be undertaken, through usage of semi-structured interviews and surveys. The methodology employed, in addition to the data collected, is detailed extensively in Chapters 4 and 5.

CHAPTER FOUR

~ The Interview Phase ~

This chapter begins with a discussion of the methodology for the interview phase of the project and how the chosen methods and analysis address the new research questions of the project. This is followed by the results of the interview phase of the project, which are split into two sections: subject matter knowledge (SMK) in initial teacher training (ITT) and subject matter knowledge and the A level curriculum. These results are discussed with relevance to the wider literature throughout the chapter. This chapter concludes with a rationale for the survey phase of the project.

4.1 Methodology: Research design

4.1.1 Data collection methods

This phase of the project was designed as a scoping study, as recently little research has been undertaken on chemistry teachers' opinions regarding the role of SMK in A level teaching and how differences in these beliefs may impact a teacher's instruction. With this research project primarily focusing on opinions and beliefs of teachers rather than gauging conceptual understanding itself, it was deemed appropriate to collect data through the use of semi-structured interviews. Semi-structured interviews consist of a pre-determined set of questions, but the ordering or exact wording of the questions may differ depending on the participants. Herrington and Daubenmire (2014) summarise the use of interviews in chemical education as 'allowing access to the "unseen", namely participants' thoughts, beliefs, and feelings'. Furthermore, the semi-structured nature of the interview allows for the interviewer to ask the participant to elaborate on responses with examples, as well as to ask about contrasting and contradicting ideas (Drever, 1995; Patton, 2002; Bretz, 2008).

There are disadvantages associated with using semi-structured interviews as the primary data collection method. The principal drawback of using semi-structured interviews is that of access to participants. Interviews are typically undertaken on a face-to-face basis (Patton, 2002; Herrington and Daubenmire, 2014), therefore meaning that researchers must be able to readily meet with participants, in addition to having a space to conduct the interview. This can potentially limit the participant pool and lead to smaller sample sizes, which can in turn reduce the variability in studies and the potential transferability of the collected data and the associated conclusions drawn (Lincoln and Guba, 1985; Pratt and Yezierski, 2018).

In order to overcome this difficulty, online interviews were deemed an appropriate alternative to face-to-face interviews, using Skype as the medium. Pratt and Yezierski (2018) suggest that in-person interview tasks can easily be adapted by using an audio- and visual-based online program such as Skype. Studies in several disciplines have found that the use of Skype for interviews may provide additional benefits over face-to-face interviews, as participants can attend the interview in their own chosen location, such as home, which can be more convenient for them (Bertrand and Bordeau, 2010; Hanna, 2012; Hamilton, 2014; Janghorban et al., 2014; Simeonsdottir Svensson et al., 2014; Nehls et al., 2015; Iacono et al., 2016; Weller, 2017), and some studies suggest that not being physically present with the interviewer may make participants more comfortable (Hanna, 2012; Weller, 2017).

A further disadvantage of using interviews is transcription bias. Poland (2003) highlights that when interviews are transcribed, there is potential for certain sounds (e.g. sighs) and intonation to be misinterpreted, which could result in the data being misinterpreted upon analysis. In an attempt to minimise this bias, the interviews were transcribed by an independent party and then read by the interviewer immediately after whilst listening to the recording, as the interviewer's first-hand experience of the interview would provide more accurate interpretation of the data.

In conjunction with semi-structured interviews, online questionnaires were used to collect data. It was deemed important to use more than one instrument for data collection, as a single instrument cannot be used to map the complexity of teachers' knowledge and beliefs (Kagan, 1990). The questionnaires were used to collect data that could inform questions at interview, including demographic information and quantitative data regarding teacher confidence in SMK.

4.1.2 Participants

The participants approached for the interview phase of the project were teachers of A level chemistry. As well as current teachers, within this sample are included those who had just started teaching A level chemistry (i.e. newly qualified teachers, or NQTs) and those who had spent part of their life teaching A level chemistry but have since stopped teaching or retired.

Initially, a convenience sampling method was used to approach participants (Robinson, 2014). Potential participants were initially approached via email. The chemical education research group at the University of Southampton has a self-selecting mailing list of chemistry teachers and teacher trainers based in the United Kingdom who wish to be kept informed about outreach activities, staff development opportunities, and research projects. An email detailing the project was sent to this mailing list and the recipients were encouraged to share it with their teaching colleagues and contacts where possible. The email included a link to the initial online questionnaire, where potential participants could respond if they were interested in the project. All participants who responded to the initial online questionnaire were self-selecting.

The fact that the participant pool consisted of a self-selecting group, contacted through a self-selecting mailing list, presented a potential limitation in the interview phase of the project with regards to whether the results obtained are transferable and generalisable to the overall population from which the participants are elicited (Burns and Grove, 1997; Freedman et al., 1997). The use of a convenience sample, therefore, can possibly favour particular outcomes, as it increases the chance of researchers recruiting participants who have strong feelings regarding the issue(s) in question (Moore, 2001).

In order to ameliorate this issue, respondents to the questionnaire were selected for interview based on their demographic information (e.g. teaching experience, their level of degree, independent or state school, etc.) to ensure a wide spread of experiences and to make the sampling more purposive. Sousa et al. (2004) recommend using demographic data such as this, if accessible, to determine whether a sample represents a population. Selecting interviewees in this manner also allowed for comparison to be drawn between the different groups in the analysis phase of the project.

Those who were selected for interview were invited to complete a second online questionnaire with their responses to this questionnaire informing certain questions during the interview. The questions were split between two different online questionnaires to promote initial participation as the inclusion of a large number of open-answer questions may have deterred teachers from responding. Both of the online questionnaires were hosted on the University of Southampton's iSurvey website. After responding to the two online questionnaires, the participant was interviewed one-on-one by the researcher, either face-to-face or via Skype (Figure 4.1). Details regarding the development of the questionnaires and the interview protocol are described in Chapters 4.2 and 4.3.

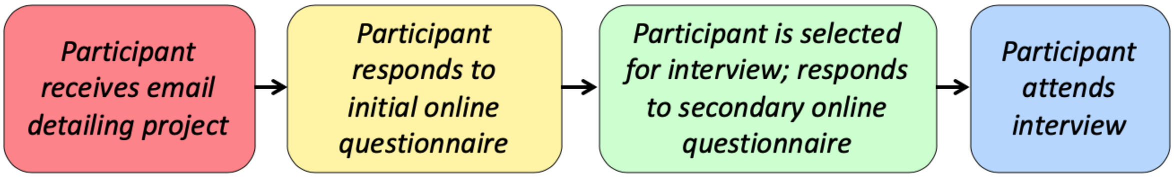

Figure 4.1 Schematic detailing the experience of participants in the interview phase of the project.

Once the first interview had been undertaken, informal analysis of the data began immediately and continued throughout the interview phase of the project. Analysis of the data during the initial stages of this phase of the project allowed for emergent themes to be compiled and for subsequent interviews to be more focused (Hatch, 2002; Merriam and Tisdell, 2016). The number of interviews undertaken during this phase of the project was informed by saturation sampling, a sampling technique whereby data collection stops when no more significant themes are identified (Mason, 2010). This will be detailed further in Chapter 4.3.

4.1.3 Sample information

22 teachers responded to the initial online questionnaire, with eleven of these respondents invited to interview (Table 4.1, overleaf). Participants are listed in order of increasing teaching experience. As will be discussed in Chapter 4.3.4, the participants' names have been fictionalised in order to maintain their anonymity throughout this thesis.

Participant	Undergraduate Degree Subject	Higher Degree Qualification (if applicable)	ITT Route	Teaching Experience (Years)
Ethan	*MChem Chemistry*	-	*PGCE*	*<1*
Daniel	*MSci Chemistry*	*PhD Organic Geochemistry*	*SD*	*1-3*
Hannah	*BSc Chemistry*	-	*SD*	*1-3*
Martin	*MChem Chemistry*	-	*PGCE*	*4-6*
Rebecca	*MEng Chemical Engineering*	-	*PGCE*	*4-6*
Arthur	*BSc Chemistry*	-	*PGCE*	*7-10*
Richard	*BSc Chemistry*	*MA Science Education*	*GTP*	*7-10*
Jenny	*BSc Biomedical Science*	-	*PGCE*	*11-15*
Gerald	*MChem Chemistry*	-	*PGCE*	*16-20*
Kenneth	*BSc Biochemistry*	*PhD Molecular Biology*	*PGCE*	*16-20*
Roland	*BSc Chemistry*	*PhD Inorganic Chemistry*	*PGCE*	*>20*

Table 4.1 Details of the participants interviewed during the interview phase of the project.

4.2 Methodology: Development of pre-interview questionnaires

4.2.1 Initial online questionnaire

The primary purpose of the initial online questionnaire was for teachers to indicate their interest in the project and signify their willingness to be interviewed whilst also providing opportunity for preliminary data collection. The initial online questionnaire was split into two sections; the first section focused predominantly on demographic information, whilst the second section focused on SMK in A level chemistry. This questionnaire was designed to take no longer than ten minutes in order to promote participation.

With the focus of the project being primarily on SMK, it was considered important to gather information regarding participants' academic background. Participants were required to provide details of their GCSE/A level (or equivalent) qualifications, state which subject they had studied for their undergraduate degree, and whether or not they had a higher degree (e.g. Ph.D.). Inclusion of these responses in the initial online questionnaire allowed for further investigation into whether undertaking a chemistry degree provides better SMK preparation for teaching chemistry as opposed to taking a degree in another subject, as these responses could be further discussed at interview. Additionally, participants were required to indicate their highest level of study of mathematics. This question was included due to the reintroduction of the Arrhenius equation to the United Kingdom's four major A level specifications in 2015 (OCR, 2014a; OCR, 2014b; AQA, 2015; Pearson, 2016), as the manipulation of natural logarithms could present a challenge for teachers with a lower level of mathematical study.

Participants were required to specify the route that they took into teaching so that inquiry into whether different routes provide more support with teacher SMK could be undertaken. Participants were also asked to provide details of the length of time they had spent in teaching to allow for comparison between the responses in the interview phase of novice teachers and experienced teachers. Teachers were also required to input the type of school in which they teach (e.g. independent school, comprehensive school, sixth form college, etc.) to again allow for comparison between interview responses of the different groups.

The second section of the questionnaire consisted of two questions. Participants were required to rate their confidence in their SMK of ten topics in A level chemistry based on four levels. For each topic, participants would input the level to which they felt confident with their SMK. The levels were based on the stages of a student's academic progression and included GCSE, A level, first year undergraduate level, and beyond first year undergraduate level. In addition to their confidence in their SMK, participants were also required to rate their confidence in their ability to teach the ten topics by ranking each of the topics relative to the others, ultimately giving a scale from the topic they feel most confident teaching to the topic they feel least confident teaching.

The ten A level topics were chosen based on a review of the UK's major A level chemistry specifications published by Read and Barnes (2015), where similarities and differences between the specifications were mapped. The ten topics encapsulate the key chemical concepts present on each of the A level specifications. These ten topics are listed alphabetically below.

- Acids, Bases, and Buffers
- Analytical Techniques
- Atomic Structure and Molar Calculations
- Bonding and Intermolecular Forces
- Chemical Equilibrium
- Electrochemistry
- Energy Calculations
- Kinetics
- Organic Chemistry
- Transition Metal Chemistry

These questions were based on the methodology employed by Carlsen (1993), where biology teachers were asked to rank fifteen biology topics in terms of their SMK. In this instance, the topic labels reflected themes that were emphasised in biology textbooks. The inclusion of these questions allowed for further questions to be asked at interview regarding how teachers deal with teaching topics that they are less confident in and how the approach taken with self-declared weaker topics differs to that of stronger topics. Furthermore, these responses can be considered during future development of SMK-specific CPD and resources for teachers, tying in with the aim of this research project.

4.2.2 Secondary online questionnaire

Upon invitation to interview, participants were sent a link to the secondary online questionnaire and were required to complete this prior to attending the interview itself. The eight questions asked in the secondary online questionnaire dealt with the participants' views regarding the nature of science and their experience of teacher training. Due to the close link between teachers' knowledge and their own beliefs, participants were asked to comment on what they personally believed the nature of science to be, and how scientific knowledge is produced. These questions were adapted from a study undertaken by King (1991), which examined the teaching goals, associated with the history and philosophy of science, of thirteen preservice science teachers.

Participants were also asked to comment on their perception of their chemistry SMK before they started teaching, during their teacher training, and at present, whilst also discussing their confidence in their SMK at those points. Questions concerning confidence were included to allow for teachers to discuss their feelings and beliefs regarding their SMK and its role in teaching, as this is not necessarily the same as the amount and quality of SMK that the teachers perceive themselves to have. Responses to this question could be compared to the questions in the second section of the initial online questionnaire, and thus together were used to inform discussion during the interview phase.

The questions described above were included in a secondary online questionnaire rather than the interview itself for two reasons. The first of these was to ensure that teachers gave concise responses to the above questions, which could then be elaborated upon at interview if deemed appropriate to the aims of research. If these points had been raised during the interview rather than in a questionnaire beforehand, there is a possibility that the interviewer may have missed the opportunity to expand on the themes at hand and thus could have led to more restricted data. Secondly, there was a desire to keep the length of time for interview restricted to no more than 90 minutes, to promote participation and to avoid taking too much time away from the teachers choosing to participate. The questions for both questionnaires can be found in Appendix A.

4.3 Methodology: Development of interview protocol

4.3.1 Interview questions

The interview consisted of four sections of questions, with potential for both the interviewer and participant to elaborate on any responses. The four sections were defined as:

- Teacher training
- The role of SMK in teaching
- The A level curriculum
- Common misconceptions in A level chemistry

The interview was structured in accordance with recommendations provided by Patton (2002) and Merriam (2009), by initiating the interview with questions related to the participants' experiences and following up later with questions regarding opinions and feelings. The first section, regarding teacher training, sought to encourage further discussion relating to the responses provided in the second online questionnaire, whilst also allowing for insight into the influence of a teacher's training on their SMK. The questions included in the interview encouraged participants to discuss how their undergraduate degree helped to develop SMK for teaching, how their teacher training addressed SMK development in the training period, and whether they engaged in self-directed activities to improve their chemistry SMK.

Broader questions regarding teachers' opinions of what makes an effective teacher were included in the second section of the interview. Direct questions asking how important participants believe SMK to be in the teaching of A level chemistry were also asked within this section, wholly overlapping with the primary research questions of the project. Participants were also encouraged to provide commentary on whether they felt that their teaching was limited by any external factors and how they would personally like to teach chemistry in an ideal world. Merriam (2009) states that the phrasing of questions is key both in terms of the data received and for making participants feel comfortable; the inclusion of questions regarding a hypothetical scenario can take direct focus off the participant and can make them feel that they aren't being put on the spot.

The third section of the interview sought to ascertain teachers' experience of the A level curriculum and how they responded to students who ask questions about concepts that lie outside of it. Additionally, teachers were questioned about what the scope of an A level chemistry teacher's knowledge should be and whether it is problematic if a teacher's SMK is limited to the A level specification that they teach.

The fourth section of the interview included questions regarding specific topics from the A level curriculum, namely atomic structure and chemical equilibrium. For the sub-sections regarding atomic structure and chemical equilibrium, participants were presented with a content-related question alongside responses that had been given to those questions in the past. Participants were then required to comment on why they thought that previous respondents had answered the question in this manner. This approach was taken in order to avoid putting participants on the spot in answering the questions themselves, a strategy devised by Merriam (2009), making participants more comfortable if they themselves did not know the answer to the question. These topics were chosen due to the use of analogies and models to teach them, and how the limitations of these models can cause misconceptions to be developed.

Alongside the content-related questions, participants were also asked about their responses to questions in the initial online questionnaire regarding their confidence in their SMK of A level chemistry topics. Participants were asked to describe why they felt more confident in certain topics than others and the approach they take in preparing to teach these topics. They then had to comment on the topics that they considered to be weaker and how they approach teaching those. Finally, participants were encouraged to reflect on the differences between their approaches to teaching the topics they felt more comfortable with to those they felt less comfortable with, and to describe the impact this may have on their students.

4.3.2 Interview protocol

The interviews were planned to take place between the researcher and the participant on a one-to-one, face-to-face basis, and were planned to last between approximately 60 and 80 minutes. If it was not possible to meet face-to-face, interviews were conducted via Skype. The audio from each interview was recorded and subsequently transcribed by someone with no connection to the project.

The interview questions and protocol were trialled with a teacher of GCSE chemistry in order to ensure that the responses and discussion provided meaningful data with respect to the research questions. Additionally, a focus group session with four experienced education researchers was undertaken at the Institute of Education, where the interview questions were discussed and amended in order to ascertain the desired data and level of response from potential participants. The finalised interview questions can be found in Appendix B.

4.3.3 Thematic analysis of interview data

Following transcription, the questionnaire and interview responses were analysed by means of content analysis (Cohen et al., 2011) using NVivo (Versions 11 & 12). An inductive approach was deemed most appropriate for analysis of the data (Elo and Kyngäs, 2007) and prominent themes in the participants' responses were coded and categorised. An inductive approach comprises of themes emerging from the responses given by the participants, with categories and codes derived from the emergent themes (Lauri and Kyngäs, 2005; Elo and Kyngäs, 2007). This is opposed to a deductive approach, where themes are decided upon *prior* to analysis of the data and are based on previous knowledge (Kyngäs and Vanhanen, 1999; Elo and Kyngäs, 2007). Deductive approaches are typically used in studies based around the testing of theories, whereas inductive approaches are used in studies that gauge the views of participants.

Additionally, Bretz (2008) comments that when utilising semi-structured interviews as a method of data collection, the researcher should avoid placing limitations on the investigation from the researcher's perspective. Defining themes and categories prior to analysis effectively undermines the premise of interview and can place researcher bias on the collected data, further supporting the use of an inductive approach in this study.

The coding of data was initially undertaken on a question-by-question basis, generating a list of categories and codes for each question of the interview. The interview transcripts were iteratively reread and recoded in order to increase reliability of the data and allowing for the interpretation of the data to hold wider meaning (Vaismoradi et al., 2016). Subsequent iterations of the coding process involved using the list of categories and codes generated for each question and devising an all-encompassing set of codes for the complete set of interview data. Sections of the interview data were coded by a second researcher and compared with the list of emergent codes from the primary researcher to minimise researcher bias and ensure intercoder agreement (Tinsley and Weiss, 1975; 2000).

The data collection process was dictated by saturation sampling; when no new major codes or themes were emergent, the primary researcher deemed it appropriate to stop undertaking interviews with new participants (Mason, 2010). New codes had emerged from analysis of each of the first eight interviews. Analysis of the ninth, tenth, and eleventh interviews yielded no new codes from both the primary and secondary researchers' independent analyses of the data. The primary and secondary researchers agreed that saturation had been reached and no further interviews would be necessary for this phase of the project. To address the potential issue of validity, a third researcher was subsequently asked to examine the codes identified from the data. A discussion then followed between the three researchers where the final codes were agreed upon. The primary researcher then analysed the data using this agreed set of codes once more to ensure a high level of confidence in the analysis of the data (Tinsley and Weiss, 2000).

The codes obtained from analysis of the interview phase of the project were organised under two main headings: SMK in ITT and SMK & the A level curriculum. These headings have been used to structure the results and discussion section of this chapter.

4.3.4 Ethical considerations

The methodology employed in this study was compliant with the ethical guidelines set out for educational research in the United Kingdom (British Educational Research Association, 2018). From the point of contact in the interview phase, potential participants were clearly informed about the nature of the study and what would be required of them if they opted to participate. It was made clear to all participants that their participation in the project was voluntary and that they would be able to opt out at any time. Participants in the interview phase were provided with an information sheet and a consent form, which they were required to sign to give their informed consent.

The nature of the research also meant that it was important to maintain participant anonymity to protect the interests of the participants. The participants' identities have been protected through the use of pseudonyms, and they cannot be identified from the information that is detailed is this study. Participants were informed of these confidentiality measures through the information sheet and consent form provided at the beginning of the study. All interviews took place on a one-to-one basis and due to the nature of the study there was no sharing of sensitive information. The anonymised data collected in this study were stored on a password-protected computer at the institution of the primary researcher with encryption and were held in line with GDPR rules.

It was also important to ensure that the participants were kept safe from any physical, emotional, or psychological harm during the research process. It was ensured that the participants would be able to choose the environment in which the interviews were conducted for this reason. The interviewer also spent some time prior to the interview making sure that the participant felt comfortable with the research. Although the nature of the questions was not considered to have the potential to cause harm, the large amount of time required for the interview was deemed to have the potential to impact the welfare of participants. This was explicitly discussed with participants to ensure that they were happy to give up their time for this study. As has been mentioned previously, the participants were provided with an information sheet and a consent form with all of the details of the research project. Participants were also invited to ask any questions if they felt unsure of any aspect of the study and were given the option to withdraw at any time. Ethical approval for the interview phase of the project was obtained from the University of Southampton's Ethics and Research Governance Organisation, ERGO (Appendix C).

Results and Discussion Part 1: SMK in ITT

4.4 Before training to teach

4.4.1 Influence of undergraduate study on subject matter knowledge for teaching

All eleven of the participants in the interview phase of this research project undertook their undergraduate degree in chemistry-related subjects: eight studied single honours chemistry degrees; the other three participants undertook their undergraduate degrees in biochemistry, biomedical science, and chemical engineering. For the purposes of this study, these three participants (Kenneth, Jenny, and Rebecca) will be considered 'non-specialists'. Despite the presence of significant chemistry content in their respective undergraduate degree programmes, those who have not studied single honours chemistry degrees will have had less exposure to certain chemical principles than those who have, and as a result their chemical education will differ significantly. Although this is different to classifications made in studies such as Childs & McNicholl's (2007), who deemed non-specialists to have 'not studied a science subject at degree or advanced level', because this project focuses purely on advanced level chemistry teaching rather than Key Stage 3 or 4 teaching it has been deemed a suitable categorisation.

In order to investigate any differences in perception between specialists and non-specialists, and to ease them into the interview, participants were asked which particular aspects of their undergraduate degree were the most important in developing their SMK for teaching. Unsurprisingly, the response here is overwhelmingly positive; Arthur considered all of his degree to be useful in his SMK development for teaching, highlighting that even now he "actually goes back to [his] notes and uses them to remind [himself] at a higher level of the concepts that [he's] teaching". Both Daniel and Hannah echo this sentiment, referring to the fact that the content they covered in their degrees, particularly in the first year, has direct overlap with the A level syllabus. Daniel goes as far to say that "a lack of a degree in [chemistry] would leave [him] in a very very poor standing having to do A level teaching now", a sentiment that will be discussed further in Chapter 4.4.2.

Aside from the overall experience of a chemistry degree and the particular elements of content covered, responses to this question at interview made direct reference to the role of practical work and its role in teaching. Following work as a demonstrator during his degree, Richard states that the particular aspect that aided with his SMK development was "the specificity of the lab instructions" and using them to "guide [students] as to what's expected", enhancing his own understanding of why experiments are undertaken in a certain manner. A trainee teacher, Ethan, makes the following point regarding his own experience, from a student rather than demonstrator perspective.

> *"I really did not properly understand things like moles and mole calculations, really didn't get that until certainly during the undergrad, and it was kind of assumed after the six month mark, certainly after the first term it was assumed that you got that it was readdressed but again it didn't really stick until actually using it in the labs [...] certainly by second year I actually got that concept, where up until then it was just a bit of I don't know why I'm doing this, I don't really know what's going on here, and then it just suddenly clicked"*

Ethan's comment illustrates the importance of laboratory experience in the development of his SMK, placing chemical ideas in context and providing meaning to the abstract concepts covered throughout the degree course. Ethan's view of the laboratory experience lies in agreement with that of Russell and Weaver (2011), who posited that the purpose of the laboratory is to enhance understanding, motivation, and interest in chemistry, as well as to develop problem solving skills.

In a similar vein to Richard, Martin notes that his experience teaching, as part of a research project, was the most influential factor in developing his knowledge for teaching. However, despite this positive experience, he did so with "no training", elaborating that he "probably developed a bit of an incorrect style which was swiftly corrected when [he] started doing [his] [Postgraduate Certificate in Education (PGCE)]".

Of the chemistry specialists interviewed, Gerald and Roland both felt that their undergraduate degrees had very little influence on their SMK development for teaching, only citing the overlap in content between the A level and the first year of undergraduate study. An excerpt of Gerald's response is given overleaf.

> *"…in terms of teaching obviously if you're teaching A level, that's at a much lower level than your degree, I think that after doing a chemistry degree, you have that more detailed knowledge of things, rather than the more general aspects of what's required for A level teaching, I think the amount of time I spent solving the Schrödinger equation at university for various things has had no impact on how I teach chemistry at A level."*

The response that Gerald gives to the question infers that having a chemistry degree provides a more holistic view of the subject, allowing for what he describes as "a more detailed knowledge of things". Similarly, Roland mentions that he only feels that he is drawing on the content from his earlier studies when answering students' questions regarding off-syllabus content.

> *"I'm not really sure that any of it did specifically […] I would say most of it is not desperately relevant for my teaching, except in those circumstances when you get asked a question from a very able student who's sort of thinking a bit beyond."*

It is interesting to note that of the specialist teachers interviewed in this study, Gerald and Roland are the most experienced, both having been in the profession for over fifteen years. Their perception that their undergraduate degrees were irrelevant in the development of their SMK for teaching may be a direct result of the amount of time that has elapsed between their undergraduate study and this point in their careers. As discussed in Chapters 1.2 and 2.1, as a teacher gains more experience, their pedagogical content knowledge (PCK) develops over time (Clermont et al., 1994). It is possible, therefore, that the development of Gerald and Roland's PCK, refining their ability to distil their SMK into explanations for their students, has had a more profound impact on their perceptions of their SMK development than their undergraduate degrees have had.

The perceptions of those participants who studied degrees other than chemistry are not hugely dissimilar from those that did. Kenneth, in line with the chemistry specialists, refers to the first- and second-year content of his biochemistry degree as being directly relevant to his A level teaching. In addition to the particular topics that he covered, he also states that his undergraduate degree helped to develop his appreciation of "how science works" and his own approach to teaching, thanks to the emphasis placed on teaching at his attended institution.

There was a notable difference between Jenny and Rebecca's perceptions on the influence of their degree on their SMK for teaching. Having undertaken a biomedical science degree, Jenny felt that her knowledge "was better across subjects because [she] hadn't just done a pure one, [she'd] spread it around a little bit". Through making connections between chemical concepts and areas of biological science, Jenny felt that her understanding of chemistry had been enhanced compared to somebody who had undertaken a pure chemistry degree. Jenny's comments are comparable to observations made by Childs and McNicholl (2007), who noted that some non-specialist teachers perceived a greater level of SMK across topics to allow them to construct numerous ways of explaining concepts when students did not understand. On the other hand, Rebecca, having studied natural sciences whilst specialising in chemical engineering, acknowledged that her chemical knowledge "wasn't equal to a full degree", with emphasis placed on specific, relevant aspects of chemistry (e.g. thermodynamics). These two perceptions highlight both potential advantages and disadvantages of undertaking multi-disciplinary or non-specialist degrees. With this being said, potential issues can be mitigated provided that non-specialists are aware of their SMK deficiencies.

4.4.2 The extent of a teacher's SMK

In order to ascertain teachers' perceptions regarding what the extent of a teacher's SMK should be, the question below was posed to those who participated in the interview phase of the project.

"How important do you believe a chemistry teacher's level of subject matter knowledge is in their teaching? Please explain your response. Do you think a teacher should be an expert in their field?"

All eleven of the participants commented that a high level of SMK is very important in teaching A level chemistry, with the vast majority stating that A level chemistry teachers should be an expert. Despite a shared view of a strong level of SMK being highly important, with Gerald going as far to say that having a "fundamental, very strong knowledge is critical" when teaching at this level, it is not considered by all participants to be the most important tool at a teacher's disposal. Arthur comments that "you can have the best subject knowledge in the world, but if you haven't got a class under control, pointless". A similar feeling is shared also by Daniel, Gerald, and Roland, who remarked that although being an expert is beneficial, it is by no means a necessity, and is only of use if you can convey that knowledge effectively and make it accessible to your students. As has been discussed prior, this idea essentially defines a teacher's PCK, and strengthens the assertion that a strong level of PCK results in better teaching (Shulman, 1987).

With respect to a teacher's students, four participants (Jenny, Martin, Rebecca, and Roland) explicitly mentioned that a teacher must hold a higher level of knowledge than their students; it follows, then, that these participants believe that a teacher should hold a level of knowledge beyond that of the specification being taught. Roland makes this assertion clear in his response to the question, given below.

> *"…I think [teachers] need to have an understanding beyond the level at which they are teaching so that A) if they get questions from students they can do something with it. B) so that if it's clear students have got misconceptions and so on they might be able to bring some additional knowledge and understanding to try and deal with the misconception, whereas actually if their knowledge just stops at the [specification], then where do you go if there's an issue?"*

Further to the comments made that a teacher should have knowledge beyond the specification, a further three participants (Ethan, Hannah, and Kenneth) stated that knowledge of the curriculum or course that is being taught is necessary as well. Curriculum knowledge was cited by Shulman (1987) in his initial discussions of PCK as one of the seven knowledge bases required for good teaching, and Magnusson et al. (1999) classify curriculum knowledge as one of the five components of a science teacher's PCK, further exemplifying its importance. It is encouraging that Ethan and Hannah, two teachers with fewer than three years of experience, already understand the importance of strong curriculum knowledge in their science teaching. In addition to the belief that a teacher should have a strong knowledge of the curriculum being taught, Ethan also discussed the importance of context when teaching chemistry topics:

> *"…I think it's not just knowing exactly what they're teaching but having context around the area certainly helps. A lot of personal anecdotes I've found to be very effective, when I can say 'actually I used this when I was' whatever my anecdote is…"*

Ethan continues by citing the impact of context on increasing student engagement, allowing students to see the relevance of the subject matter that they are learning and better understand it as a result, a position that is aligned with Gilbert's (2006) views on context-based learning.

A number of participants also referred to confidence in their responses to the above question, both from the perspective of the teacher and their students. Both Hannah and Rebecca stated that as long as your students perceive you to be an SMK expert, then they will have confidence in you and your teaching. It can be inferred from this that for students to have confidence in what a teacher is saying, then the teacher should be confident in what they are teaching. During her interview, Jenny noted that she "really [felt] the lack [of confidence] with those topics that [she doesn't] have as many extra bits [she] can add to", despite being a relatively experienced teacher. Jenny's feelings demonstrate further the negative impact that low confidence in SMK can have on teaching topics that teachers are less familiar with.

Although most participants believe that chemistry teachers should be SMK experts, some participants stated that it is unreasonable to expect them to be experts at the beginning of their careers, particularly if they are non-specialists. Kenneth's comments on this viewpoint are shown here.

> *"...you can't expect new teachers to be total experts, I think that's unrealistic. And I think the comment I made earlier about my mentor, the head of physics, he said it was about six years before he felt totally comfortable...I think that once that kind of period has gone, has elapsed, then people really should be an expert. They should have a mastery of the subject matter content for whatever courses they are teaching."*

Kenneth suggests that it takes time to become an SMK expert in the context of teaching, defining expertise with respect to the curricula being taught, again highlighting the importance of experience in developing areas of teacher knowledge (Shulman, 1987). Richard shares a similar view regarding new teachers, remarking that although "SMK is definitely important…there are tools in place that can overcome that [if it is lower than required]". Comparably, Martin notes that in one of the school chemistry departments that he worked in he was the only specialist, whilst the other teachers were non-specialists (biochemists). In that experience, he found that his non-specialist colleagues were lacking in confidence in physical chemistry topics, regardless of their experience.

Although it should not be expected that teachers are SMK experts immediately, a certain level of SMK at the beginning of a teacher's career is necessary. Childs and McNicholl (2007) assert that before teachers can learn how to teach unfamiliar concepts, they must first acquire the SMK necessary to understand the topic at hand. Furthermore, teachers will struggle to plan lesson activities that result in meaningful learning for their students if their SMK in a topic is limited, as they will not possess the understanding necessary to make informed judgements (Sanders et al., 1993). It is important, therefore, for novice teachers (or their trainers) to identify these deficiencies early in their training or career so that they can be improved upon, allowing for more effective lessons to be planned. As mentioned by Richard, there are tools available that allow for the improvement of teachers' SMK; these tools, which will be discussed in depth in Chapter 4.6, should therefore be made easily accessible to novice teachers.

4.5 Confidence in chemistry subject matter knowledge

4.5.1 Initial confidence in chemistry SMK

Participants in the interview phase of the project were asked how they perceived their level of chemistry SMK before they started teaching, as well as how confident they felt in their chemistry SMK at that time. Of the eleven interview participants, eight of them felt that they had a strong level of SMK before starting their teaching careers. Jenny felt that although her knowledge was good up to GCSE level, it was "less consistent" with respect to A level content. Martin noted that he was in a similar position, with a good knowledge in some topics but a lack of knowledge in other relevant topics:

> *"The deeper you study a subject the more you realise how little it is possible to truly understand it. Before teaching I had excellent subject knowledge in niche areas, but wouldn't have rated my knowledge outside those areas."*

In addition to these comments, Rebecca stated that although she felt that her knowledge was initially good, she felt that as a mature entrant her SMK was now "old and possibly outdated", referring to the fact that curricula and specifications may have changed since she undertook her own studies. Although Hannah noted that she perceived her level of SMK to be good, she went on to mention that as she started teaching, she "realised that [she] had to improve". This comment is discussed later in this chapter (4.5.2), where attention is paid to how perceptions of SMK changed once trainees began teaching for the first time.

Three of the interview participants, Ethan, Richard, and Roland, noted that their perceived SMK was adequate rather than good. Both Ethan and Roland remarked that they were quite unfamiliar with certain topics of the A level specification and felt that they would need to put in work to improve their SMK in these areas. Richard remarked a similar feeling, noting that his knowledge was "limited" in that he had a "very specific understanding of those topics [he] had studied at degree level". He further elaborated that he "understood little about the nature of learning, or how to present such ideas", noting that he was yet to develop a reasonable level of pedagogical knowledge.

Six of the eleven interview participants reported that before they started teaching, they felt completely confident in their chemistry SMK. Gerald remarked that because he went straight into teaching following his undergraduate degree he was "confident that not much had changed since he was at school", whilst Jenny found that her confidence came from having a higher level of SMK than her PGCE peers. Despite his confidence in his SMK, Richard again reported that his pedagogical knowledge and PCK were lacking, and that these needed to be enhanced:

> *"For Chemistry yes [...]the development needed was to differentiate to allow all students to understand chemistry."*

The other five participants stated that they were mostly confident with their chemistry SMK, although they were not completely confident. Roland noted that although he was confident with understanding chemical processes, he was not confident with the more "informational" aspects of the A level specification (e.g. properties of Period 3 elements). Both Ethan and Martin stated that they were confident with some topics but were less confident with those that had not been covered in a long time; in Martin's case, these topics included electrochemistry and chemical equilibrium (see Chapter 4.7). Kenneth discussed that as a non-specialist he was only confident in certain areas, explicitly mentioning that having studied an interdisciplinary degree his "subject knowledge of chemistry was patchy". Rebecca, another non-specialist, reported that although she did not feel completely confident in her chemistry SMK before teaching, she was confident that she would be able to "get to grips with it" when she started teaching.

4.5.2 Changes in SMK and confidence during ITT

To investigate the impact of their first lessons as a teacher on their awareness and confidence in their SMK, participants in the interview phase of the project were asked whether their perception of their level of chemistry SMK changed when they initially started teaching. Their responses are shown in Table 4.2.

Response	Respondents
Yes – underestimation	*Arthur, Gerald, Martin*
Yes – overestimation	*Ethan, Daniel, Hannah*
No – no change in perception	*Jenny, Kenneth, Rebecca, Richard, Roland*

Table 4.2 Interview participants' responses to the question "When you initially started teaching, did your perception of your level of subject matter change?". The terms "overestimation" and "underestimation" refer to whether these participants overestimated or underestimated their level of SMK.

Five of the eleven participants reported that there was no change in their perception of their level of chemistry SMK. Both Kenneth and Richard knew that certain topics would have to be worked upon, and in both cases, this proved to be true. Rebecca commented that although her perception did not really change, as she has become more experienced, she has realised that some students "ask questions that [she] can't answer because it is outside of the realms of what [she] has prepared". This comment may suggest a lack of general familiarity with the content itself, something that she noted may be due to her time in industry work between her degree and her ITT.

Jenny found that her perception of her SMK did not really change, but because her knowledge of GCSE content exceeded that of her colleagues, she felt more confident with the subject matter. Gerald, one of the participants who felt that they underestimated their level of chemistry SMK upon starting teaching, similarly found that his chemistry SMK was higher than his colleagues', therefore increasing his own perceived level of knowledge and increasing his confidence as a result. Of the other participants whose perceived level of knowledge increased, Martin found that he knew more than he first believed himself to, whilst Arthur commented that you "never truly understand something until you try to teach and explain it to someone who is at the beginning of their learning". Arthur's comment falls in agreement with the findings of Clermont et al. (1994), where teachers were observed to be more accurate and confident in explanations of concepts, and hence their understanding of them, as they became more experienced.

Daniel, Ethan, and Hannah all found that their perceived level of SMK dropped as they started teaching, showing that they overestimated their SMK. Although little elaboration was provided by all three participants, they all stated that they found that they knew less than they first thought in particular topics. It is important to note that these three participants were the least experienced of those interviewed, all with fewer than three years of teaching experience.

The fact that these participants have less experience could suggest the presence of a recency bias amongst the responses to this question; as these three participants have experienced ITT most recently, they may be more likely to reflect on the aspects that they perceived to be more negative, such as overconfidence in their SMK. Alternatively, it may also suggest that those with more teaching experience have since developed their SMK further and cannot fully recall their perceptions of their SMK during their ITT; in other words, those with less experience have a more accurate recollection of their feelings during ITT. If this were to be investigated further in future, it is recommended that a longitudinal study be undertaken, following a sample of teachers through the early years of their career.

In addition to being asked how their perception of their level of SMK changed, interview participants were asked whether their level of confidence in their chemistry SMK changed upon starting teaching. Their responses are shown in Table 4.3.

Response	**Respondents**
Yes – confidence increased	*Ethan, Hannah, Martin, Rebecca, Richard, Roland*
Yes – confidence decreased	-
No – no change in confidence	*Arthur, Daniel, Gerald, Jenny, Kenneth*

Table 4.3 Interview participants' responses to the question "When you initially started teaching, did your confidence in your subject matter knowledge change?".

Five of the eleven participants found that their confidence in their SMK did not change when they started teaching. Arthur, Daniel, and Jenny stated that whilst they feel that they pitched their confidence accurately, their confidence began to increase in particular areas. Arthur and

Daniel found that they became more confident in their SMK in specific topics that they had not visited for a long time, whilst Jenny noted explicitly that she has become more confident in her overall chemistry SMK over time. Kenneth remarked a similar feeling to Jenny, stating that "every time [he teaches] a topic…[his] confidence improves, as each lesson brings new problems and questions, that if reflected on well, lead to improved understanding". These feelings demonstrate further consistency with the findings of Clermont et al. (1994), highlighting the importance of experience in developing an understanding of the topic.

The other six interview participants all felt that their confidence in their SMK increased upon starting teaching. Ethan, Hannah, Martin, Rebecca, and Richard all stated that as they started to teach more, they felt that their confidence in their SMK increased, with Hannah explicitly stating that this increase in confidence came as a direct result of an increased understanding of the content. Unlike the other participants, Roland felt that his confidence increased because he realised that his SMK was far greater than that of his students, though noted that he had issues with "what the exam board wanted". Roland's comment highlights the importance of a teacher having both strong SMK and strong curriculum knowledge. If a teacher's curriculum knowledge is weak and they have issues with particular aspects of the curriculum and, as Roland puts it, "what the exam board want", then they may be tempted to "teach to the test", an undesirable practice in school education (Popham, 2001). It can be argued that SMK and curriculum knowledge are synergistic; through enhancing their understanding of concepts, a teacher can better understand the content in a curriculum that they are teaching. Equally, as a teacher becomes familiar with the curriculum they are teaching, it allows for them to target their SMK development specifically. These two knowledge bases are considered to be closely linked in numerous models of teacher knowledge (Magnusson et al., 1999; Gess-Newsome, 2015).

4.6 Development of chemistry subject matter knowledge during initial teacher training

4.6.1 Methods of SMK development

To investigate how teachers proceeded to develop their SMK during ITT, and to investigate the methods by which ITT providers address SMK development, participants in the interview phase of the project were invited to discuss the extent to which their ITT addressed their chemistry SMK development. Their responses are displayed in Table 4.4.

Response	Respondents
Significant focus on SMK development	*Daniel**, *Ethan**, *Gerald**, *Jenny**, *Kenneth**, *Martin**, *Rebecca**
Little focus on SMK development	*Arthur**, *Hannah*†, *Richard*‡, *Roland**

Table 4.4 Interview participants' responses to the question "To what extent did your teacher training address subject matter knowledge development during your training period?". * denotes the participant undertook a PGCE programme; † denotes the participant undertook a School Direct programme; ‡ denotes the participant undertook a GTP programme.

Seven of the interview participants found their ITT to have addressed their SMK development to a reasonable extent, whilst four of the participants found that their ITT provided very little targeted SMK development. The most frequently mentioned method by which ITT providers facilitated SMK development was through use of SMK audits. Jenny commented that her SMK was assessed through a test at the beginning of her ITT course, with a few sessions (at secondary level) on SMK. Daniel reported that the person who ran subject sessions during his PGCE was "very hot on subject knowledge" and "made sure we very meticulously went through and [documented] how we went through our subject knowledge and got us to reflect on what it might be". Similarly, Ethan reported that he would have to undertake his own SMK audits, updating it as he went through the course whilst identifying and reflecting on his weaknesses.

Martin's experience of ITT also involved SMK audits, where he identified which topics were of particular weakness before teaching more of the content that he deemed himself to be "not very good at". Martin reflected that having to teach the topics he felt weaker on allowed for him to improve his confidence, because "if you don't understand it, you then have to think really logically about how to explain it". He also found that in the topics he believed himself to be confident in, upon planning lessons and teaching it for the first time he found that he "was not as 100% on [them] as [he] thought".

Kenneth, a non-specialist, was aware that his SMK was "patchy" before undertaking his ITT and found that through SMK audits the PGCE course was good at "getting [him] to realise where [he] was particularly weak". He cited his mentors and head of department as particularly instrumental in facilitating his SMK development, as they ensured that he observed and taught many different types of lessons in different topics. This further emphasises the importance of experienced colleagues in allowing for confidence in SMK to develop (Youens and McCarthy, 2007).

Two participants also discussed the emphasis placed on practical work in SMK development during their ITT. Gerald reported that during his ITT he attended sessions focusing on revision of individual topics, which would then lead on to how to implement practical work in lessons based around those topics. Although her experience of course-led chemistry SMK development during her training was limited, Hannah commented that she was informed about specific practical techniques she could use in her teaching, but these sessions had minimal focus on content.

Gerald reported that the sessions delivered during his PGCE were structured with SMK experts delivering content and facilitating discussion with preservice teachers on how they would teach particular topics, providing feedback on both SMK and the methods presented by the trainees. This style of session, providing focus on both SMK and PCK development simultaneously, was observed by Gerald to be particularly positive for those with a lower chemistry SMK, especially non-specialist teachers.

Richard, who undertook a Graduate Teacher Programme (GTP) course, reported undertaking similar sessions to those undertaken by Gerald, with emphasis on how to teach particular topics (i.e. PCK development). However, Richard mentioned that these sessions did not focus on SMK development at all, and that it was assumed that preservice teachers' SMK was already sufficient prior to starting training.

During his PGCE experience, Arthur also felt that there was very little attention paid to SMK development, commenting that "they did some things with [him]" but that "it was such a low level [he] didn't really learn anything". Arthur did, however, feel confident in his chemistry SMK prior to undertaking his ITT. Roland found that during his PGCE experience SMK was not addressed at all, and that instead it mainly focused around meeting a competence standard with general pedagogy. Hannah noted that during her School Direct programme she had SMK training sessions once every two weeks, but these were centred around biology and physics rather than chemistry, because she was assumed to already possess strong chemistry SMK.

To investigate preservice teachers' personal approaches to SMK development, interview participants were asked whether they engaged in any self-directed activities during their ITT in order to help develop their chemistry SMK. The response is displayed in Table 4.5.

Response	Respondents
Yes	*Daniel, Hannah, Jenny, Kenneth, Martin, Richard, Roland*
No	*Arthur, Ethan, Gerald, Rebecca*

Table 4.5 Interview participants' responses to the question "Did you engage in any self-directed activities to develop your subject matter knowledge while you were training, which were not formally part of your training?".

Seven of the eleven interview participants engaged in self-directed activities to help develop their chemistry SMK during their teacher training. Daniel and Hannah stated that in order to develop their SMK they identified their weakest areas from the specifications that they were teaching and worked on those, mainly through use of internet and book-based resources. Roland also discussed having to "refresh [his] knowledge of some of the more informational aspects of the A level" (e.g. reaction series in Group 4 of the Periodic Table), using textbooks to do so.

The use of books as a means of enhancing SMK were also discussed explicitly by Richard, Jenny, and Kenneth. Kenneth's comment on his use of books is included below.

> *"I've got a little bookshelf up here, and a number of those are books I acquired once I'd become a teacher, essentially because I was curious about questions would come up from students, and sometimes it would be an area, so for example aspects of electrochemistry."*

In his own personal experience, when Kenneth identified areas of SMK that he had not encountered during his undergraduate degree (e.g. electrochemistry), he purchased books in order to improve his understanding. Jenny, who like Kenneth is a non-specialist, used books in the same manner, but also used them to "go quite in depth and […] research, find all the stories, rather than just teach a certain topic [she'd] try and find stuff around it", to make her teaching more interesting. Jenny further remarked that to find these stories she would also use the internet and scientific magazines.

Alongside books, Richard mentioned that he developed his SMK through observing more experienced teachers' lessons, focusing on "how they support [students]" and "what was similar and different about the style of teaching" in comparison to his own style. It can be inferred that Richard's focus through observation was more about how to teach particular topics rather than aiming to understand the topics themselves, paying attention to his PCK development and his knowledge of learners. Martin noted that he primarily used the internet to aid with his SMK development in weaker areas of understanding, citing chemistry revision websites and chemistry video content as the most helpful.

Of the four interview participants who did not engage with any self-directed chemistry SMK development during their ITT, Arthur and Gerald reported that they did not feel the need to as they already had a high level of confidence in their chemistry SMK. Conversely, both Ethan and Rebecca stated that they did not engage with self-directed activities because they did not have the time to do so during their respective PGCE courses. Ethan simply stated that he did not have any free time during his PGCE, though commented that others on his course were recommended a one-month SKE prior to commencement of the course. Despite not undertaking any self-directed SMK development, Rebecca maintained that she still undertook the SMK enhancement tasks recommended to her by her ITT provider, including completing past examination papers.

4.6.2 Looking to the future: supporting teachers with their SMK development

Although the interview participants were not asked about it explicitly, Kenneth (an experienced non-specialist) commented that continual SMK development is very important, both for novice and experienced teachers. When asked to discuss methods of SMK development, Kenneth stated that posing difficult questions about particular topics "would be fantastic, that's the kind of stuff that should be included in teacher training", going on to say that "it should be part of continuing professional development, so people are constantly being challenged in a way that's supportive…we realise people are going to have areas of strength and weakness, and that areas come up from…[identifying] them nationally as areas of weakness."

Kenneth's comments show that there is likely a desire amongst both novice and experienced teachers for topic specific CPD, with a focus on topics that are either notoriously difficult to teach or are complex in their subject matter. A discussion of these topics, based on findings from the interview phase of this study, is presented in Chapter 4.7.

Results and Discussion Part 2: SMK and the A Level Curriculum

4.7 Teacher confidence in A level chemistry topics

4.7.1 Identification of high and low confidence topics

Participants in the interview phase of the project were invited to rate their confidence in their ability to teach ten A level chemistry topics, ranking them from 1 to 10, where 1 indicates the highest level of confidence and 10 indicates the lowest level of confidence. As discussed in Chapter 4.2, the ten topics were chosen based on a review of the content on the UK's major A level chemistry specifications (Read and Barnes, 2015). These ten topics are listed alphabetically here.

- Acids, Bases, and Buffers
- Analytical Techniques
- Atomic Structure and Molar Calculations
- Bonding and Intermolecular Forces
- Chemical Equilibrium
- Electrochemistry
- Energy Calculations
- Kinetics
- Organic Chemistry
- Transition Metal Chemistry

The responses to this question are detailed in a diverging stacked bar chart (Figure 4.2). It should also be reiterated that these rankings relate to teacher confidence, and that confidence may not be an indication of level of knowledge, so this should be considered when interpreting the data.

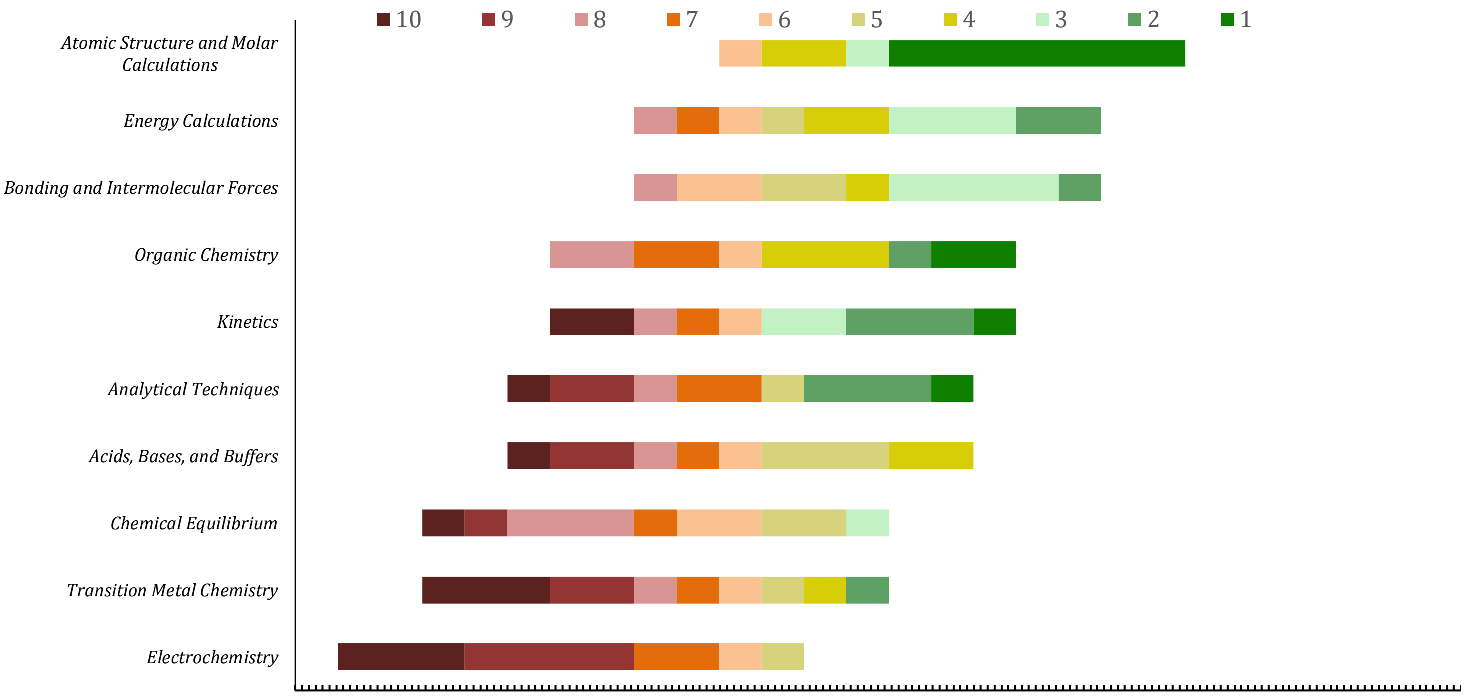

Figure 4.2 Interview participant response to the statement "Please rate your confidence in your ability to teach the ten A level chemistry topics given below from 1 - 10, with 1 being the topic you feel most confident teaching and 10 being the topic you feel least confident teaching" (*N* = 11). For each topic, the size of each coloured bar corresponds to the percentage of respondents that rated that topic at each rank. Topics are listed from top to bottom from the lowest mean rating to the highest.

It is immediately evident from the data presented in Figure 4.2 that the majority of participants placed the topics of atomic structure and molar calculations. energy calculations, and bonding and intermolecular forces in their top five positions. Given that these three topics are typically the first ones taught as part of the A level, in addition to the fact that the concepts involved underpin most of the other topics, it can be said that this is an expected observation. This is confirmed by Harriet's comments at interview, which are given below.

> *"I suppose because atomic structure, the kids just tend to know what's going on anyway because they've learnt it from year 7 and it's reinforced every year, and then moles we introduce in year 10 […] I'm teaching all through the school so actually I might teach a moles lessons three times in one week, so yeah I think that's why I'm more confident with it."*

It is encouraging to observe that the majority of participants feel comfortable with teaching these fundamental concepts. Without a reasonable level of SMK and confidence in basic chemical concepts, it can be argued that a teacher's SMK in other topics will become more flawed, and teachers will be more likely to have developed misconceptions.

With some topics, participants' confidence ratings are more polarised, including the organic chemistry topic. Although it places in the top four topics when considering both the mean and modal average ranks, it exhibits a significant proportion of participants who placed it amongst their least confident topics. The most cited explanation for these rankings, both high and low, was experience. Those who rated the topic as one of their most confident remarked that they had either taught it for many years or worked with organic chemistry in research or industry prior to teaching. Conversely, those who ranked it as a topic of lower confidence had "little opportunity to teach this topic" or had not studied it as part of their undergraduate degree or initial teacher training (ITT) course.

With respect to organic reaction mechanisms, students have been seen to lack an understanding of what curly arrows represent (Bhattacharyya and Bodner, 2005; Ferguson and Bodner, 2008), which in turn has caused students to struggle to propose mechanisms using the curly arrow model (Bhattacharyya, 2014).

These issues may arise due to rote memorisation of mechanisms. Grove and Bretz (2012) state that students can sit in different places along a "continuum of learning" between meaningful learning and rote memorisation in organic chemistry, which can account for their relative performances in the first year of their undergraduate degree. It can be argued that it is easier for students to apply a rote memorisation strategy to learning reaction mechanisms whilst studying for A level qualifications, as the mechanistic processes included in the major specifications typically have no more than three steps. It is important, therefore, for teachers to teach in a process-based manner, establishing the fundamental concepts before emphasising the dynamic nature of reaction mechanisms. Gerald summarised this point succinctly whilst discussing the teaching of off-specification topics:

> *"I think mechanisms, if you teach it in the way that I do, which is teach them what the curly arrows mean, what could happen, and then throw the mechanisms out after that, [students] have some idea of actually how could this work."*

Arthur reported organic chemistry to be a lower confidence topic, noting that it encapsulates a large amount of content and that it is difficult to understand due to its nature:

> *"[Organic chemistry], you could argue that's even more abstract because it's just like there are these dots flowing about these letters."*

Arthur's comment highlights the difficulties that both teachers and students may face with organic chemistry and its abstract nature, which could potentially lead to learners using rote memorisation due to the difficulty of seeing meaning in the symbols used to represent these chemical reactions. It is recommended, therefore, that resources intended to enhance SMK and/or PCK in organic chemistry are designed with the topic's process-based nature at their core.

Another topic that appeared to have a polarised response amongst the respondents was analytical techniques. Those who ranked it highly reported that they had a significant amount of experience working with these techniques prior to their teaching careers, providing extra context for their teaching. Conversely, Roland felt that his lack of confidence in teaching analytical techniques relative to other topics did not stem from SMK concerns, but rather from issues with the way the topic is examined at A level. Roland's comments are included below.

> *"I think sometimes students, particularly weaker students, do find it sometimes quite difficult to get hold of, putting all the information together, and again it's not, its frequently not about whether they can actually do it…the issue becomes do they actually explain it and put down the points of explanation that the examiner is wanting them to write? Because otherwise they get no marks or very few marks…that's what my less confidence is about, is not so much the subject matter, it's what is going to be required in the exam."*

It should be noted that Roland possesses over twenty years of experience teaching A level chemistry. Roland's comments demonstrate that teachers may have a high degree of SMK, but their confidence in delivering it may be impacted by their confidence in their curriculum knowledge or knowledge of assessment, two key aspects of a teacher's PCK (Magnusson et al., 1999).

Only one of the interview participants placed chemical equilibrium in their three highest confidence topics. Conversely, six of the eleven interviewees placed this topic amongst their four topics of lowest confidence. Reasons provided for low confidence in this topic included a lack of teaching experience, a lack of practical experiments that can be used to illustrate it effectively, and the fact that it is difficult to explain in simple terms. These findings are similar to those discussed in Chapter 2.4.

In terms of the topic's difficulty, Jenny noted that for a while she felt that she "was teaching it in a particular manner" but then stopped teaching it that way because she was "worried [about] teaching [her] students misconceptions". Gerald also commented on the difficulty of understanding equilibrium:

> *"...the exam board require [the students] to...calculate K_c...does that mean much to them? No, because you just told them that, and then that. It's one of those topics where you feel that the kids are just jumping through the hoops of getting the exam question right rather than having a more in depth understanding of why it's important...I can teach what the exam board want but then I'm fully aware that's not the same as teaching them what equilibria is."*

Gerald's comment provides an insight into his pedagogical considerations when teaching chemical equilibrium, displaying an awareness of how deep his explanations should be to ensure that his students can answer examination questions, regardless of their understanding of the topic, demonstrating an example of his PCK at work. His methods raise an interesting philosophical point of whether education should be more concerned with understanding or with passing examinations; this is discussed briefly in Chapter 4.8.

Another topic that was observed to have a degree of polarisation between high and low confidence was the kinetics topic, where six participants rated it amongst their three most confident topics and four participants rated it amongst their four least confident topics. The most cited explanations for these rankings, both high and low, were the underpinning mathematical concepts involved in understanding kinetics.

Of those who selected kinetics as one of their most confident topics, the most common explanation provided was that the maths involved is "simple", and that there is "an expected right answer". Conversely, of those who ranked kinetics amongst their least confident topics, the majority of participants commented on the fact that the mathematical concepts involved were too complex. One representative comment, from Ethan, is included below.

> *"It's all the equations associated with it, I always got them messed up myself, got all the first order, second order, zero order all of them muddled up and all the associated graphs, even though you can work it all out, it's just I never got my head around it fully."*

The comment presented here demonstrates potential difficulties with rearranging formulae and logarithms, two necessary elements of understanding chemical kinetics. Similarly, mathematical processes were also observed to be most common in participants' explanations for their high and low confidence rankings of the energy calculations and acids, bases, & buffers topics.

Additionally, the majority of those who cited mathematics as a reason for their low confidence explicitly mentioned the Arrhenius equation, which was reintroduced to A level specifications in 2015. These comments further support the comments regarding future SMK development resources made previously, where it was advised that significant SMK support should be offered to teachers when major changes are made to A level specifications, especially to non-specialists.

Two participants, Hannah and Rebecca, reported that they were confident in teaching kinetics because of its links to experimental data, allowing for students to reinforce their conceptual understanding through practical work. They also felt that they were confident in their ability to teach kinetics due to its overlaps with the GCSE specification. These comments are given below.

> *"… you know that if you raise the temperature of something it's going to make the reaction faster. The kids seem to think, "yeah, that makes sense [with] what happens in other subjects as well" […] you can talk about the particle model and everything they've learnt in year 7 […] so I think that's why they are easier to teach because it's familiar territory."*

> *"…it's a development of GCSE chemistry. And having taught GCSE for four years and then moved into A level teaching, that might have sort of*

built up my own level of confidence with those topics, and it's not a huge leap up to A level."

These comments demonstrate that increased experience allows for a teacher to grow more confident in their SMK of, and therefore their ability to teach, specific topics, in agreement with the findings of Nixon et al. (2016). Furthermore, these comments infer that some teachers may be more confident in topics that are prominent in both GCSE and A level teaching.

This claim is supported by the fact that the two topics with the lowest mean and modal average rankings are transition metal chemistry and electrochemistry, two topics with little more than simple qualitative treatment on GCSE specifications.

The three participants classified as non-specialists all ranked transition metal chemistry within their bottom three topics. It can be argued that this result is unsurprising, as it is unlikely that degree programmes such as biochemistry and chemical engineering include a large amount of discussion of coordination chemistry on their syllabuses, and as such these teachers will have had little exposure to the topic outside of teaching.

The most common explanation provided by participants for their lack of confidence in teaching transition metal chemistry was the nature of the topic as it appears on A level specifications. It was remarked that very few explanations are required for the A level, with a greater emphasis on rote memorisation of aspects such as the colours of transition metal ions. Comments from Gerald and Richard on this matter are included here.

"…when you come to transition metal chemistry […] you're just making up silly rhymes for [remembering the colours]…and then kids go 'why?' 'because that's what we observe' and…it's true you can't argue against it, but it's such a weak argument without going into a lot of very complicated university level stuff."

"I think in terms of transition metal chemistry…it's one of those topics [that's] just "learn it". Copper(II) complexes make blue complexes just learn it, but I was never really happy with that and I'm not sure I'm completely concrete in terms of electron excitation and the colour wheel and electrons moving down from higher energy orbital level to lower energy orbital level."

Based on these comments, it could be argued that teachers do not need to understand particular aspects of transition metal chemistry, such as why different complexes exhibit different colours, in order to teach the topic at A level. However, as evidenced above, a significant proportion of the participants in this study find this topic to be one of lower confidence relative to other A level topics, and the lack of deeper understanding provides a prominent explanation as to why. These findings indicate that there is some scope for SMK support within the topic of transition metal chemistry.

The reasons why transition metal complexes exhibit colour can be explained through use of sub-microscopic models. Taber (2019) highlights the colour of copper sulfate as an example, supporting the evidence provided by the participants above:

> *"Usually in school chemistry, then, the deepest level of explanation required of students would be along the lines of "Why is copper sulphate blue?": "because copper is a d-block element, and the salts of d-block elements are often coloured"." (p. 66)*

To explain exactly why this is the case, a deeper level of explanation is required. If a teacher's knowledge is limited to the A level specification, then they would not have the SMK required to explain this phenomenon. Taber continues by discussing the balance between SMK and PCK in discussing this with students:

> *"…the depth of possible explanation that [a teacher] could offer is a matter of subject knowledge, but a judgement about how much detail might be useful to offer a particular student also draws upon PCK". (p. 66)*

Taber's comments further illustrate the importance of possessing both strong SMK and PCK in explaining complicated phenomena to students.

Roland, who undertook a Ph.D. involving organometallic chemistry, echoes the other participants' comments despite his background in the subject:

> *"The reason I put transition metal chemistry there is not because I have any problem with transition metal chemistry, it's because that particular topic ends up being more about learning facts frequently than it is about understanding the sort of thing going on…it's incredibly interesting, there's a lot to it, but unfortunately it gets mangled up a bit in the A level [specification] and again you end up "oh right okay, the chromium hydroxide precipitate is grey-green, it's not grey-blue, its grey-green because the examiner decided that you've got to have the word green in it" and you're like 'What? Why is that a demonstration of how good you are as a chemist?'"*

From Roland's comments, it is evident that specific language in A level specifications can also be a source of low confidence amongst teachers. Jenny also commented that differing interpretation of colours caused issues in her teaching, as two specifications she taught required students to recall transition metal ion colours, with the colours differing on each specification. It is important, therefore, for specification authors to ensure that all scientific language, especially in areas of subjectivity such as colour, is clear and not easily misinterpreted.

Of those participants invited to interview, only one participant (Martin) ranked transition metal chemistry as one of their top two topics. Martin reported that during his undergraduate studies, one of his specialisms was organometallic chemistry, where he "did a lot of work on [transition metals]". He also remarked that he liked organometallic chemistry as he considered the ability to think in 3D as one of his strengths. Understanding valence shell electron pair repulsion (VSEPR) theory and the shapes of complexes are key concepts in organometallic chemistry, so it can be said that being able to understand, perceive, and predict the structures of coordination complexes are necessary skills in developing a strong comprehension of transition metal chemistry. Hence, it can also be said that if SMK/PCK enhancement resources were to be developed for this topic, then they should include a focus on these skills.

It is evident from the data presented in Figure 4.2 that the majority of participants ranked electrochemistry as a topic of low confidence. Nine of the eleven participants placed electrochemistry in their lowest three topics. Analysis of responses showed that unlike other topics, where the most common theme identified was typically a lack of experience teaching the topic, the most common explanation observed was that participants struggled with electrochemistry during their personal studies of it, at both A level and undergraduate level. Of all the topics considered, participants' comments regarding their SMK of electrochemistry were observed to be the most negative, with several references to a lack of understanding. As has been discussed previously, there is evidence to suggest that weaker levels of understanding can lead to underdeveloped PCK (Rollnick et al., 2008; Van Driel et al., 2014), and can result in the dissemination of misconceptions to learners.

Although teachers may be confident in their knowledge of the electrochemistry that appears on the A level specification, some may find that their confidence in their SMK is impacted by the inability to go beyond the specification. Kenneth, despite responding that he felt confident with his electrochemistry SMK up to first year undergraduate level, illustrated this feeling when discussing electrochemistry:

> *"I think if I were to look at just the nuts and bolts, just as two simple half cells connected by a salt bridge or something like that, that would be okay. I think that it's…I realised there's a lot more to it, which I don't know. I think that's probably it. And I think actually that's an interesting question because my knowledge, I mean I did A level physics, maths, and chemistry, I've got a fairly solid background, but I realise it's A level, I can't go beyond that… I think that underlies my unease with it, that I've got enough, but no more."*

Further to Kenneth's comments, Gerald also remarked that electrochemistry is a confusing topic for students, highlighting the terminology involved as a specific point that can lead to misunderstanding. His comments are included below.

> *"There are so many confusions…yes or no, true or false, plus or minus, reduction/oxidation…because unless you're precise, if you're talking to them about even what a reducing agent is, you say "itself is oxidised". They can just make a mistake…it's too easy for them to kid themselves that, like an electro-potential they get E_{cell} to be -7.3 and it's +7.3 and they go "Oh no, I see where I've gone wrong I meant to do that" but they don't understand."*

The issue of terminology can be especially problematic in electrochemistry. This is partly due to the inclusion of electrolysis in GCSE specifications, where certain terms can be easily confused with aspects of electrochemical cells; in electrolysis, the term 'cathode' refers to the negative electrode, whereas in an electrochemical cell, it refers to the positive electrode. As identified by Gerald, there are many terms with an exact opposite in electrochemistry (e.g. oxidation and reduction), requiring teachers to be extremely precise in their language. If they are not, this may cause students to develop misconceptions.

In addition to the differences between electrolytic and electrochemical cells leading to lowered confidence, Daniel noted that a lack of confidence can stem from the overlap of the topic with physics. His comments are given below.

> *"...in people's minds they're expecting electrochemistry to be as advanced as, you know, electrochemistry at degree level was, which really goes to town, proper heavy level physics, and probably that's what's invoking in their heads when they think of it."*

This comment indicates that it is not actually the content on electrochemistry that is the problem, and rather that its connections to physics concepts can be off-putting to chemistry teachers. This attitude can be harmful to teachers' understanding of electrochemistry, as they may have to overcome a psychological barrier to become more familiar with the topic's key concepts. Additionally, this could present further challenges to those who are not specialist chemists or physicists, who may have had limited exposure to the relevant areas in both physics and chemistry.

Based on these responses, and the data presented in Figure 4.2, it can be observed that electrochemistry is an almost universal topic of low confidence amongst the interview participants, and it could be inferred that this extends to the wider population of A level chemistry teachers. Although it does not comprise a particularly large section of A level specifications, it is underpinned by several key chemical concepts, such as chemical equilibrium and redox, and so a greater level of confidence amongst participants might be expected. However, it seems that some participants found that when they were learning the topic as students (A level and undergraduate), they did not understand the topic, resulting in a lack of confidence. Gerald summarised that he believed teachers' aversion to electrochemistry to be "a historical thing", because "teachers have always been taught by people who don't find that area a strength, that it's a thing [that] will keep on appearing throughout". It can be described as a cycle; students don't have a strong understanding of electrochemistry, some of these students become teachers, these teachers are less confident in their SMK/ability to teach the topic, their students don't have a strong understanding of electrochemistry, and so on.

Although the original aim of this project was to inform the development of resources to enhance teacher PCK within the topic of chemical equilibrium, the responses provided here suggest that electrochemistry is perceived to be a topic of considerably lower confidence than the other nine topics presented in this chapter. As a result of these findings, it can be recommended that there is perhaps more demand for resources designed to improve teachers' SMK (and subsequently PCK) in electrochemistry, and as a result work should be undertaken to inform the development of such a resource.

4.7.2 Differences in teaching approach between high and low confidence topics

Interview participants were invited to discuss their approaches to teaching their most and least confident topics, and to reflect on the differences (if any) between them. When asked about this, Jenny reported that she felt that she had a lower tendency to use 'stretch and challenge' activities with her students on the topics that she felt less confident in:

> *"I do worry, looking back that maybe with the ones I'm less confident on that I don't stretch them enough. Maybe I'm not giving them enough of the really tough questions, perhaps because…I really have to go "right hold on" and go back to first principles every time."*

Whilst this was not mentioned explicitly by any other interview participants, it was deemed an interesting insight that should be investigated further. This further investigation is included in Chapter 5.5.

Another concern regarding teaching approaches that was discussed at interview was that some teachers do not feel as if they always have the time in the classroom to stretch their students. Gerald remarked that with the way the A level course is structured, there is "no time to go and investigate something more exciting", and that there is "no time for pupils to do their own independent research", explaining that this time must be spent covering the minutiae of the specification.

Gerald also noted during his interview that in areas of high confidence, he had a greater awareness of potential misconceptions:

> *"I think sometimes if you, the topics which you are aware the pupils find most difficult, you have to be much more careful when you are teaching it and therefore you have to have the strategies that you know in the past pupils have made these mistakes so if you set it out like this it's not going to happen."*

Gerald's comment may provide further evidence supporting the importance of strong SMK in teaching, as well as the importance of developing a deep knowledge of learners (Magnusson et al., 1999). Two of the comments displayed above cite the importance of experience in developing an appreciation for common issues in learning topics. The importance of experience in developing PCK is well-known, but it should be considered that an awareness of misconceptions can be accelerated if SMK development resources are designed with them in mind.

In terms of teaching high confidence topics, most interview participants stated that due to their greater knowledge, and in some cases simply greater interest, they felt that they had a better grounding in the topic and are more prepared to answer student questions and evaluate the extent of students' progress. These views were neatly summarised by Martin, whose comments are included below.

> *"Whereas with the ones I'm strong at, I'm typically more confident that I've taught it in a way, I'm more confident in the way that I can test it, in the way that I've sort of captured every sort of imaginable question you could possibly have with this sort of area, and then we can do something a bit more interesting. Because I could probably do that quicker and get someone to the end results faster than with an area that I'm less confident on, I'll probably force them to do more practice."*

This comment also highlights the shared view that in low confidence topics, teachers are more likely to be formulaic in their teaching, sticking to a more rigid lesson plan than they perhaps otherwise would. Through forcing the students to do more practice, Martin is restricting his lessons to a more formulaic structure, as was also observed by Childs and McNicholl (2007).

Perhaps unsurprisingly, the most common theme regarding the teaching of low confidence topics was that participants were required to put more time into preparation and lesson planning than they were for high confidence topics. Planning strategies discussed by participants included a higher focus on exam questions, background reading (online and from a textbook), and discussion with more experienced colleagues.

4.8 Teaching to the A level specification

To investigate the role of SMK further rather than the role of qualifications, interview participants were asked whether they believed it was an issue if an A level chemistry teacher's SMK was limited to the A level specification. Participants' general responses are shown in Table 4.6.

Response	Respondents
Yes, it is an issue	*Arthur, Hannah, Jenny, Kenneth, Martin, Rebecca, Roland*
It can sometimes be an issue	*Ethan, Gerald, Richard*
No, it is not an issue	*Daniel*

Table 4.6 Interview participants' responses to the question "Do you personally believe it to be an issue if a teacher's SMK is limited to the A level chemistry specification?".

Most interview participants reported that it would be an issue if a teacher did not have SMK beyond the specification, whilst only Daniel believed that it is not an issue. When asked to elaborate, Daniel provided the following comment (overleaf):

> *"Not at all, I think that if they are limited to just the A level specification that would be good enough to get a student to pass the A level, whether or not that student then will continue to it further is another matter. So if the question is will that prevent that student getting a good grade? Probably not, it would probably be absolutely fine. If you're trying to spark a bit of enthusiasm in students and maybe get them to pursue chemistry further, which is a little bit of our job to be honest, it's what we should be, you know if somebody is going to entice them in it's probably going to be us, we've probably got to give them a little bit more than the curriculum, the curriculum in places is pretty dry. And being able to give those real-world examples is a really good way to kind of entice people in that there might be a little bit more."*

Daniel believes that if the sole aim of the teacher is to ensure that their students pass their A level examinations, then it does not matter if a teacher's knowledge is limited to the specification that they are teaching. Given that not all students who pursue chemistry at A level wish to study the subject as undergraduate level, this is an understandable outlook to have. However, taking this approach may result in students misunderstanding concepts that may underpin aspects of another undergraduate course, such as pharmacology or physics. Provided that the teacher possesses deep SMK of the content on the specification, this should not be perceived as a major issue.

Despite this, Daniel commented that a lack of knowledge beyond the specification may cause students to lose interest in the subject, as providing context and further background may engage students with the content to a higher degree. This belief is echoed by Hannah and Kenneth, who both remarked that if a teacher does not have knowledge beyond the specification, they will find it more difficult to enthuse students in the subject matter. Hannah and Kenneth's responses are included below.

> *"I think you need to have a higher understanding, definitely…I've even seen colleagues of mine, and they're brilliant teachers, but they are biologists and they teach chemistry, and it's just so boring because they don't like it… I think if you enjoy it and you've actually gone ahead and studied it at a higher level, you're always going to make it more interesting." (Hannah)*

"An area I did work on for a while is transport across cell membranes, these boundaries, these surfaces they're really interesting, so what I can do there is, I don't know very much about this area, but I know enough from beyond the A level syllabus that it's very interesting. And hopefully what I can do, I'm trying to get people to really think about this. "Okay, I can't tell you everything that's happening at the surface here, but I can tell you there are people that do know quite a lot more"…and that's why I feel it's important, that you can sort of highlight things and maybe plant a little seed of "Okay, this might be interesting"." (Kenneth)

Arthur, Gerald, Martin, and Rebecca referred to stretching their students in their responses, with Martin and Rebecca remarking that examination questions often require application of knowledge to new situations that are not explicitly mentioned on A level specifications. Martin's comment is included below.

"You have to have a bit of knowledge above. I have to say, because when I first started teaching, I did [think] "you just need to know what's in the [specification]" but there's so much in just the way they examine it, even if you are thinking about A level chemistry they always put stuff you know in an unfamiliar context and the more you can push students a little bit beyond the [specification], and get them used to applying what they know in a context they've never seen before, the more they find those sort of questions fine, and that's also entirely what any degree will be like."

Martin noted the increased importance of stretching the students in preparing them for undergraduate study. Similarly, although Gerald believes it is not always an issue if a teacher's SMK is limited to the specification, he does believe it to be an issue when teaching high-achieving students. His comments are included overleaf.

> *"It can be if you're teaching bright kids. You don't want to be in a situation where pupils feel that you're redundant and you don't know as much as them, or that there's someone in the class that seemingly knows more than the teacher. I think you have to [know] stuff really well I think...chemistry, although it is topic based...every has topic has something that you've built upon from previous information, if you get to a point where you're coming to an end of your knowledge and you're having to go further at the same time with pupils, it's just going to get messy, and they will see very quickly through it, and then they lose trust."*

Ethan and Richard also felt that it is not always an issue if a teacher's SMK is limited to the A level specification. Ethan commented that, in his opinion, having an SMK limited to the specification does not make someone a bad teacher, but it does make them less effective. In his words, the issue is "for the students who want to find out, you can't help them, and that's where the struggle would be". Richard commented that if a teacher does not have a specialism within chemistry (e.g. organic, analytical), then he does believe specification-limited SMK to be an issue. Conversely, if they do have a specialism, then he considers it to be less of an issue, especially if all areas are covered sufficiently by the teachers in one science department. Following this, he commented on the advantages of this approach, in that "we don't know all the answers as scientists and…this is how we go and research it…modelling that can be a learning gain, in terms of a life skill".

Numerous participants also referred to examinations during the interview phase of the project. When asked to discuss the extent to which a teacher should be an expert, Richard made similar comments to those discussed above, stating that it "depends on the end goal", and that "strong SMK is less important if the aim is simply to get students to obtain an A grade…it is important if you are trying to engage and enthuse students in the subject". Roland, an experienced teacher, remarked that the content that is included on the specification can sometimes be "dry" or "irrelevant", believing that this was primarily due to using examination as a method of assessment. His comments are included overleaf.

> *"I think as with anything, there are things that when I'm teaching I think, "Why is that there, why is that in the specification? Why isn't this in the specification, that might be a bit more of an opportunity to explore things in more depth?" And sort of get more of an understanding rather than just a knowledge. Unfortunately, there's a tendency in A level for things to be governed sometimes by what's testable, because it's driven by a test."*

Conversely, Martin, a less experienced teacher, commented on how in his school's department, the attitude towards teaching was more about understanding the content, rather than the final assessment.

> *"I'm going to enjoy…just teaching purely 'do they understand' and worrying less about exams because they seem to have the opinion here that if you teach the subject the exams will sort themselves out."*

4.9 Models, analogies, and limitations

During some interviews in this phase of the study, the usage of models and analogies were discussed by the participants, and how they related to teacher confidence. Daniel commented that although there was no correlation between his confidence in topics and his usage of analogies, he stated that he used them more often with more abstract and theoretical concepts. In his response, however, he reported that:

> *"Even…talking about a chlorine radical wanting to react for instance. It doesn't want to react, it's not got a consciousness or any sorts of wants or desires at all, but what I mean by that is it would be an energetically favourable thing for it to take part in this reaction we're considering or whatever. Sometimes using analogies makes very theoretical far more accessible."*

Daniel's comments highlight the use of anthropomorphism in his teaching, discussed previously by Taber (2000; 2002) as a cause of misconceptions relating to chemical bonding. Although Daniel states that he is inferring that it is energetically favourable, it is unclear if this is how the concept would be communicated to his students using such language. To investigate the use of analogy and anthropomorphic language further, undertaking lesson observations would be recommended.

Gerald also noted that there was limited correlation between his most confident topics and his usage of analogies in teaching. Despite commenting that he uses analogies in "most lessons", Gerald also stated that by using analogies "you lose a lot of the science behind it" and that sometimes analogies can be "[extended] too much and it just gets a bit messy", finally commenting that "[aspects of analogies] have no chemistry value, but the kids get the answer right". Gerald's comments indicate that the analogies being used do not align with Taber's (2001) three key points when using them, as the limitations of the analogy are not being discussed. Equally, Gerald's comments further raise the question of whether it is more important to consider student understanding or students passing examinations. Ideally, both would be achieved, but if such methods can be applied to answering examination questions, it perhaps raises issues with the nature of the examination itself.

In addition to ideas concerning confidence, some interview participants discussed the limitations of models and analogies in chemistry teaching. One such response, from Martin, is included below.

> *"I'm normally a little bit careful when I try use analogies, normally the way it works I will try and just explain it, just explain it using sort of as much as I can just trying to get them to understand. Normally I will layer it so I won't automatically just use the analogy, because sometimes that can cause confusion. But if I have a class that aren't getting it I will then go to an analogy in order to help them understand it, but I will try not to start with the analogy if I can help it."*

Martin's comments demonstrate an awareness of how analogies may cause students to misunderstand aspects of the taught material, and as a result he believes it best to explain concepts first in terms of the scientific language and context of the concepts involved. In discussing this, Martin is also highlighting an awareness of Taber's (2001) key principles regarding the use of analogy, commenting on both familiarity and the advantages/limitations. There is also some similarity between Martin and Gerald's responses, with the analogy being a "last resort" to help students who do not understand the subject matter at hand, most likely with a focus on the final assessment.

Arthur also declared that he was more likely to use analogies in topics of high confidence. One of his comments is included below.

"If we look at electrochemistry, do I have any analogies for that? I don't think I do really. But then it's such a dry topic, isn't it?"

Electrochemistry was ranked as Arthur's second-least confident topic in the pre-interview questionnaire. He also cited a lack of interest in the topic as a reason for not being able to devise analogies relating to it. In addition to Arthur, Richard also reported that he was more likely to use analogies in topics of high confidence, though he commented that he avoids using them when possible. He described one of the analogies used when discussing chemical equilibrium and Le Chatelier's principle:

"…my analogy that I do [when teaching chemical equilibrium] is I say, a teenager, so whatever you ask them to do they say "screw you", it does exactly the opposite."

As has been observed previously, there is a clear case of anthropomorphic language being used in this analogy, and so it may lead to the development of misconceptions if students do not understand it (Taber, 2000; 2002). Additionally, the language used in this analogy is ambiguous; commenting that the equilibrium system "does exactly the opposite" does not necessarily help. For example, if the temperature of a system were increased, Richard's language could imply that the system would respond by decreasing in temperature, which is not what is observed. Both Richard and Gerald's comments demonstrate the importance of clear and precise language when using analogies. If resources based around SMK/PCK development were to be developed, this should therefore be discussed when considering teaching strategies.

4.10 Rationale for the survey phase

A significant limitation of using semi-structured interviews as the primary data collection source is that although the data collected is rich in detail, conducting and later analysing them is a time intensive process. As a direct result of this, it was not viable to conduct a large number of interviews, and therefore the data is not always generalisable to the population that the participants represent. It was decided, therefore, that following the interview phase of the project a survey would be distributed online to increase the size of the dataset and to aid with generalisability. As a result, the next phase of the project was guided by the research question overleaf.

Are the results obtained from the participants in the interview phase of the study indicative of the wider population of A level chemistry teachers? (RQ5)

The structure of the survey was heavily informed by the structure of the interviews, as well as the participants' responses to certain questions at interview, which is discussed in greater detail in Chapter 5.

CHAPTER FIVE

~ The Survey Phase ~

This chapter begins with a discussion of the methodology for the survey phase of the project. This is followed by the results of the survey phase of the project, which are split into two sections: subject matter knowledge (SMK) in initial teacher training (ITT) and subject matter knowledge and the A level curriculum. These results are discussed with relevance to the wider literature throughout the chapter.

5.1 Methodology: Development of the nationwide survey

5.1.1 Survey questions

To support the data received during the interview phase of the project, and to address research question RQ5, the questions in the nationwide survey were heavily based on those asked at interview. For the survey not to seem daunting to potential participants, the questions were grouped into five main sections:

- Demographic Information
- Impact of Teacher Training
- Subject Matter Knowledge for Chemistry
- The A Level Curriculum and Beyond
- What Makes a Good Teacher?

These sections were informed by the questions that were asked in the pre-interview questionnaires and the interviews themselves, which were in turn informed by the research questions of the project. The 'Impact of Teacher Training' section of the survey included questions regarding teachers' own experiences both before and during initial teacher training, and how their confidence in their SMK changed during this period. The 'Subject Matter Knowledge for Chemistry' section focused on specific topics within the A level and teacher confidence within those topics, in addition to any other jobs that participants may have worked in and how those experiences are relevant to their chemistry teaching. Due to being discussed considerably during the interview phase, questions regarding whether teachers felt that they could stretch their students in topics of low confidence were also included.

The section titled 'The A Level Curriculum and Beyond' required respondents to discuss their feelings with regards to the mathematical content of the A level specification, in addition to discussing whether they believed the octet rule or Le Chatelier's principle to have any limitations. These specific areas were discussed due to the prevalence of misconceptions in these topics, following the work outlined in Chapters 1 and 2. The final section, 'What Makes a Good Chemistry Teacher?', required respondents to discuss the qualities essential to effective science teaching. As it was raised on numerous occasions during the interview phase, questions regarding the effective use of analogies in chemistry teaching were also included in this section. The full transcript of questions in this survey can be found in Appendix D.

For the data obtained to be both meaningful and easier to interpret, three main types of question were used in the nationwide survey. Simple yes/no questions and Likert scales were used for participants to inform us of their opinion and to make the data quantifiable. In addition to these, open-response questions were included in the survey. Most of these questions were coupled with the yes/no or Likert scale questions to give participants the opportunity to explain their responses in more detail, providing more meaningful qualitative data in addition to the quantitative. Some open-response questions were standalone and not linked to closed-response questions; much like those asked at interview, these questions were included to ascertain participants' opinions on particular aspects of the role of SMK in teaching. In turn, coupling the themes drawn from the survey responses with those received at interview allowed for more generalisable conclusions to be drawn from the data.

To encourage greater participation in the survey phase of the project, a shortened version of the survey was released in the same manner as described earlier. This version of the survey only contained the two sections headed 'Demographic Information' and 'Subject Matter Knowledge for Chemistry'. The decision to only include these sections stemmed from their direct overlap with one of the primary research questions of the project (RQ4) and to investigate the confidence in individual topics of A level chemistry using a wider participant pool.

The nationwide survey was initially trialled and discussed with a focus group of four A level teachers, with amendments made to ensure that the desired data and level of response would be received from potential participants, before it was distributed online.

5.1.2 Participants

The participants approached in the survey phase of the project were teachers of A level chemistry. The survey was hosted on the University of Southampton's iSurvey website and was publicised in several ways: via email to the mailing list described previously; via email to subscribers of the RSC magazine Education in Chemistry; and publicly via Twitter. The survey was of considerable length; completion times typically sat between 45 minutes and one hour per participant. All participants who responded to the online survey were self-selecting, and therefore the dataset obtained represents a convenience sample. As previously discussed, there are limitations associated with convenience sampling; however, due to the increased size of the sample and the observed variety in demographic information of the respondents, these were considered to be negligible (Sousa et al., 2004). In order to promote further participation, a shortened version of the survey was also released and distributed via the same methods. The dataset collected represents all of those participants who completed the survey; no saturation sampling techniques were employed in this phase of the project so that the maximum possible respondents could take part. This is in line with research question RQ5, as it was considered that the greater the sample size, then the more generalisable the sample would be to the wider teaching population, provided that sample represented a range of demographics. 51 participants responded to the online survey in the survey phase of the project, with a further 22 responding to the shortened online survey.

5.1.3 Analysis of survey data

Responses to the closed-response questions were quantified and tabulated or graphed. As with the interview data, participants' responses to the open-response questions of the survey were analysed by content analysis using NVivo (Versions 11 & 12). Initially, an inductive approach to coding was used in the analysis of the survey responses to ensure that researcher bias was minimised (Bretz, 2008). This process was iteratively repeated to ensure that the interpretation of the data was credible (Vaismoradi et al., 2016). Sections of the survey data were also coded by a second researcher and compared with the codes generated by the primary researcher to minimise researcher bias and ensure intercoder agreement (Tinsley and Weiss, 1975; 2000).

Once a set of codes had been generated in this manner, they were compared with the list of codes generated from the interview data, where the most prominent themes arising from both datasets were identified. These themes form the basis of the results and discussion sections in this chapter.

5.1.4 Ethical considerations

The methodology employed in this study was compliant with the ethical guidelines set out for educational research in the United Kingdom (British Educational Research Association, 2018). From the point of contact in the survey phase, potential participants were clearly informed about the nature of the study and what would be required of them if they opted to participate on the home page of the online survey. It was made clear to all participants that their participation in the project was voluntary and that they would be able to opt out at any time. Participants in the interview phase were provided with an information sheet and a consent form, where they were required to tick a box to give their informed consent.

The nature of the research also meant that it was important to maintain participant anonymity to protect the interests of the participants. The participants cannot be identified from the information that is detailed is this study and did not provide any personal information that would allow the researchers to link the data back to them. Participants were informed of these confidentiality measures through the information sheet and consent form provided at the beginning of the survey. The anonymised data collected in this study were stored on a password-protected computer at the institution of the primary researcher with encryption and were held in line with GDPR rules.

It was also important to ensure that the participants were kept safe from any physical, emotional, or psychological harm during the research process. Although the nature of the questions was not considered to have the potential to cause harm, the large amount of time required for the survey was deemed to have the potential to impact the welfare of participants. This was explicitly stated on the information sheet, alongside the statement that if they felt unsure of any aspect of the study or wished not to continue then they could withdraw at any time.

To encourage participation in the survey, participants were knowingly entered into a prize draw to win one of two £50 Amazon vouchers. The full survey remained open for five months, while the shortened survey remained open for three months before being closed. Ethical approval for the survey phase of the project was obtained from the University of Southampton's Ethics and Research Governance Organisation, ERGO (Appendix E).

Results and Discussion Part 1: SMK in ITT

5.2 Before training to teach

5.2.1 The undergraduate degree and confidence in chemistry teaching

To explore whether the views of the interview participants were indicative of a larger teaching population, and to further investigate the perceived influence of the undergraduate degree on SMK for teaching, participants in the nationwide survey were required to respond to the statements 5a and 5b using a five-point Likert-type scale.

> *"My undergraduate degree provided me with enough chemistry subject matter knowledge to feel confident teaching **GCSE** chemistry." (5a)*

> *"My undergraduate degree provided me with enough chemistry subject matter knowledge to feel confident teaching **A level** chemistry." (5b)*

After providing responses to these statements, participants were then prompted to briefly explain their choices. The responses to the two statements are shown in Figure 5.1.

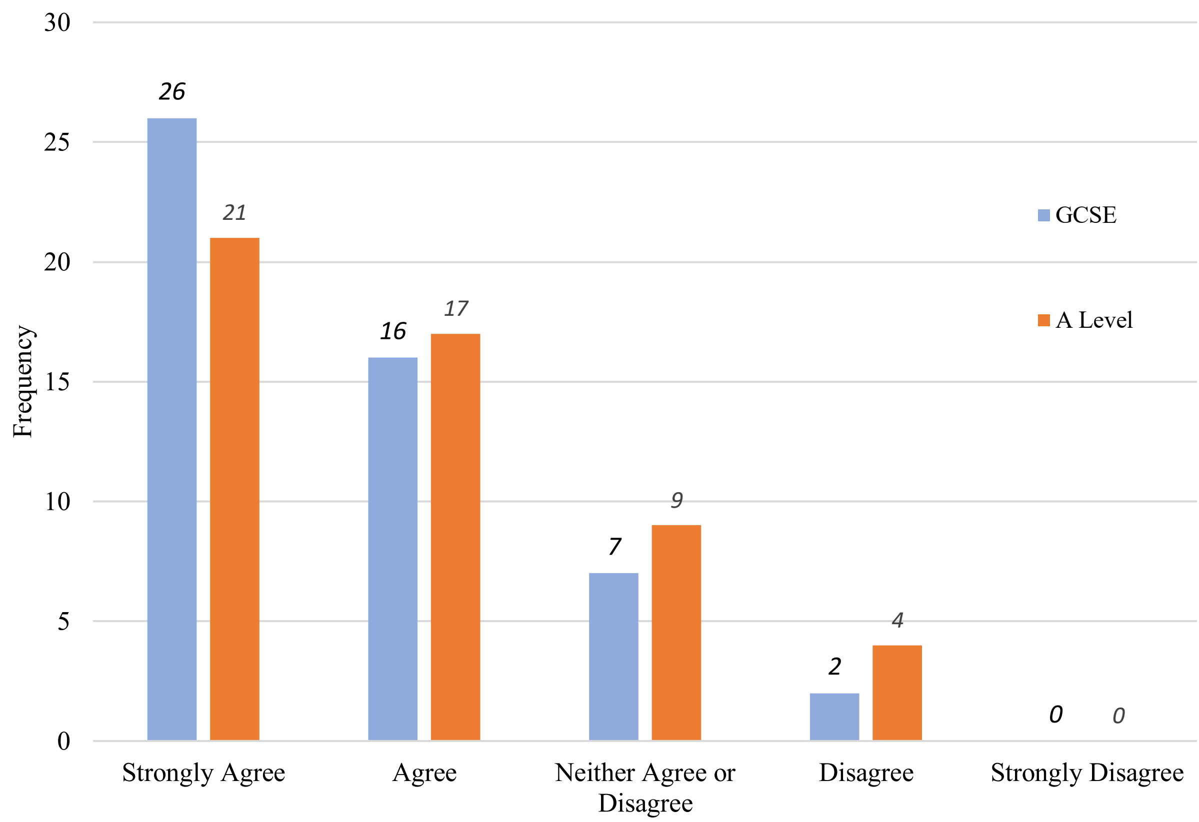

Figure 5.1 Survey participant response to the statements "My undergraduate degree provided me with enough chemistry subject matter knowledge to feel confident teaching **GCSE** chemistry" ($N = 51$) and "My undergraduate degree provided me with enough chemistry subject matter knowledge to feel confident teaching **A level** chemistry" ($N = 51$).

100% of the survey participants responded to these statements, indicating an excellent response rate. The overall response to both of these items was positive, with 82.4% of respondents (n = 42) strongly agreeing or agreeing that their undergraduate degree provided them with enough chemistry SMK to feel confident teaching chemistry at GCSE level, and 74.5% of respondents (n = 38) strongly agreeing or agreeing regarding chemistry teaching at A level. It is positive to see such a high level of agreement amongst participants, revealing a clear belief that the completion of a degree has provided them with enough SMK to feel confident teaching chemistry, as well as echoing the views of the interview participants.

The most prominent explanation cited by those who agreed with the statements, determined through thematic analysis, was that a degree covers all of the aspects that will be encountered at A level, and as such is "enough" when it comes to a teacher's SMK. The following quotes are typical of those who agreed with the two statements.

"My degree gave me an extensive and deep grasp of chemistry - certainly more than enough to handle anything that A level brings up."

"I do not teach anything which I had not encountered when I was at school/university."

"Chemistry degree completed so required good knowledge of fundamentals."

While this is a positive observation, it is worth noting that the responses given refer solely to confidence in teaching at that level. As one participant notes, "feeling confident is not the same as having the required knowledge for some topics which may be sparsely covered (or not at all) at university level". Although teachers may feel that their undergraduate degree has provided them with enough SMK to feel confident teaching their subject, this is not necessarily an indication that their SMK is sufficient. On this matter, Kind (2014) observed that while chemists outperformed biologists and physicists in a test on five concept areas in chemistry for preservice teachers, they were still seen to display a considerable number of misconceptions despite their undergraduate study, highlighting that care needs to be taken when interpreting the participants' responses. In addition, it should also be noted at this point that a teacher's views regarding the relationship between their undergraduate study and chemistry SMK will also be influenced by the degree classification that they obtained, as it can be inferred that those who hold a higher degree classification are likely to have a stronger understanding of the subject matter involved.

Another prominent theme amongst those who agreed with the statements, as already exemplified by the quote in the previous paragraph, is that though these respondents felt that there were no significant issues regarding SMK, not all topics examined at GCSE and A level are covered during undergraduate study, typified by the below response.

> *"Broad subject knowledge covered for degree is a different learning style to the precision for a prescriptive specification like GCSEs and A Level. So broad strokes the same but finer gaps needed filling and [are] sometimes hard to identify."*

Similarly, some respondents reported that they had gaps in their SMK because there are differences in content between A level exam specifications (see Read and Barnes, 2015). Despite encountering these issues, these participants reported that they were able to easily look up these topics and rectify their deficiencies. As stated by one respondent:

> *"A-level teaching depends on the teacher complementing their prior knowledge with good depth background reading."*

This point becomes increasingly pertinent when A level specifications change, as was the case in 2015 when the amount of mathematical content was increased across the major specifications (OCR, 2014a; OCR, 2014b; AQA, 2015; Pearson, 2016). Teachers must therefore be prepared to adapt to these changes, with these adaptations seemingly easier if the teacher has studied an undergraduate degree in chemistry. Particular specification changes, and participants' experiences of them, will be discussed in more detail in Chapters 5.5 and 5.6.

Although some respondents reported minor issues with specific content from their degrees, there was also a considerable amount of praise for the holistic nature of studying a degree and how it provides further context around concepts that are first encountered at A level. Some participants discussed this in relation to stretching their own students, illustrated by the quotes below.

> *"My degree helped somewhat with A level, but not lots, the main thing that it provided me with a deeper level of understanding of organic chemistry and ways to extend students."*

> *"Knowledge of university-level chemistry gives the background knowledge and confidence to answer the 'why' questions from students which can sometimes be beyond the specification."*

> *"I am able to stretch those from GCSE to A level and then beyond, [based on] my own education."*

These comments are in line with Roland's views on the role of the undergraduate degree in SMK development for teaching, allowing for the teacher to go beyond the scope of the specification and discuss chemistry from a new and perhaps more challenging perspective with their high-achieving or more inquisitive students. The act of stretching students in particular topics, and having the confidence to do so, will be discussed further in Chapter 5.5.

In addition to their undergraduate degree providing them with enough knowledge to teach at GCSE and A level, a small number of teachers stated that they felt that their knowledge from their own experience of A levels was sufficient to teach at that level, with one participant going as far as to say that their degree "did not undermine [their] previous (strong) school level knowledge". The use of the term 'undermine' is of particular interest here, almost implying that undertaking a chemistry degree could harm a teacher's knowledge of content on the A level specification rather than enhance it. This participant's comment aligns with the findings of Harris and Sass (2007), where in some cases higher level qualifications were found to be linked with lower levels of student attainment.

A small number of those who agreed with the two survey items stated that while they perceived themselves as confident in their knowledge, they were not necessarily able to convey this knowledge to students in an accessible manner:

> *"The knowledge was there but the application of that knowledge to the lowest basic level needed developing."*

> *"I would always research a new topic that appears on the [specification], but the majority of what we teach has little intellectual demand in understanding it. The challenge is to make it accessible and relevant to students."*

These responses indicate the importance of PCK in a teacher's professional knowledge; although the participants are highlighting that they were comfortable with their SMK for teaching, this knowledge is only useful to their students if it can be distilled down into a comprehensible manner. The specific knowledge of how particular topics should be taught is a key component of a teacher's knowledge (Shulman, 1987), and so it is encouraging to see teachers aware of its importance relative to their SMK. These comments were provided by teachers with more than ten years of teaching experience, denoting an increased awareness of PCK with time, as has been observed previously (Grossman, 1990; Magnusson et al., 1999; Van Driel et al., 2001).

Following the two comments quoted above, an argument can be made to advocate for the inclusion of PCK-related activities during an undergraduate student's degree, highlighting common misconceptions in chemistry topics and allowing for students to develop their own understanding of the topic further through explanations to their peers. Equipping prospective teachers with an awareness of PCK before proceeding with their training could accelerate the development of good PCK and could therefore result in better teaching. These considerations can also be applied to those looking to pursue a career in academia. However, considering the fact that only a small percentage of chemistry graduates will pursue a teaching career, and that there is already a significant burden on undergraduate students' time with the content already covered, it may be more beneficial to include more of these activities during ITT. The inclusion of these activities in ITT will be further discussed later in this chapter.

A very small number of respondents indicated disagreement with statements 5a and 5b; 3.9% (n = 2) in the case of GCSE teaching and 7.8% (n = 4) in the case of A level teaching. The two participants that disagreed with statement 5a felt that GCSE content is so far removed from undergraduate degree level that it is hard to draw any sort of comparison between them. These two participants, however, both agreed with statement 5b, with one of them reporting that "[with the A level] you can draw on your experience so [it] is more closely linked".

Of the four participants who disagreed with statement 5b, two of them studied chemistry at undergraduate level, whilst the other two studied biomedical sciences and sport & exercise science, respectively. The two quotes given below denote that the two non-specialists felt that their undergraduate degrees did not completely prepare them, in terms of SMK, to teach all components of A level chemistry, as was also observed by Kind (2014).

> *"I felt confident to deliver organic chemistry to A level but did need to brush up my inorganic and physical chemistry for A level teaching."*

> *"In terms of specific subject knowledge it did not contribute much, but in terms of scientific skills it was invaluable."*

Despite these concerns, it is encouraging that they perceive their undergraduate degrees to have had a positive contribution to their overall knowledge and skillsets. Conversely, the two chemistry specialists who disagreed with statement 5b felt that despite covering the majority of A level content in a chemistry degree, the A level specification is too complex for this knowledge to be enough, as shown by their responses.

> *"The A-level specification is more complicated and although all the content was covered in my degree, I felt that you need to know more to be able to confidently explain it to the students."*

> *"GCSE can be mugged up rapidly by any intelligent teacher with a book, A Level is another can of worms."*

As with previous comments, these statements suggest that an investigation of SMK from a pedagogical perspective, focusing on the development of PCK, would be a highly beneficial exercise to undertake. Although an argument exists to say that it should be expected, these responses also indicate that it should not be assumed that an ITT candidate will have the sufficient knowledge to teach their subject at A level. It is suggested, therefore, for ITT providers and the candidates themselves to evaluate the extent of preservice teachers' SMK, and to consider methods by which it can be enhanced. However, despite these recommendations, it should be reiterated that whilst the responses of those who disagreed with statements 5a and 5b are important to discuss, these feelings are held by a distinct minority of respondents.

A small but noteworthy number of participants neither agreed nor disagreed with statements 5a and 5b, with slightly more selecting the impartial option for statement 5b (5a: 13.7%, n = 7; 5b: 17.6%, n = 9). Similar to what was observed with those who agreed with the statements, thematic analysis revealed that the majority of these participants felt that the content covered at undergraduate level held little direct relevance to the content covered at GCSE and A level, with minor overlap between the different levels. Additionally, three of these respondents felt that to teach GCSE they did not need a degree; in their view, simply studying the A level content is enough to teach chemistry at GCSE level.

Two participants, both specialists with fewer than five years of teaching experience, recalled specific instances during their teaching where they felt let down by their chemistry SMK. Their comments are recorded here in full.

> *"My major problem was that I never fully understood the subject. So when I went to university again these gaps in my knowledge were never filled in (from both GCSE and A-level). [It] took until I started teaching to realise this."*

> *"I've had some issues with subject knowledge when teaching A-level. Some students have questioned me and I have had quite a weak understanding and only surface learned some topics."*

These comments support the argument presented earlier; if somebody holds an undergraduate degree in a subject, then this does not imply that their SMK in that subject is sufficient to teach it at A level. Conversely, it can also be argued that teachers' exposure to these situations in their early years of teaching will allow them to become aware of any gaps in their SMK, allowing for them to reflect on them and enhance their understanding of the subject as a result. Both participants have clearly stated that their understanding of the subject was weak and/or non-existent, hinting at the possibility of them having had to unpick their own misconceptions that they acquired as students.

Regarding misconceptions, another participant who neither agreed nor disagreed with both statements 5a and 5b contributed the comment below.

> *"I think it's very important to understand where student misconceptions appear from and how to challenge them with care. Degree programmes don't do this, teacher training should do this but from my experience (20 years ago) they definitely didn't."*

An important element of a teacher's knowledge is to know what their students do and do not know, so that a meaningful educational experience can be provided (Ausubel, 1968). This awareness should include an understanding of student misconceptions, so that a teacher can easily identify and rectify these misconceptions as soon as they are realised. This comment supports the need for specific training regarding student misconceptions and implies the contribution of experience to a teacher's PCK, as has been seen previously (Grossman, 1990).

In line with the comments discussed in the previous paragraph, and throughout this section, although many of the participants feel that their undergraduate degree prepared them well with their SMK to confidently teach A level chemistry, there are a considerable number who felt that the degree was not relevant to their teaching, and some who found that they had obtained a superficial understanding of the subject. Moreover, feeling confident with SMK is not the same as having strong SMK; although confidence can be a crucial factor in delivering good teaching, it is potentially damaging if this confidence is misplaced. As a result, both factors should be considered accordingly when preservice teachers begin their ITT. It follows, then, that the subsequent question can again be asked; to what extent should a teacher of A level chemistry be an expert in their field?

5.2.2 The extent of a teacher's SMK

To explore whether the views of the interview participants were indicative of a larger teaching population, and to further explore teachers' views regarding SMK expertise, the same question was posed during the survey phase of the project as statement 5c, with participants required to respond using a five-point Likert-type scale.

"In relation to subject matter knowledge, a teacher of A level chemistry should be an expert in their field." (5c)

After providing their response to this statement, participants were then prompted to briefly explain their choice. The response to statement 5c is displayed in Figure 5.2.

98% of the survey participants responded to this statement, indicating an excellent response rate. The overall response to this item was positive, with 76.0% of respondents (n = 38) strongly agreeing or agreeing that an A level chemistry teacher should be an expert in their field. It is not surprising to see that none of the participants disagreed or strongly disagreed with this statement, as it is probable that the majority of teachers (or indeed any professionals) perceive themselves as experts in their field. What is of more interest here are the reasons behind the participants' choices.

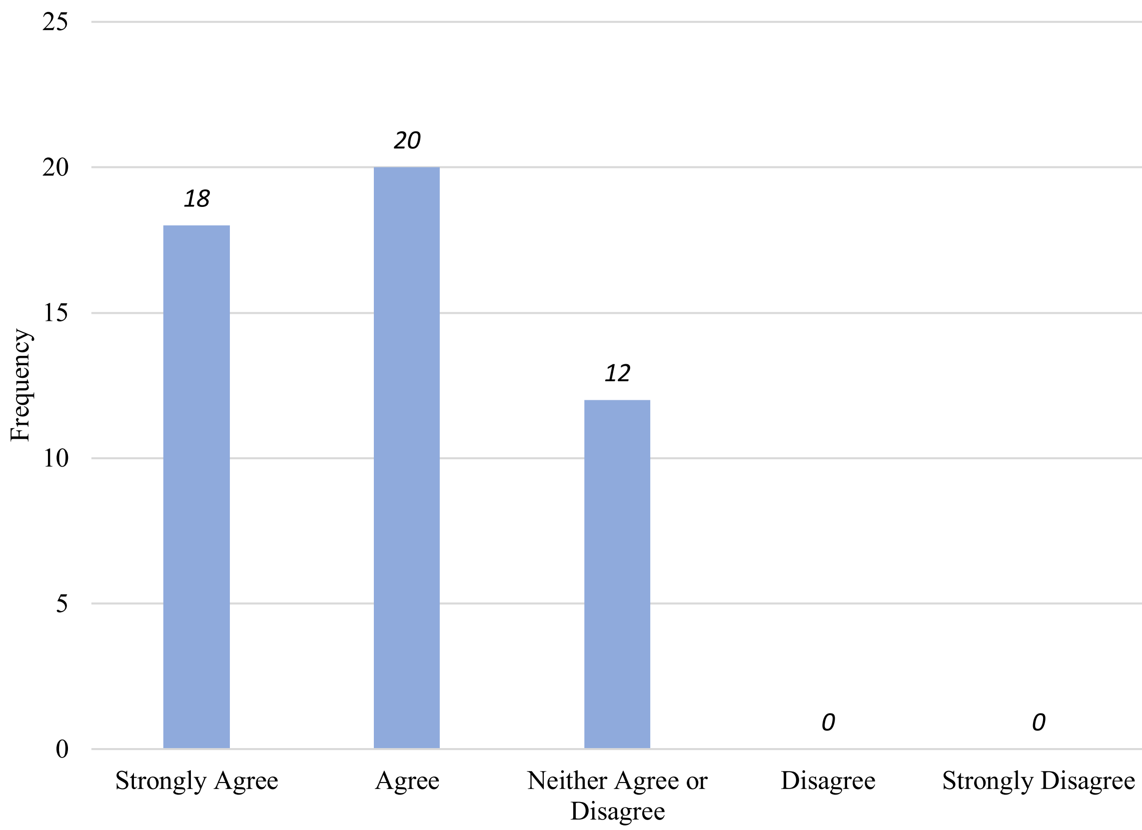

Figure 5.2 Survey participant response to the statement "In relation to subject matter knowledge, a teacher of A level chemistry should be an expert in their field" (*N* = 50).

Amongst those who strongly agreed or agreed with statement 5c, the most prominent theme identified in their explanations was that there is a requirement of knowledge beyond the A level specification (n = 14), a theme aligned with responses obtained during the interview phase. Representative quotes from a small number of survey participants are shown here.

"In order to gain pupil confidence you need to know your stuff…how much of an expert you need to be may be up for discussion but you need knowledge beyond the A level spec."

"You need to have a grasp of what lies beyond A level, even if it is a hazy fuzz from years ago. It helps frame the teaching you do post 16 and pre 18."

"No doubt members of staff should have the strongest subject knowledge in their department, and the more their subject knowledge the more confidence students have."

The responses given previously support the responses provided during the interview phase of the project, acknowledging the influence of SMK expertise on both providing context to the content being taught and inspiring confidence in students.

Confidence was also observed to be a prominent theme in the responses of those who agreed with statement 5c (n = 9). These participants justified their agreement with the statement through arguing that to be able to communicate content effectively, a teacher must be confident in their SMK of that content. In addition to this, as seen in the quotations above, if a teacher has a high level of confidence in their SMK, they are more likely to instigate a greater level of confidence in their students. These views are exemplified by the comments below.

> *"This goes without saying. If you are not an expert it will be obvious to students and you will lose their confidence quickly. You need to be an expert to clearly deliver the content."*

> *"It is a challenging A-level. A teacher who is not secure in their knowledge cannot develop confident learners."*

As was discussed by Kenneth, Richard, and Martin during the interview phase, teachers will not necessarily begin their careers as 'experts'. One survey participant's response to statement 5c reflects this view:

> *"Only now I have taught the organic topics a few times do I feel confident - this is perhaps becoming an expert in those topics and this allows me to be a much better teacher, make curricula links as well as explaining clearly why things happen."*

This participant highlights the importance of strong SMK in being able to make links between different concepts, something that has been previously identified as integral to strong PCK (Hashweh, 1987). This also lies in agreement with Childs and McNicholl's (2007) assertions that a teacher cannot plan effective lessons until they have learnt the content to a good standard themselves.

Similarly, a number of responses (n = 9) related to teachers having an awareness of their students' learning and interest in chemistry. Some exemplary quotes are depicted below.

> *"All teachers should be experts in their field, otherwise it devalues teaching and education. Pupils have the right to be taught and inspired be someone who has a deep interest and love for their subject."*

> *"Students will find it hard to be inspired by someone who they do not consider an expert."*

Other responses relating to an awareness of the student experience considered those students that are considered the 'most able' (i.e. those seeking to achieve high grades and/or apply to top universities). It would be difficult to stretch these students if the teacher themselves does not have a level of SMK that lies beyond the specification being taught. From a comparable perspective, one participant notes that "to inspire students to study your subject", you must "be able to answer their questions with ease". It is implied from these teachers' experiences and beliefs that a student's enjoyment of a subject can be strongly influenced by their teacher's level of SMK, and indeed the teacher's enjoyment of the subject. This is discussed in further detail later in this chapter.

A small number of participants (n = 2) who agreed with statement 5c discussed the role of SMK expertise in developing an appreciation for student misconceptions and how they may arise. These two responses are given in full here.

> *"I'm not sure that they have to be an 'expert', but their subject knowledge needs to be strong enough to be able to teach able students and develop an understanding of how misconceptions arise."*

> *"Very difficult to truly understand subject misconceptions & why students struggle with some topics and how to deal with this if you are not a subject matter expert."*

Both comments were provided by experienced teachers (7-10 years and 16-20 years of experience, respectively). As noted by these participants, knowledge of the content is not enough on its own; the teacher's knowledge must also encompass an appreciation of how misconceptions can develop. It is predictable that a skill such as this would develop with time as a teacher gains experience in the classroom, developing knowledge of learners and the learning processes involved in particular topics, thus enhancing their PCK as a result. Although it is difficult to always ascertain exactly what may cause particular misconceptions, Taber and Tan (2011) state that in order to approximate what may cause misconceptions, then attention must be paid to the broad sources of students' ideas. As discussed in the two participants' quotes above, discerning the source of a students' ideas on a topic can only be possible if the teacher themselves understands the topic to a high degree.

Two of the participants who agreed with statement 5c did so with the caveat that it depends on how you define an expert. Eight of the twelve participants who selected the 'neither agree or disagree' option also cited this as the reason for their choice, with some going as far to say that a high level of expertise can actually be of detriment to teaching, as evidenced in the quotes below.

> *"Depends what is meant by expert. I have been taught by people who are "experts" i.e. at the cutting edge of research who have not been able to explain things very well."*

> *"Depends what you mean by expert [...] expertise in a field often leads to a very narrow focus. This can be unhelpful when helping students deal with the obstacles to developing a broad basic understanding of a subject."*

These comments imply that there is a link between having a very high level of SMK and a low level of PCK (in this case, a knowledge of how to convey fundamental ideas in topics of great expertise), similar to the findings of Harris and Sass (2007). This demonstrates and supports the differences discussed previously between SMK and PCK; although a high level of SMK is argued to be required in order to develop strong PCK, it is not sufficient on its own (Van Driel et al., 2014). It is a part of the amalgam that makes up a teacher's knowledge (Shulman, 1987). Although a high level of SMK expertise can benefit teachers of A level chemistry (and in turn their students), especially with regards to the identification of student misconceptions, it is of little use if they are unable to convey this information at the required level. As discussed previously, greater experience is likely to have a positive impact on PCK development.

Aligned with the views outlined by interviewees Kenneth, Richard, and Martin, two of the participants who selected 'neither agree or disagree' in response to statement 5c referred to the fact that you don't need to be an expert from the beginning of your teaching career, and that experience is essential in developing expertise. Their two responses are shown below.

> *"Depends on the extent to which you're defining expert! […] I don't think it's realistic to expect a teacher to be an expert in the specification content of a subject from the word go, but it's something that they should be working towards over the course of the first few years of their teaching career."*

> *"You can become an expert by teaching a topic you have previously felt low confidence with."*

It is also noteworthy that the first of these comments discusses being an expert in the specification content. As was discussed previously, three of the interview participants (Ethan, Hannah, and Kenneth) explicitly cited curriculum knowledge as a key area for A level chemistry teachers to demonstrate expertise, further aligning the survey findings with those from interview and in alignment with accepted models of teacher knowledge and PCK (Magnusson et al., 1999).

As the definition of an expert can be perceived as ambiguous, to further clarify survey participants' responses and to allow for further elaboration on prior comments respondents were also invited to respond to statements 5d and 5e using a five-point Likert-type scale.

> *"Having at least an* ***A level (or equivalent)*** *in a chemistry-related subject is necessary for teaching A level chemistry." (5d)*

> *"Having at least a* ***degree (or equivalent)*** *in a chemistry-related subject is necessary for teaching A level chemistry." (5e)*

After providing their responses to these statements, participants were then prompted to briefly explain their choices. The responses to both statements are shown in Figure 5.3.

96% and 98% of the survey participants responded to statements 5d and 5e respectively, indicating an excellent response rate. The overall response to both of these items was positive, with 93.9% of respondents (n = 46) strongly agreeing or agreeing that A level chemistry teachers should possess a chemistry A level, whilst slightly fewer respondents (86.0%, n = 43) strongly agreed or agreed that they should possess a degree in chemistry or a chemistry-related subject.

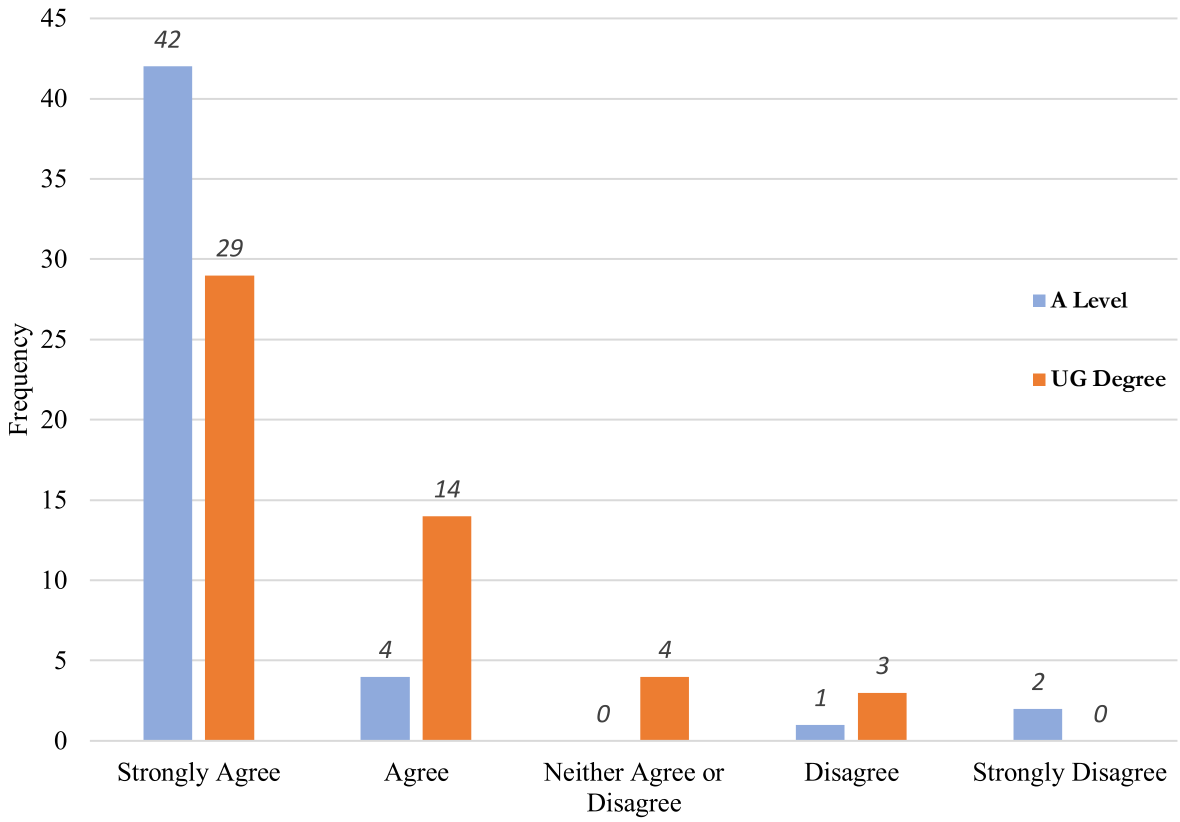

Figure 5.3 Survey participant response to the statements "Having at least an **A level (or equivalent)** in a chemistry-related subject is necessary for teaching A level chemistry" (*N* = 49) and "Having at least a **degree (or equivalent)** in a chemistry-related subject is necessary for teaching A level chemistry" (*N* = 50).

The most common theme identified in the responses of those who agreed with statements 5d and 5e was that studying chemistry to A level or degree level provides a deeper understanding of the subject (n = 35). Some representative comments illustrating this theme are included here.

"A level is a must. Degree also necessary due to curriculum changes meaning a large number of previously undergrad topics have dropped to a level."

"You absolutely need the subject knowledge above A-level to help with your stronger students. It also improves your understanding of the subject and helps you to understand how misconceptions arise."

"Absolutely essential given the complex and challenging nature of some of the questions. Non-specialists with A-Level chemistry tend to have a ceiling at AS-Level chemistry."

> *"Very difficult to truly understand subject misconceptions & why students struggle with some topics and how to deal with this if you are not a subject matter expert."*

The quotes above provide further support to the claims discussed previously in this chapter regarding curriculum knowledge and awareness of misconceptions. Changes in specifications can cause problems for educators, especially if they have not encountered the newly included content before. This particular issue, with reference to the inclusion of the Arrhenius equation in the 2015 A level reforms, was explicitly discussed by one participant.

> *"...a higher-level knowledge would help skip over the huge gaps when specifications change - Arrhenius anyone? I didn't think I heard of the chap let alone his equation before it was thrust on us having to teach it in the new spec."*

Being in possession of a chemistry degree will aid with issues such as this, but in the case of those who do not have a degree in chemistry, support should be in place to allow for the necessary development of SMK (and PCK) to occur. Ideally, SMK support should be provided by those organisations overseeing specification changes; methods by which this could be facilitated are discussed in Chapter 5.4.

Within this theme, other participants (n = 2) note the importance of a high level of study in instilling confidence in students, seen in the quote given here.

> *"...it is a massive advantage to have both a wider and deeper background: it enables you to think of other ways of explaining a concept and inspires confidence in your pupils that you can prepare them properly for the examination."*

According to other respondents, confidence is a "major factor in teaching" and that "you need to feel confident in what you're doing and so do your students". These participants believe that a deeper understanding of the subject allows for a teacher to have greater confidence in their knowledge, and as a direct result greater confidence in their content delivery. Other participants emphasised that higher levels of study (and subsequently confidence) allow for greater discussion beyond the specification with their students, enthusing the students more in the process. This is illustrated in the response overleaf.

> *"You should always be ready to go a bit beyond what is needed. A student might ask a question that needs a higher level of understanding. e.g. a Y7 once asked how the hi-vis stripes on his cycle helmet worked, some sixth form students guessed that there was a link between Gibbs free energy and equilibrium. It was good to be able to explain these...and maybe grab their interest a bit more."*

A small number of respondents (n = 7) made explicit reference to the fact that chemistry is a conceptually difficult subject to approach as a learner. As a result, for somebody to teach the subject they must already have a solid grounding in the fundamental principles and how they link together. Making direct reference to this, one respondent claims that "to be able to teach chemistry", you must be able to "intertwine the different strands and enable the student to use an armoury of sources to answer questions and think for themselves". These views are consistent with the findings of other studies (e.g. Rushton et al., 2008, where students found it difficult to consider numerous concepts relevant to reactivity simultaneously and developed misconceptions as a result). Again, the importance of strong PCK in communicating abstract concepts is noted here. The value of context is also mentioned again, with one participant commenting that "it is also important to understand how the students will have to apply the chemistry later in their science careers to make sure what you are teaching is relevant and correct". Additionally, three participants discussed the step up between GCSE and A level chemistry, with one commenting that you cannot "get away with a surface understanding" when teaching A level content.

Teachers' workloads were also considered by one agreeing participant. The participant comments that:

> *"Not having a suitable subject qualification to teach chemistry makes workload much higher [...] teachers rarely have the time in their day to day work to top up their subject knowledge."*

Despite only being raised by one participant in this study, it is possible that this comment holds truth for numerous teachers. Teachers experience a large number of responsibilities as part of their day-to-day work, and so if their SMK is not at the appropriate level it may be difficult to find the time necessary to improve this. For teachers experiencing these pressures, discussions with other specialist members of staff may prove useful, in addition to participating in subject knowledge enhancement (SKE) courses or relevant CPD.

As was discussed in both Chapter 4 and earlier in this chapter, possession of the relevant qualifications (such as an A level and an undergraduate degree) is not necessarily an indicator of strong SMK. One respondent confesses to this, despite strongly agreeing with both statements 5d and 5e:

> *"I have a 2:1 from a Russell Group university and I felt completely unprepared for teaching A-level. It is possible (like myself) to get decent grades without fully actually understanding the subject."*

This respondent's comments further demonstrate that in order to teach chemistry effectively and confidently, then a fundamental understanding of the subject must be achieved. Although these comments were only provided by one respondent, it can be assumed that there will be others who feel the same way. To assist preservice teachers in this position, audits of trainee teachers' SMK could be undertaken in the early stages of ITT, to highlight areas of potential weakness and to allow for the individual to target specific areas with appropriate resources or CPD. Kind (2009a) suggests the use of diagnostic instruments to ensure that teachers become aware of their misunderstandings.

Of the four participants who selected the 'neither agree or disagree' option in response to statement 5e, two discussed their personal experiences working with teachers who lacked chemistry-related undergraduate degrees but were still excellent teachers. These teachers actively sought to develop their SMK, undertaking chemistry SKE courses. One respondent offers a 'reverse argument' approach in their response to the statement, commenting that they "know people with degrees in chemistry who are not very good A level teachers". This comment again highlights both the difference between SMK and PCK as well as the fact that possessing a degree does not necessarily infer subject matter expertise.

Three of the four participants who responded to statement 5e with 'neither agree or disagree' remarked that an undergraduate chemistry degree is not necessary for teaching A level chemistry, but it is very beneficial. An exemplar quote is included below.

> *"I believe if the A level in Chemistry has been studied recently, it should suffice for teaching A level Chemistry, though having knowledge at a higher (i.e. degree) level, or knowledge of the application of chemistry in industry, is a bonus."*

As with those who showed agreement with statement 5e, one participant remarks that possession of a degree is especially valuable in inspiring their students, providing context to the concepts covered at A level.

Of the three participants who showed disagreement with statement 5d, only one of them additionally showed disagreement with statement 5e. Their explanation specifies that although they do not believe a chemistry A level or degree to be necessary, it would be of great benefit:

> *"I don't have either! But I still feel I am an effective teacher. Furthermore in some ways I think I can give better explanation as I'm less likely to over complicate things. I have worked hard to be an expert teacher, rather than an expert chemist. Of course I think a higher level of chemistry education would have helped me even more."*

Another of the participants who disagreed with statement 5e reiterates the belief that a degree is not necessary but is of high value, especially when providing insights and background knowledge to students. Of the other participants who showed disagreement with statements 5d and 5e, the only other notable theme was a discussion of personal experiences, i.e. where participants knew individual teachers who did not possess a chemistry degree but were perceived to be 'excellent' teachers. No further elaboration was given to explain why these individuals were perceived as excellent.

5.3 Confidence in chemistry subject matter knowledge

5.3.1 Initial confidence in chemistry SMK

Like those at interview, participants in the nationwide survey were asked to comment on their perception of their level of chemistry SMK before they started teaching (Table 5.1).

Response	Number of Respondents
High level	*36 (70.6%)*
Reasonable level	*10 (19.6%)*
Low level	*4 (7.8%)*

Table 5.1 Survey participants' response to the open-answer question "What was your perception of your level of chemistry subject matter knowledge before you started training to become a teacher?" (*N* = 51). Responses are based on themes identified through thematic analysis.

100% of the survey participants responded to this question, showing an excellent response rate, though one participant's response did not clearly explain how they perceived their SMK level. Of the 51 respondents, the majority (n = 36, 70.6%) reported that they felt they had a good level of SMK, a similar result to that observed with the interview participants. Generally, those who stated that their SMK was of a high level did not elaborate on this, typically giving a very short response. Fourteen of these participants stated that whilst they perceived their SMK to be good, they felt that they had weaknesses in certain specific topics. This is most common amongst those participants who did not pursue a teaching career immediately after completing their university studies, and who instead opted to work in industry and other work sectors. This also applies to those who reported their SMK to be of a reasonable level. One participant who reported their SMK to be at a reasonable level commented that differences in specification between GCSE and A level, as compared to when they studied them, lowered their perception of their SMK, further evidence that supports the comments made regarding specification changes discussed in the interview phase of the project.

A small number of participants (n = 4, 7.8%) reported that they felt their level of SMK was poor before they started teaching. Of these four participants, one remarked that they "went to work in industry before coming back to teaching", a common theme identified amongst those reporting a reasonable level of SMK as well. A further two of the four participants did not study a single honours chemistry undergraduate degree, instead undertaking degrees in medicinal chemistry and biochemistry, respectively.

The survey participants were also asked to comment on their confidence in their chemistry SMK before they started teaching, responding to a yes/no question followed by an open-answer question requiring them to explain their response. Their response is displayed in Table 5.2.

Response	Number of Respondents
Yes	*40 (78.4%)*
No	*11 (21.6%)*

Table 5.2 Survey participants' response to the question "Were you confident in your chemistry subject matter knowledge before you started teaching?" (N = 51).

100% of the participants responded to this question, indicating an excellent response rate. Most participants felt confident in their chemistry SMK before starting teaching. Following thematic analysis, the most common theme identified amongst the responses of those who reported high confidence was reference to their degree studies, with those who had undertaken postgraduate degrees making explicit reference to these courses. Despite this high confidence, eleven of the participants reporting an overall high level of confidence reported that their confidence in specific topics was lower and would need to be built up. Amongst these responses, these specific topics ranged from organic chemistry as a whole to particular aspects of physical chemistry; no one particular topic was observed to be mentioned by numerous participants.

The most common theme identified amongst those who reported low confidence in their chemistry SMK before teaching was the time spent away from education (n = 6), similar to what was observed with the previous question. As well as a lack of familiarity with the content itself, these participants also commented on a lack of familiarity with the level at which it is taught. An important part of teachers' PCK is being able to discuss complex concepts at a level appropriate to their students (Geddis et al., 1993). These teachers' feelings, possessed prior to starting their ITT, may be useful for ITT providers to consider when designing and running their courses.

A small number of the participants reporting a low level of confidence felt that their SMK was "rusty", or in some cases felt that they did not understand particular areas of content at all. One representative response is reported on the next page.

> *"Never properly understood A-level - just managed to get through by memorising stuff and not fully understanding and making links between topics. Same at university."*

This comment implies that a student's educational habits, including rote learning and cramming material for exams, can impact heavily on their SMK, with serious implications if they choose to pursue a teaching career; on this matter, Henderleiter et al. (2001) found that rote learning may cause students to develop misconceptions relating to organic chemistry. Conversely, one experienced participant (16-20 years) discussed how they felt very confident in their SMK, but expressed that this would not be enough when teaching:

> *"…I felt that I had the knowledge and understanding to confidently teach difficult content but I think it's important to understand the many misconceptions that students bring to the subject."*

As discussed in Chapter 5.2, holding an awareness of common misconceptions and the reasons why they might arise is a crucial element of teacher knowledge as it can enable teachers to tackle students' misunderstandings early in the learning process and prevent further damage to understanding from being done (Gomez-Zwiep, 2008).

Five survey participants reported that their confidence was influenced by revisiting the A level content before they started teaching, with reference being made to using textbooks and working through past A level examination papers. One of these respondents noted that they had to "work hard to catch up…especially with the additions to new A level specs in 2015".

5.3.2 Changes in SMK and confidence during ITT

Participants in the nationwide survey were also asked to comment on whether their perception of their level of chemistry SMK changed after they initially started teaching. Their responses are shown in Table 5.3.

Response	Number of Respondents
Yes	*26 (51.0%)*
No	*25 (49.0%)*

Table 5.3 Survey participants' response to the question "When you initially started teaching, did your perception of your level of chemistry subject matter knowledge change?" (N = 51).

100% of the survey participants responded to this question, indicating an excellent response rate. The responses obtained from the survey are near-identical to the responses from the interview phase, with a near 50:50 split between yes and no. Survey participants were asked to explain their responses through an open-answer question. Three participants did not further elaborate on their response. Responses were analysed using thematic analysis, with the most prominent emergent themes discussed below.

A significant number of participants (n = 19) made direct reference to the fact that teaching increased awareness of areas of weaker understanding. These views are exemplified in the comments given below.

"I realised how much I had forgotten (or possibly never knew)."

"Realised I didn't have as much fundamental knowledge as I had originally expected, had to refresh on these areas."

"The gaps in my knowledge which I had skipped over were now exposed."

As was observed with Daniel, Ethan, and Hannah in the interview phase, these participants overestimated their SMK, and upon attempting to teach the relevant content found themselves struggling with their own understanding of particular topics. This is supported by another participant, who reported that they "realised [they] needed to have a much deeper understanding to support all students". In order to facilitate student understanding, the teacher must have a good understanding of the topic being taught.

Nine participants' responses were considered to bring elements of PCK, and aspects of other areas of teacher knowledge, into their explanations. One participant noted that they "realised that to teach [they] had to get below the level of the students to make sense of what [the students] were trying to do with their knowledge", whilst another stated that they "still [had] expert subject knowledge, honed to fit the various levels being taught". These comments demonstrate an awareness of PCK development from the beginning of these teachers' careers, highlighting the importance of delivering content at the appropriate level (Shulman, 1987). Discussion of curriculum knowledge and knowledge of learners was also observed. One participant commented that "your understanding can be excellent, but without a thorough understanding of how students can misunderstand your subject then you will find it difficult to teach them." A further two participants remarked that they "had to adjust downwards", because compared to the knowledge they had acquired during their undergraduate degrees the "requirement for specificity was very different".

Four participants reported that teaching allowed for them to consolidate their understanding, either validating their previous perceptions or highlighting that they had a higher level of SMK than they originally believed. An exemplary quote is included below.

> *"I realised I understood what I was teaching and was more confident in my ability to try and teach/explain it to others."*

A further four participants referred to the fact that revisiting particular topics allowed for their perception of their level of SMK to increase. One participant noted that they "found that any gaps could, indeed, be fixed quite easily", while another commented that "the process of thinking about chemistry all day meant [they] gained new and deeper understanding".

Of the four participants who reported a low level of SMK before they started teaching, only one of them reported that their perceived level of SMK remained the same after they initially started teaching. They commented that they "felt OK but…realised there were quite a few gaps in [their] knowledge". The other three participants, reporting positive changes in their perceived level of SMK, felt that teaching allowed for them to enhance their SMK as they went along. A quote from one of these participants is included below.

> *"...although there were some knowledge gaps (e.g. Electrochemistry), I felt ready to start teaching A-level Chemistry. I needed constant support, but I had plenty of resources to use."*

This participant identifies the importance of support in enhancing their SMK, citing the use of resources to facilitate their SMK development. The resources that participants have used to facilitate SMK development will be discussed later in this chapter (5.4).

Another theme identified amongst the responses was the impact of retrospect and reflection at the initial stages of a teacher's career, explicitly discussed by two participants. Both participants reported that they held a high level of SMK, but that teaching changed their perception. Their comments are included below.

> *"Before I started teaching I had the impression I was rather good. However one week into teaching A Level showed up the massive gaps in my knowledge that needed plugging. Teaching is very exposing!"*

> *"I felt that I had a comprehensive understanding of Chemistry. However, looking back I know that I wasn't confident enough in how to teach difficult concepts."*

Both participants hold over sixteen years of teaching experience, providing further support to the claim that experienced teachers are likely to have stronger PCK than those with less experience. These comments also highlight the fact that it is easy to become overconfident in SMK, and how even with a "comprehensive understanding of chemistry" a teacher may not have the knowledge or the confidence to disseminate that knowledge to their students.

Participants in the nationwide survey were also asked to comment on whether their confidence in their chemistry SMK changed after they initially started teaching. Their responses, compared to their responses regarding their confidence before teaching, are displayed in Table 5.4.

Before teaching	After teaching	Number of Respondents
Not confident	No change	*1 (2.0%)*
Not confident	Confidence increased	*9 (17.6%)*
Not confident	Confidence decreased	*1 (2.0%)*
Confident	No change	*18 (35.3%)*
Confident	Confidence increased	*17 (33.3%)*
Confident	Confidence decreased	*5 (9.8%)*

Table 5.4 Survey participants' responses to the questions "Were you confident in your chemistry subject matter knowledge before you started teaching?" and "When you initially started teaching, did your confidence in your chemistry subject matter knowledge change?" (*N* = 51).

100% of the survey participants responded to this question, indicating an excellent response rate. A slight majority of participants found that their confidence did change (n = 32); of these, a greater number found that their confidence increased (n = 26). Survey participants were prompted to explain their responses through an open-answer question, though two participants did not further elaborate on their response. Responses were analysed using thematic analysis, with the most prominent emergent themes discussed here.

Of the respondents who reported that there was no change in their confidence, the most observed theme was simply that they did not encounter any issues with their SMK. The singular respondent who answered that they were not confident in their SMK before teaching and stated that there was no change in their confidence initially after they started teaching explained that they were "confident [they] would be able to improve [their] chemistry SMK". As was the case with responses to the previous question, a small number of participants (n = 5) reported that although they were confident in their SMK they still needed to work on their awareness of learners' knowledge and the appropriate level for delivering content. Additionally, three participants mentioned that although there were gaps in their knowledge, they were confident that these could be fixed easily.

Of those who reported an increase in their confidence in their SMK, a significant number of participants (n = 15) mentioned that their confidence increased as they felt their SMK develop, most commonly through their classroom experience. Seven participants explicitly mentioned the positive impact of more teaching time on their confidence. Some exemplary quotes illustrating this theme are given below.

"Confidence improved the more I taught and reflected."

"Once teaching my confidence improved as I gained curriculum knowledge."

"It also reinforced that I can have a good enough knowledge to teach/be able to answer possibly random [questions] that students might have about chemistry."

The influence of mentors and other experienced teachers was also discussed by five participants. Two participants' comments on this point are shown below.

"I found it easy to refresh my knowledge and had a very helpful Head of Department."

"I also had a very experienced teacher to ask for help when needed, so I felt confident enough to teach."

These comments demonstrate the importance of experienced teachers in the early stages of novice teachers' careers, as was previously noted by Youens and McCarthy (2007). As reported by other authors (Grossman, 1990; Magnusson et al., 1999; Van Driel et al., 2001), the greater a teacher's classroom experience, the more developed their PCK is likely to be. It is important for novice teachers, especially those lacking confidence in their SMK or pedagogical knowledge, to communicate with more experienced teachers to learn from them. Further to these comments, another participant reported that they received "a lot of positive feedback from students as someone who could answer their questions and explain things thoroughly", indicating that there is a role for feedback from both mentors and from the students themselves.

Two participants found that their confidence in their SMK increased as they discovered the links between different concepts. Their responses are recorded here.

> *"As I taught more and more topics, I realised the many links between concepts."*

> *"I learned what topics influence others and why the order of topics is important."*

These comments were made by teachers with greater than twenty years of experience, further supporting the evidence that more experienced teachers are likely to hold a greater level of SMK and PCK. It can be argued that if a teacher has a high awareness of how concepts overlap, more meaningful learning can occur in their lessons, as it provides students with an appreciation for the holistic nature of chemistry and provide a focus on understanding rather than rote memorisation.

Only one distinct theme was noted amongst those who found their confidence in their SMK to decrease upon initially starting teaching. Six participants reported that teaching a class exposed their lack of knowledge of particular topics. Some exemplary quotes are included below.

> *"This was impacted by the level of my subject matter knowledge. There were many aspects of the A-level course particularly that I hadn't considered for years, so required some significant re-study."*

> *"Realised my organic chemistry knowledge and some physical topics were very rusty."*

As was observed with those whose confidence increased, one participant noted that although their confidence decreased, other members of staff helped them to feel more confident with their SMK over time. Their response is included below.

> *"My confidence definitely decreased for a year or so after I initially started teaching A-Level Chemistry. Being in a great department with 2 other Chemistry specialists really helped."*

This comment further supports the claims above regarding the importance of novice teachers working with experienced teachers, as noted by Youens and McCarthy (2007).

One participant reported that their confidence in their SMK dropped as a result of being "unsure of how to deliver content". This comment indicates that this teacher was in possession of a low level of PCK at the beginning of their teaching career, as they were not always sure of the most effective way to teach particular topics, highlighting the advantages of providing resources and/or training on teaching specific chemistry topics during ITT.

It is positive to see that most participants in the interview and survey phases of the project felt confident in their SMK both before and after they started teaching. However, there is still a considerable number of participants reporting low confidence in SMK as they enter the classroom, demonstrating that there is a potential need for SMK (and, once SMK is at an appropriate level, PCK) development during ITT courses, even for subject specialists.

5.4 Development of chemistry subject matter knowledge during initial teacher training

5.4.1 Methods of SMK development

To further investigate the role of SMK development in ITT, participants in the nationwide survey were asked whether chemistry SMK development was a compulsory component of their ITT (Table 5.5), and if it was, to elaborate on the methods used by their ITT provider for SMK development. The methods described were identified through thematic analysis of participants' responses.

Response	**Number of Respondents**
Yes	*21 (41.2%)*
No	*27 (52.9%)*
N/A	*3 (5.9%)*

Table 5.5 Survey participants' response to the question "Was chemistry subject matter knowledge development a compulsory part of your teacher training?" (N = 51).

100% of survey participants responded to this question, indicating an excellent response rate. It can be seen that a small majority of survey participants were not required to undertake any compulsory chemistry SMK development during their ITT, implying that some providers assume that those training to teach chemistry already have sufficient SMK to do so. Despite this, it is positive to see that a significant proportion of survey participants did experience compulsory SMK development during their ITT.

Sessions based around particular chemistry topics, such as workshops and lectures, were the most commonly observed method used by ITT providers for SMK development, reported by sixteen participants. Some examples of these sessions and what they would entail are included below.

"Specific A level lessons targeted to only the Chemistry candidates to refresh our subject knowledge and enhance our ability to see what the students may find difficult to understand."

"We were given a topic to teach the rest of the group - mine was kinetics and orders of reaction."

"[In PGCE sessions we] did mind maps of KS4 and KS3 curricular to link ideas across Science."

Group teaching, as mentioned in the second of the above comments, was also mentioned briefly by one other participant. One participant mentioned that they had an entire module of their ITT devoted to SMK, which included "self-assessment, identification of weaker areas, and a plan to fix it by developing a lesson sequence". This process is not too dissimilar to the SMK development experienced by Gerald during his ITT and is comparable to the SMK audits described previously.

The second-most cited method of SMK development, after workshop sessions, was through practical sessions, reported by seven participants. Representative comments regarding practical sessions are included below.

"Planning practical [sessions] teaching challenging concepts like bonding."

> *"I think the key areas were common misconceptions in chemistry and practical work. We did quite a few of the common chemistry practical [sessions]."*

These comments infer that the practical sessions in ITT courses were used to provide context to the content being presented, in addition to highlighting misconceptions that commonly arise amongst students. Despite these positive comments, one participant mentioned that there was little focus on the development of SMK in their practical sessions, rather the focus was just on the skills involved:

> *"Practical demonstration techniques were the main enhancement. There was no "new chemistry" in the course."*

This participant was, however, confident in their chemistry SMK prior to undertaking ITT, so this could simply be a case of a teacher not requiring a great amount of SMK development.

Two participants noted that classroom observations played a key role in their course-led SMK development, though both participants noted that it was "up to the trainee to prove that they had developed their knowledge" and "familiarise [themselves] with the content". A further two participants undertook a SKE course before starting their ITT, with both commenting that the course focused more on teaching methods and how to teach particular content rather than understanding the content itself, providing a further example of PCK enhancement. However, as has been discussed previously, it must be assumed that a teacher's SMK is of a significant level before they can begin to meaningfully develop their PCK (Van Driel et al., 2014), so it is important to consider this when running such sessions.

One participant explicitly stated that the SMK development elements of their ITT course were "very poor", due to a focus primarily on "some" GCSE level chemistry content but no A level chemistry content. It is understandable that an ITT provider would include more GCSE level content in SMK sessions than A level content; science teachers in the UK are required to teach biology, chemistry, and physics up to GCSE level, and therefore it is sensible for ITT providers to deliver SMK development sessions for teachers in their non-specialist areas. However, as has been previously noted, it can be said that a specialist degree is not necessarily an indicator of strong SMK, and it can be argued that ITT providers should therefore work with preservice teachers more in ensuring that their SMK is at an appropriate level. Additionally, preservice teachers can be encouraged to engage in activities that are not led by ITT providers themselves.

Survey participants were also asked whether they engaged in these activities during their training (Table 5.6), and to indicate the resources and methods they used to further their SMK. These responses were analysed through thematic analysis.

Response	Number of Respondents
Yes	*31 (60.8%)*
No	*20 (39.2%)*

Table 5.6 Survey participants' response to the question "Did you engage in any self-directed activities to develop your chemistry subject matter knowledge while you were training that were not formally part of your training?" (N = 51).

100% of the survey participants responded to this question, indicating an excellent response rate. It is encouraging to see that most participants (60.8%) took the time to develop their SMK beyond the scope of their ITT, as was observed with the participants in the interview phase of the project.

As was observed with the interview participants, the most cited method of self-directed SMK development was through textbooks. Twenty participants commented that they consulted textbooks to revise the content they would be teaching. Some representative quotes are included below.

"I read all the relevant GCSE and A level textbooks to ensure I had a good grasp of what needed to be taught for each syllabus."

"I bought a general A-level chemistry textbook and worked through each chapter, completing all questions."

Nine participants stated that they used past examination papers, at both GCSE and A level, to work on their chemistry SMK. Of those who reported using past papers, two participants stated that they used them to test their knowledge, whilst another remarked that although they found using textbooks and past papers useful there are now "far more resources available" to help with

SMK development. This participant also remarked that "Twitter is a great community for advice on where to go for help", drawing on the experience of other teachers. Only three other participants commented on seeking direction from colleagues or other chemistry teachers, whilst four others commented on using internet resources to allow for SMK development.

Six survey participants stated that they undertook continued professional development (CPD) or other training courses to further their SMK development. Two of these participants focused explicitly on targeting chemical misconceptions, with one participant going as far as developing material alongside a university lecturer to "ensure teaching in a way that didn't develop misconceptions". The use of magazines, journals, and non-fiction books in enhancing SMK was discussed by four participants, whilst one further participant reported that they undertook revision of some undergraduate level chemistry alongside the topics covered at A level.

5.4.2 Looking to the future: supporting teachers with their SMK development

To investigate teachers' views regarding the amount of SMK development training that they were offered during their ITT and follow up on the responses received at interview, participants in the nationwide survey were required to respond to statement 5f using a five-point Likert-type scale.

"Training providers should offer more subject matter knowledge development support during teacher training." (5f)

After providing their responses to this statement, participants were then prompted to briefly explain their choices. The responses to this statement are shown in Figure 5.4.

100% of the survey participants responded to this item, with two participants opting not to elaborate on their responses, indicating an excellent response rate. It can be seen that a significant majority of participants (72.5%, n = 37) strongly agreed or agreed that ITT providers should offer more SMK development support, whilst only two participants held disagreement with this statement.

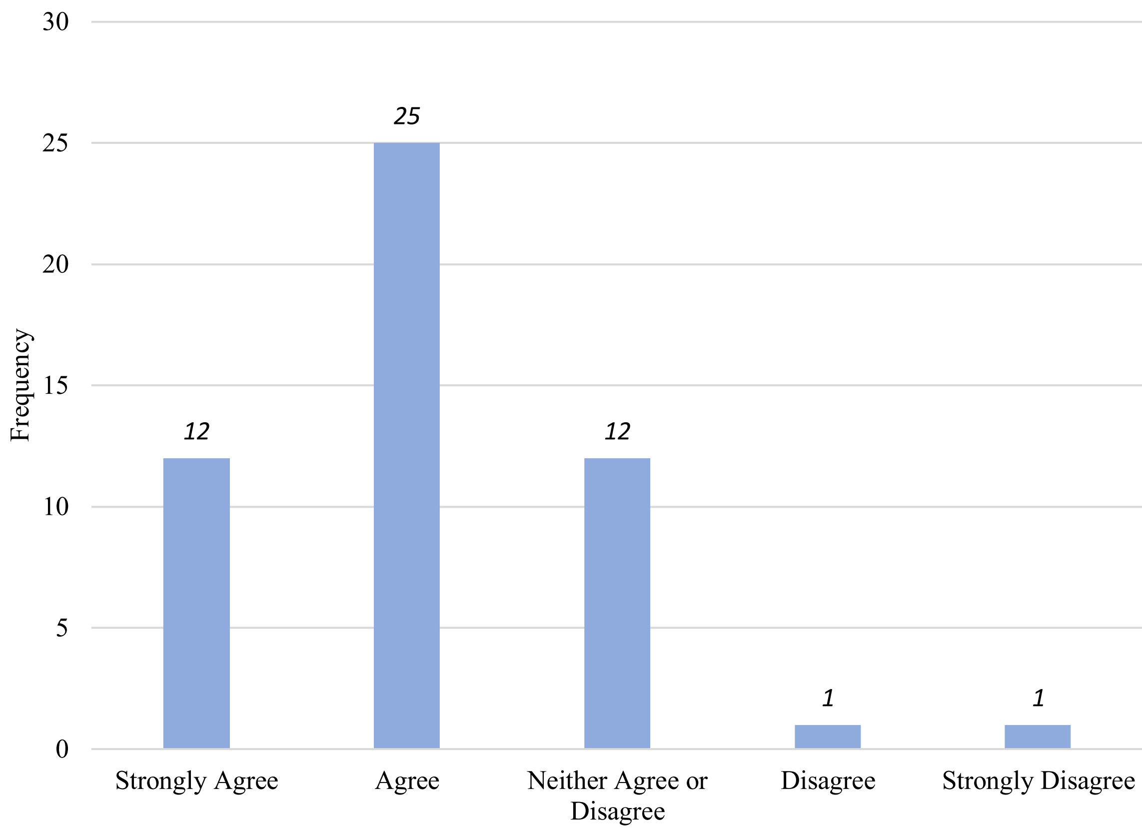

Figure 5.4 Survey participant response to the statement "Training providers should offer more subject matter knowledge development support during training" (*N* = 51).

Of those who showed agreement with statement 5f, thirteen participants discussed their own personal experiences of teachers that they knew with underdeveloped chemistry SMK. Some representative comments are included below.

> *"A lot of trainee teachers have got misconceptions that they pass onto the students."*

> *"I found that, as a teacher, I became very familiar with GCSE and A-level but lost touch with further knowledge. When [specification] changes (e.g. introduction of NMR/proteins etc I had to go back to the books!"*

> *"My training provider offered a lot of subject knowledge support, but I have since worked with other teachers trained by different providers and their subject knowledge [has] been very poor (despite good university degrees)."*

The comments here highlight some of the particular issues surrounding chemistry SMK and its role in teaching. It can be seen that the issue of teachers passing on misconceptions to their students is a significant concern amongst some in-service teachers, and it is therefore necessary to attempt to tackle this problem during ITT if possible. As was discussed previously, specification changes can cause major issues for those whose SMK is restricted to the A level syllabus, and so it is crucial to address these areas of knowledge when changes are made.

Nine survey participants commented on the importance of working with non-specialists to enhance their SMK. Some representative quotes are displayed below.

> *"...I find new colleagues coming into teaching with less specific degree courses (Chemistry teaching with Forensics degree or Bio Chem degree) who find the more technical and mathematical topics a challenge to teach."*

> *"People on my course without a strong chemical background really needed more subject help."*

These comments illustrate the point that those with non-specialist degrees will require greater assistance with their SMK development and that this should be offered by ITT providers as appropriate. Moreover, one participant remarked that "even if you are confident in certain aspects the breadth and depth of ideas at A level…is considerable even for specialists", further demonstrating that these issues are prevalent amongst both chemistry specialists and non-specialists; another participant remarked that they "work with and have been involved in training teachers who are not that competent in their supposed specialism". On this matter, one participant discussed the role of PCK in aiding specialists with their SMK, and emphasised the importance of understanding how to deliver content appropriately for both specialists and non-specialists:

> *"I think there are two important aspects to this. One is highlighting difficult topics to specialist teachers, and strategies for teaching them as well as [just] teaching of the required subject knowledge. Another aspect is ensuring sufficient training is provided to non-chemistry specialists who may end up having to teach GCSE Chemistry. With this increasingly being the case in schools, it's arguable that these teachers need even more subject support to ensure they have the confidence to teach chemistry."*

Additionally, another participant reported that it is important for attention to be paid to making links between concepts in the A level curriculum, as well as making links to undergraduate level content.

Twelve participants neither agreed nor disagreed with statement 5f, with the majority (n = 9) commenting that it would be difficult for ITT providers to offer further SMK development due to various constraints, the most prominent of these being time. Some representative quotes are included below.

> *"A very tricky one for training providers - there is a huge range of other parts of ITT that need to be covered in a very short time."*

> *"I think that it is not realistic unless you extend the course. As professional teachers we should be responsible for improving our own subject knowledge."*

It is essential that these comments are considered in addition to those supporting increased SMK development above. It is understandable for ITT providers to assume that a preservice teacher already has the appropriate level of chemistry SMK if they have previously undertaken an undergraduate degree in that subject, and as such providers can use the time available to focus on the development of pedagogical knowledge, pastoral support, behaviour management, and other necessary teaching skills. One of the two participants who showed disagreement with statement 5f agrees with this point, making the following comment:

> *"It is up to an individual as to what they want/need to do to prepare. There are enough resources out there for someone to use if they need to develop their subject knowledge. Teacher training should be focused around skills needed as a teacher."*

The other disagreeing participant also noted that the teacher's skills should be the focus of ITT, remarking that "subject matter was covered in a chemistry degree, [teaching] is more to do with communication of the material".

Nine total participants commented that SMK development is not the responsibility of the ITT provider, but is rather the responsibility of the individual. One representative comment is included on the next page.

> *"As professional teachers we should be responsible for improving our own subject knowledge. The [ITT] course is mainly to provide us with the skills to help deliver the Chemistry in the classroom effectively."*

It can be argued that a teacher's SMK development should be their own responsibility. As was discussed by some interview participants, pinpointing the areas of the A level curriculum where they felt their SMK was weaker and working on them using textbooks and past examination papers was observed to increase their confidence in their SMK. However, there is potential for the learner to develop their own misconceptions during this process, as well as the possibility of incorrectly assessing one's own understanding of particular topics and developing an illusory competence. This phenomenon, a cognitive bias known as the Dunning-Kruger effect (Kruger and Dunning, 1999), has been observed in those learning chemistry (Potgieter et al., 2010; Bell and Volckmann, 2011; Pazicni and Bauer, 2014), and so it is important to avoid this where possible. It is essential, therefore, for those undertaking SMK development to reflect on their learning and work with SMK experts (where possible) to ensure that their SMK is of an appropriate level.

To provide a potential focus for the future development of resources and training courses to support SMK development, survey participants were asked to follow up on their responses to statement 4f and respond to the question below (5g).

"In your opinion, what can teacher training and CPD providers do in order to support A level chemistry teachers with their subject matter knowledge development during teacher training?" (5g)

The most common theme identified in the responses to question 5g involved focusing on specific topics (n = 10), especially those that are deemed to be more difficult (see Chapters 4.7 and 5.5). Some representative quotes are included here.

"More focus on 'difficult to teach' topics. Tailored rather than blanket approach - what's difficult for one trainee may be straightforward for another depending on their background."

"Training providers should provide chemistry training in the areas the trainees have identified as a weakness."

"Inexperienced teachers need [...] subject knowledge workshops specific to certain topics (e.g. redox, notoriously difficult to teach)."

Providing a focus on specific topics allows for both SMK development and for PCK development to occur, as attention can also be given to communicating concepts effectively and designing successful lesson plans, a process that is eased through possession of strong SMK (Kind, 2009a). Four further participants discussed that SMK development training should involve approaching topics from different perspectives, whilst five participants discussed the possibility of creating "customisable CPD", with preservice teachers focusing solely on those areas they have identified as weak. Sessions focusing on specific topics also allow for emphasis on common misconceptions within those topics, something that eight participants reported should be a key focus for SMK development training. Some representative comments are included below.

"Specific sessions focusing on misconceptions and limitations of models used at A level."

"Time to develop materials that help to overcome misconceptions with students I think would help as it will push trainee teachers to develop their knowledge and understanding of their subject from a student position."

"Understanding how language and sentence construction can lead to misconceptions, i.e. the gas expands is easy to say until the student reflects back to you that the gas particles expand!"

Eight participants reported that more diagnostic SMK testing should be used throughout ITT, as has also been suggested by Kind (2009a). Provision of diagnostic tests allows for preservice teachers to identify weak areas and then respond to them on an individual basis. Further to this, four participants noted that following testing, it is essential that ITT providers offer preservice teachers feedback and help them to devise an action plan, providing "SMK support (including teaching them the content)" where required.

Six participants commented on the positive impact of communication with other teachers on SMK development, especially experienced teachers with strong PCK. One participant stated that more opportunities "for trainees to meet and discuss issues with each other" would be beneficial, whilst two participants commented on the effectiveness of peer teaching. One of these participants' comments is included overleaf.

"Give model lessons of more complicated (mathematical) lessons [...] trainees will sit at the back of my lessons while I'm teaching a given topic and complete all tasks themselves."

Six participants noted that preservice teachers would benefit from more SMK development through practical work. Some representative comments are included below.

"Training within practical context and ensuring a good understanding of. techniques for skills that are required to be understood."

"Practical protocols and how to embed [practical work] as learning resources with much more impact than straight learning."

Utilisation of practical work to enhance student understanding of concepts is seen to be a key component of chemistry education, and so it is essential that teachers are fully aware of how the laboratory can aid with teaching and understanding of specific chemical concepts. It can be further argued that providing practical support for particular topics and discussing how misconceptions can be avoided in a practical context would also be a beneficial method of providing SMK development for preservice teachers.

As was the case with the responses to statement 5f, a number of participants (n = 3) believe that there is not enough time during ITT to introduce further activities such as SMK development. Two of their comments are included below.

"...there is so much to do in the training year, the development of competence needs to be happening over the course of the first five years of a teaching career."

"I think during teacher training it is more important for a teacher to develop teaching skills rather than subject knowledge. It is such a manic time that extra CPD on top of this would be a lot."

Based on these comments, it can be argued that further SMK development should be undertaken after ITT has been completed, throughout the first few years of a teacher's career following acquisition of qualified teacher status (QTS). One other participant agrees with this sentiment, stating that "it is only really during the teaching of a subject that gaps in knowledge become evident". Although it has been observed in this study that teaching topics for the first time did expose areas of teachers' SMK weakness, it can be said that this could be detrimental to the students' learning, introducing misconceptions and perhaps a lack of confidence in the teacher's SMK. In an ideal world, a teacher's SMK should be of a high level prior to starting ITT, but because this is not always the case, it can be argued that continual support should also be in place, especially in the case of specification changes.

To investigate how continual SMK support can be provided for teachers following their possession of QTS, and to provide insight into the methods and resources that could be used, survey participants were invited to respond to question 5h.

"In your opinion, what can teacher training and CPD providers do in order to support A level chemistry teachers with their subject matter knowledge development after they have qualified?" (5h)

As was the case with question 5g, the most prevalent theme identified was the want for resources and CPD sessions on specific topics (n = 23), especially those that are more difficult to teach. As discussed by the participants, the most important things to be considered are misconceptions and how they can be identified, as well as focusing on specification changes. Some representative comments are included below.

"Provide SKE for established teachers in well-known trickier topics e.g. electrochemistry and kinetics."

"When new specifications come out, have CPD courses BEFORE they have to teach the new spec, bridging the gap between old and new specs."

"This is essential for topics which are new to the syllabus in particular (e.g. TOF mass [spectrometry])"

"It is important to understand when new technologies and changes to existing ones are introduced into the syllabus - e.g. mass spectroscopy, or nanomaterials."

In addition to discussion of the SMK content itself, some participants also expressed a desire for training in how to teach particular topics, as was observed in responses to question 5g. One participant noted that they would like more CPD on "novel ways of delivering content", as they saw SMK development as an individual issue.

Nine participants commented on the importance of communication with other teachers, and how it is important for CPD and other sessions to be available in school settings. Some representative quotes are included below.

> *"Providing resources that can be adapted to in school/school group settings so more expert teachers can deliver/support other teachers."*

> *"It is difficult because teachers can be as bad at students in asking for assistance if they don't know something. More informal meetings between newly trained teachers and experienced teachers of the same specifications may be the way forward."*

Some of these participants noted that local chemistry teacher networks are very valuable in helping develop teaching skills (including SMK), reporting that having opportunities to share good practice with colleagues and other teachers has been beneficial for their development of SMK and PCK. In addition to local networks and running events at schools, five participants reported that having access to online events, such as conferences and webinars, would be an effective way of providing SMK enhancement. Providing resources online allows for them to be accessed in a flexible manner, as it can be challenging for teachers to attend in-person CPD sessions outside of school time or take time off during school time to attend sessions. These participants also noted the advantages of having online resources available to them, including journals and education articles.

Four participants noted that SMK can be contextualised using practical work, and that this can be focused on especially with respect to the transition between A levels and university. Three participants commented that conferences specific to SMK development could be organised, with discussion related to delivery of content (PCK). One participant noted that it would be beneficial if university staff, who undertake research in a particular field of chemistry, delivered sessions that "break their subject knowledge down to help explain the more difficult subject areas".

Results and Discussion Part 2: SMK and the A Level Curriculum

5.5 Teacher confidence in A level chemistry topics

5.5.1 Identification of high and low confidence topics

As was the case in the interview phase, participants in the survey phase of the project were invited to rate their confidence in their ability to teach ten A level chemistry topics, ranking them from 1 to 10, where 1 indicates the highest level of confidence and 10 indicates the lowest level of confidence. As discussed in Chapter 4.2, the ten topics were chosen based on a review of the content on the UK's major A level chemistry specifications (Read and Barnes, 2015).

The responses to this question are detailed in a diverging stacked bar chart (Figure 5.5). It should also be reiterated that these rankings relate to teacher confidence, and that confidence may not be an indication of level of knowledge, so this should be considered when interpreting the data.

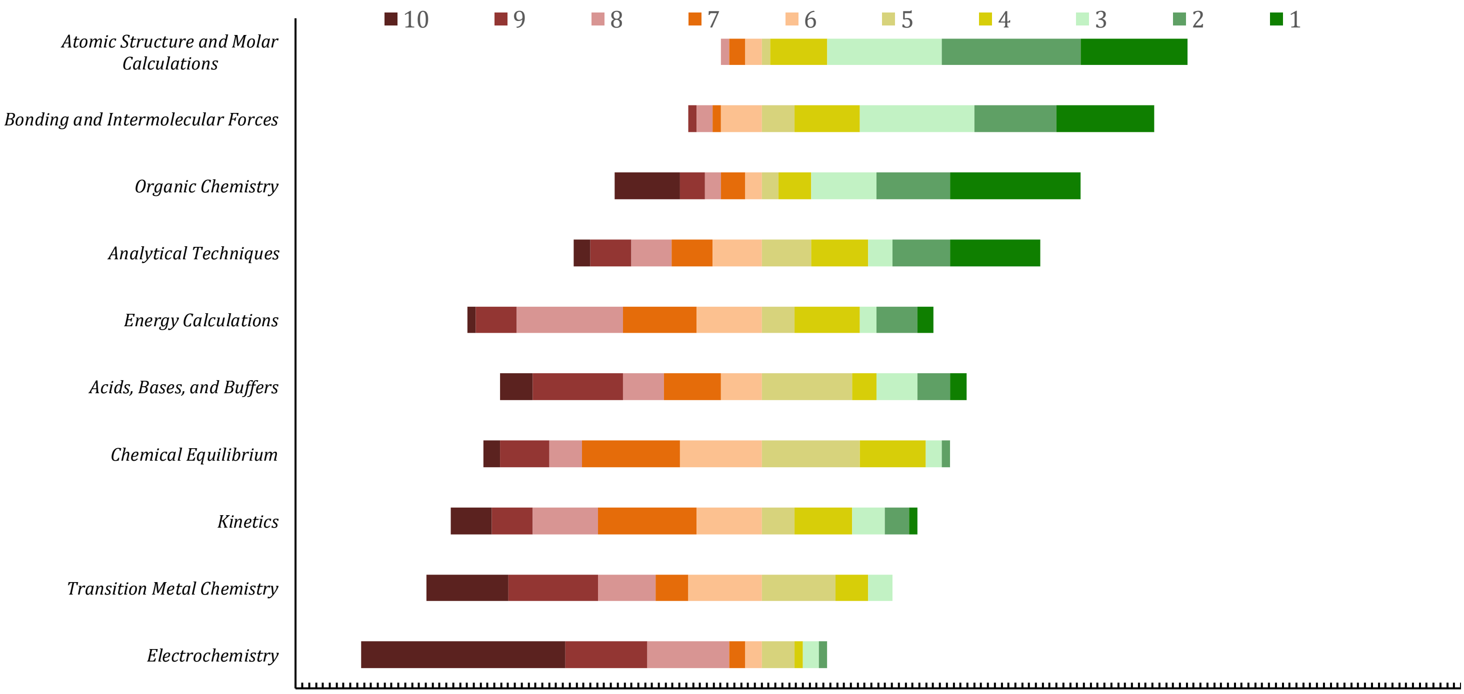

Figure 5.5 Survey participant response to the statement "Please rate your confidence in your ability to teach the ten A level chemistry topics given below from 1 - 10, with 1 being the topic you feel most confident teaching and 10 being the topic you feel least confident teaching" (N = 57). For each topic, the size of each coloured bar corresponds to the percentage of respondents that rated that topic at each rank. Topics are listed from top to bottom from the lowest mean rating to the highest.

There is a great deal of similarity between the results found during the survey phase of the project and those of the interview phase (Figure 4.2). It is immediately evident that the topics of atomic structure and molar calculations, bonding and intermolecular forces, and organic chemistry appear in the top four topics in both sets of results, as well as the fact that chemical equilibrium, transition metal chemistry, and electrochemistry all fall into the bottom four subjects in both sets of results.

Although their positions differ slightly in both datasets, a comparison of the mean results shows that the topics of acids, bases, and buffers (6.6 in interview phase, 6.1 in survey phase) and analytical techniques (5.6 in interview phase, 4.70 in survey phase) have similar average rankings between the two groups, indicating that the results of the interviewees can likely be generalised to the greater teaching population.

Interestingly, the two topics that have more variation between their positions are energy calculations (2^{nd} in interview phase, 5^{th} in survey phase) and kinetics (5^{th} in interview phase, 8^{th} in survey phase). These results may suggest that those who were interviewed had a higher affinity for the mathematical side of chemistry, given the high degree of mathematics required in the teaching and learning of these two topics. This may be supported by the fact that sixteen of the survey participants were non-specialists, who generally ranked these two topics in the bottom half of the ten.

The reasoning behind the selections from survey participants was generally the same as that given by the interview participants. Like Harriet's comments regarding atomic structure, survey participants noted a high degree in confidence in atomic structure and molar calculations due to its fundamental nature within the A level specification. Some representative quotes are included below.

"Underlying concepts which get studied often, so I have lots of practice with it."

"A fundamental topic that you must know well in order to explain and teach and absolutely necessary to the understanding of the rest of chemistry."

As was the case with the interview responses, though organic chemistry was selected more often as a topic of high confidence, there are a considerable number of participants selecting it as a topic of low confidence. Nine of the survey participants commented that organic chemistry was a topic of high confidence because they enjoy the problem-solving nature of it. Some illustrative comments are included below.

"I like structures and mechanisms. There is an element of filling the gaps if you don't know the exact reaction."

"It's possible to see the big picture and get [the students] to understand the key principles that they can then apply."

It is encouraging that a considerable number of participants find this aspect of organic chemistry enjoyable as it is a cause of significant difficulties amongst learners.

Twelve participants ranked analytical techniques amongst their three least confident topics. As observed previously, a lack of experience teaching the topic was observed to be the most-cited explanation for participants' lack of confidence. Two participants reported that the level of study was a cause of low confidence, but for opposing reasons. One participant remarked that the level that it is studied at during the undergraduate degree is "not helpful" for A level teaching, in that it is too in-depth, whilst the other noted that there is a "lack of familiarity from GCSE". One participant mentioned that there is a "lack of good practical [sessions]" to support learning of the topic, making it harder to provide relevance and context to their lessons. Those who remarked that it was a topic of high confidence discussed its relevance to their previous jobs, aligning with the responses given at interview.

Very few survey participants ranked the topics of chemical equilibrium and kinetics amongst their top four topics, with the majority placing them towards the bottom of their rankings. The reasons provided for these rankings greatly aligned with those given during the interview phase. For chemical equilibrium, participants remarked that they did not have as much teaching experience of this topic, as well as finding it difficult to simplify when students were struggling with it. For the kinetics topic, nine participants remarked that the mathematics behind understanding the topic were too difficult to grasp. Some representative explanations are included overleaf.

> *"Some of the mathematical applications solving Arrhenius equations means that it can be difficult to help pupils pinpoint errors."*

> *"Purely Arrhenius equations and rearranging as I only have GCSE level maths."*

These comments are similar to those given by Ethan during the interview phase, where he mentioned the difficulties rearranging formulae and using logarithms. The explicit reference to the Arrhenius equation in these comments further supports the comments made in Chapter 4.7, regarding the need for significant SMK support when A level specifications are changed.

The finding that both transition metal chemistry and electrochemistry appear in the bottom two positions in both the interview and survey phases of this project is a significant one that highlights a general lack of confidence in these topics across A level chemistry teachers of multiple levels of experience and backgrounds. Those with non-specialist degrees were again observed to have a general lack of confidence in transition metal chemistry relative to other topics, with no non-specialist ranking this topic higher than fourth. This is supported by their responses to the survey, some of which are included below.

> *"[Transition metal chemistry] was not part of my degree /PGCE course."*

> *"I did not do this at A Level."*

> *"Not studied in detail at degree."*

A small number of participants (n = 6) cited their lack of experience teaching the topic as a reason for their low confidence, as has been observed with the other topics presented so far. These remarks lie in agreement with the assertion that a teacher's PCK develops with greater classroom experience (Grossman, 1990; Magnusson et al., 1999; Van Driel et al., 2001). As was the case at interview, the primary reason given for the lack of confidence in transition metal chemistry was the amount of rote memorisation required, as exemplified by the below response.

> *"Principally because the level of understanding [required at A level] doesn't really have a lot of explanation behind it. So it feels more along the lines of this is what happens and this is how you apply it. Not much why."*

For electrochemistry, the most common reason given by survey participants for their lack of confidence was that they found the topic difficult when they studied it themselves, either at A level or at undergraduate level (n = 17). Some representative quotes are included below.

"I did not understand electrochemistry during my degree."

"Really disliked at A level. Never truly understood it."

"Negative feelings relating to ability at university to answer questions."

Three participants remarked their unease with electrochemistry due to how it is covered on A level specifications, with one participant stating that the A level "doesn't give satisfactory explanations, so students often ask questions I find difficult to answer". Another participant goes on to say that "the level [of] understanding A level want doesn't really have a lot of explanation behind it, so it feels more along the lines of this is what happens and this is how you apply it. Not much why."

Further to these comments, seven participants reported that electrochemistry can be a confusing topic for students, with a further six remarking that the terminology used can lead to further confusion and the development of misconceptions, supporting the comments made by Gerald during the interview phase. Some representative comments are included below.

"I find that pupils tend to get themselves in a muddle over different rules."

"Brings together equilibrium with a number scale that runs from negative to positive, always seems to cause confusion."

As was the case with Daniel during the interview phase, one survey participant commented on the link between electrochemistry and physics and how this can cause confusion. Their comment is included below.

"There can be conflict with the physics department on precise definitions and my weaker background in electrochemistry means I am less confident with my explanations."

The comment presented here infers that the teaching of fundamental concepts in physics (e.g. the direction of current flow), at both GCSE and A level, may not fully overlap with how electrochemistry is taught at A level. For those who are required to teach both physics and chemistry, this could be especially problematic. As detailed by Garnett et al. (1990), the compartmentalisation of science subjects, (e.g. using different terminologies to describe the same things in physics and chemistry) is a potential cause for misconceptions in electrochemistry, in addition to inadequate prerequisite knowledge. Four further participants reported a lack of interest in electrochemistry as the reason they felt less confident in their ability to teach it.

One participant noted that their lack of confidence arose from the fact that fuel cells are "confusing", and that there are "often errors in published [teaching] resources". Although only mentioned by a single participant, this observation is not unique; Sanger and Greenbowe (1999) conducted an analysis of ten university-level chemistry textbooks, evaluating examples of statements and drawings that could lead to misconceptions. They noted that most analysed textbooks included information that could lead to the development of misconceptions, such as misleading language and terminology (e.g. the implication that individual half-cell potentials are independent of each other) and incorrect electrostatic arguments (e.g. "cation movement in solution is not an electrical current"). They recommend that authors avoid using ambiguous language, and rather that they use simple and direct descriptions of electrochemical processes, in addition to avoiding simplifications (e.g. always drawing the anode as the left-hand half-cell).

5.5.2 Differences in teaching approach between high and low confidence topics

The survey participants were asked to discuss their approaches to teaching their most and least confident topics, and to reflect on the differences (if any) between them. Three survey participants did not respond to this question, whilst six commented that they held a high level of confidence in all topics and therefore could not draw a comparison.

Nine participants reported that there was there was no change in their approach between teaching their high and low confidence topics. One of these participants commented that they try to "follow the same style of teaching throughout", but noted that with those of lower confidence they would "take longer to work out exam questions" and "not be able to extend pupils to the same level as other topics". Another of these participants commented that they try to approach all lessons the same and "make it as interactive for the students as possible" and "get them to reflect on what they are doing", though their own enthusiasm for certain topics (electrochemistry and acid/base chemistry) "may be drooping". One participant commented that they "don't think [they] change [their] teaching approach and that "perhaps this is what

[they] need to do to improve [their] confidence", demonstrating a small level of reflection and suggesting that alterations in approach may cause changes in confidence in SMK.

As was observed previously with most responses regarding transition metal chemistry, the intricacies of exam specifications were discussed by three participants. These responses are displayed below.

> *"I genuinely do not have any issues with any of the A level topics. The only issues I have are with the subtlety of the exam board requirements."*

> *"Extra planning into the more irritating aspects of the syllabus."*

> *"In the lower confidence topics I have a list of specification points to ensure I cover everything on the syllabus. In these less familiar topics it is important to remember what is or isn't required by the specific syllabus, and I am not quite a familiar with these."*

These comments further demonstrate that some teachers have issues regarding their knowledge of certain aspects of A level specifications, and that they lack confidence in whether they can convey all necessary information to their students.

When discussing their approaches to teaching high confidence topics, nine participants mentioned that they provide more examples to their students and are more likely to employ 'stretch and challenge' activities. Some representative quotes are included below.

> *"Probably more exemplification in high-confidence lessons than in lower confidence ones (or at least a higher quality of exemplification)."*

> *"My ability to stretch and challenge my students is so much more with the topics I teach most often."*

> *"High confidence: Less structured, more able to stretch students with challenging questions."*

As was mentioned in Chapter 4.7, in the interview phase Jenny explicitly commented on her concerns regarding the use of 'stretch and challenge' activities with her students in her less confident topics. To investigate whether Jenny's concerns were prevalent amongst chemistry teachers, survey participants were required to respond to statement 5i (shown overleaf).

"I worry that I don't stretch my students enough in topics where I am less confident in my subject matter knowledge." (5i)

The responses are displayed in Figure 5.6.

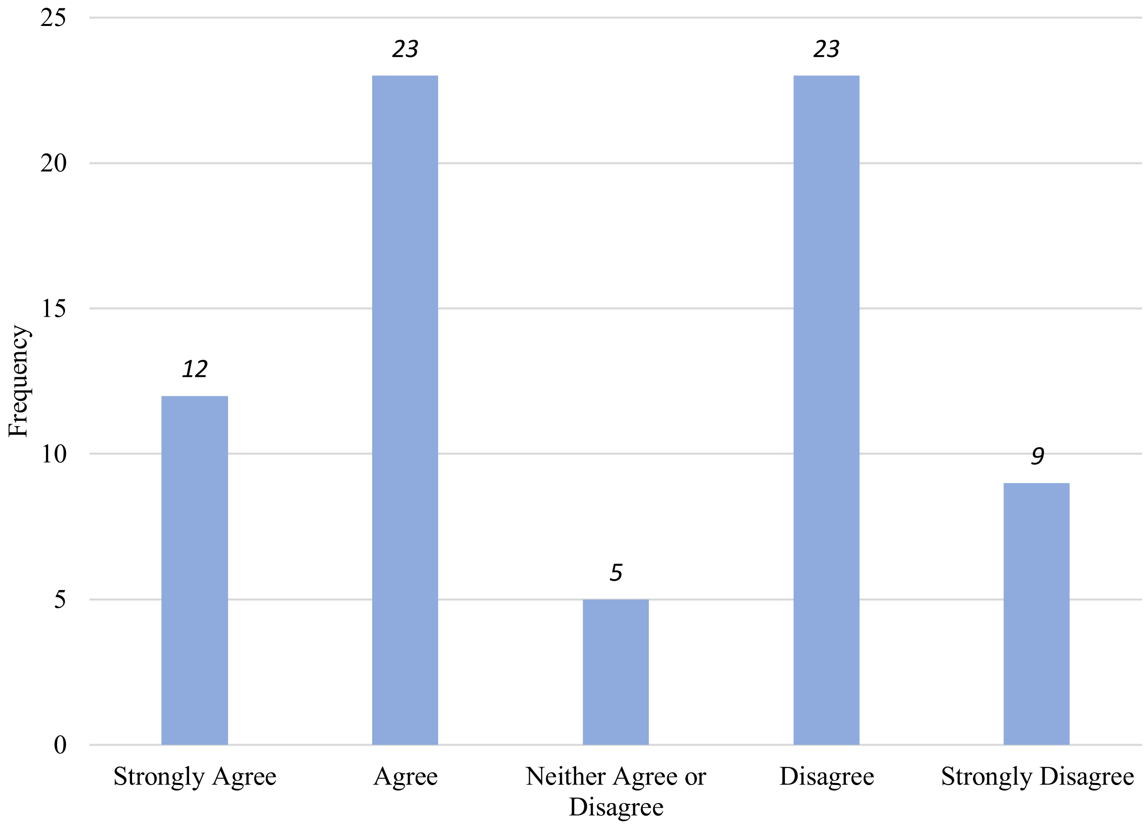

Figure 5.6 Survey participant response to the statement "I worry that I don't stretch my students enough in topics where I am less confident in my subject matter knowledge" (N = 72).

99% of survey participants responded to this item, indicating an excellent response rate. There is a near 50:50 split in response to statement 5i between participants; 48.6% declared agreement, whilst 44.4% declared disagreement. Those who neither agreed or disagreed with the statement reported that they either prepared more for lessons of lower confidence to mitigate any issues (n = 3) or that they were unlikely to use problems and contexts where answers are not immediately obvious (n = 1).

Of the 35 participants who disagreed or strongly disagreed with this item, eight declared that they are confident in all areas of their SMK, and therefore felt no worry with respect to stretching their students. Additionally, six participants who indicated disagreement reported that although they may not feel confident in a topic, this does not affect their ability to obtain and implement higher difficulty questions for their students. One of these participants commented that they "look for challenging examples" for both them and their students.

A further six participants who indicated disagreement with statement 5i reported that their worries were mitigated by the high levels of preparation that they had undertaken for lessons on topics of low confidence. Examples of how these participants prepared for such lessons include revising the topic before teaching it using textbooks and working through exam-style questions themselves to ensure that they understand the content.

Two participants disagreed with statement 5i as although they felt confident in their SMK, they felt as if they did not always have the time in the classroom to implement activities to stretch their students. Their responses are included below.

> *"I worry I don't stretch my students enough because I don't have enough time, or focus on pulling up the bottom end, not because I feel unable to [regarding] subject knowledge."*

> *"I have enough resources gathered and used over 17 years to feel confident that I do stretch students. The only limiting factor is time in the classroom."*

One further participant reported that they do not worry about whether they can stretch their students because they have "excellent colleagues…who can and do help when needed".

Although there were a range of different explanations provided by survey participants, the most prominent theme identified amongst the responses given by those who agreed with statement 5i referred to the application of knowledge to unfamiliar situations (n = 7). Some representative comments are included below.

> *"Less able to give examples and contexts for application (exams are more about application than knowledge these days)."*

> *"If I don't feel like I am confident in the knowledge then it is harder to consider more challenging [questions]."*

These comments indicate that if teachers are less confident in their SMK and their ability to teach certain topics, then they will be limited in their discussions with students of the subject in context, and additionally may also struggle to plan appropriate activities for the teaching of these topics. This is exemplified in another participant's response, where they report that "a lack of confidence in subject matter can lead to a lack of awareness of strategies to approach problems based on it". As mentioned in Chapter 5.4, Kind (2009a) noted that stronger SMK can support a teacher's PCK development and therefore enhance their ability to select appropriate teaching resources, and so it is important to consider the context of concepts when they are being taught to allow for effective application of them to occur.

Despite their agreement with statement 5i, three participants commented that any worries regarding stretching students can be lessened through help from other teachers. One of these participants goes on to say that if a teacher is less confident on a topic, they can "rely on questions that other people have made, rather than being able to construct your own". Although discussion with other teachers, especially those with more experience, can be an effective strategy to learn more about topics of lower confidence (Youens and McCarthy, 2007), relying on questions written by others without an understanding of how to answer them effectively could present risks during lessons, and may lead to the introduction of misconceptions. If this strategy is to be employed by teachers, it is important that they have an awareness of the thought processes in how to answer the question, and an understanding of the underpinning concepts.

Three participants discussed that their worries were based around the A level specification and potential exam questions. One participant noted that they "never know what questions are going to be on exam papers", whilst another reported that they are "sometimes limited by [the] specification" and "struggle to go beyond it or answer questions relating to it". One participant simply stated that in the topics where they lack confidence in their SMK, they find it "harder to stretch beyond [the] specification". Teachers' ability to teach beyond the specification is discussed further in Chapter 5.6.

Two participants made direct reference to having an awareness of what their students know. One participant commented that they "find it hard to stretch students if they do not know the next step they can take", whilst another commented that the "best teachers are not the ones who know the most but the ones who allow students to surpass them". Another participant cited that their worries stemmed from time constraints, remarking that they "feel that [they] could always stretch [their] students further" but that a "lack of time is [their] major issue in this matter.

If a teacher lacks confidence in their SMK in a particular topic, then they may be reluctant to discuss certain aspects of that topic through fear of introducing misconceptions or delivering incorrect information. This is illustrated by the comments below.

> *"I don't want to put myself in a situation where I might need to explain something [that] I don't feel confident in."*

> *"Wouldn't be confident in my own knowledge to answer questions I might give students to stretch them."*

These sentiments, in addition to those discussed in Chapter 5.4, demonstrate that a lack of confidence in SMK may be detrimental to both learning and the teacher's own understanding of a topic, as they may be unwilling to work on their knowledge through fear of misunderstanding. It can therefore be argued that improving teacher confidence in SMK should be a major focus of a teacher's development, both in their ITT and throughout their career.

Returning to the discussion of the differences between teaching high and low confidence topics, eight participants reported that when teaching high confidence topics their lessons are more personalised, and that they can easily adapt their own individual teaching style, with four participants mentioning that they are more likely to be flexible in their approach. Some representative comments are included below.

> *"High confidence: I tend to teach in quite an 'explorative' way - starting out with the student's ideas and bring them together, developing them and moving them towards the accepted models."*

> *"With more confident topics I rely less on PowerPoints with information and allow myself to talk more."*

> *"More likely to plan adventurous, different, challenging and stimulating activities for topics I'm confident in."*

Conversely, nine participants reported that when teaching low confidence topics their lessons were more formulaic, with less scope for flexibility in the lesson plan. Representative comments are included below.

> *"Low confidence topics are much more highly planned and therefore less flexible. There are occasions where I do not know the answer to a high level question, and although I have no problem saying, "let's both look that up tonight and talk about it tomorrow", I would rather not have to!"*

> *"In general, I spend more time looking up the breakdown of the low-confidence topics and have more structured tasks as opposed to the high-confidence topics."*

> *"Low confidence topics tend to be more formulaic and more closely follow the specification."*

Further to these comments, references to following the specification were observed in six participants' responses, and five participants commented that in teaching low confidence topics their lessons were more "content-heavy" and relied more on resources, most notably PowerPoint presentations and pre-made worksheets. Childs and McNicholl (2007) noted that teachers did not possess the necessary knowledge to select appropriate resources when planning lessons beyond their specialism. The findings of Childs and McNicholl present a potential issue; if teachers are less confident in their SMK of certain topics, they are more likely to rely on resources, but are unlikely to possess the necessary knowledge to select appropriate resources for these lessons. It can be recommended, therefore, that attention should be given to selecting appropriate teaching/learning resources when delivering activities centred on SMK development, during both ITT and CPD sessions.

Similarly, these outcomes corroborate the findings of Hashweh (1987), who observed that biology and physics teachers planned their lessons around the textbook when teaching outside of their specialism. Additionally, Hashweh observed that specialist teachers had a stronger ability to link concepts between subjects than non-specialists. Given that some of the responses above were provided by specialist chemistry teachers, it can be argued that this phenomenon is not only limited to non-specialists, but also those who lack confidence in their ability to teach certain topics within their specialism.

With reference to teaching high confidence topics, two participants stated that they had a greater awareness of potential misconceptions and issues that students may encounter. Their comments are included overleaf.

"I'm more aware of common misconceptions and how to anticipate them."

"With the high confidence topics I have taught these multiple times, have recognised in part where issues might lie and hopefully can overcome these."

These comments align with those made by Gerald in the interview phase of the project, providing further evidence supporting the importance of strong SMK in teaching and the importance of possessing a deep knowledge of learners (Magnusson et al., 1999).

As was also found in the interview phase of the project, the most common theme regarding the teaching of low confidence topics was that participants felt they needed to spend more time preparing and planning their lessons than they did for topics they were more confident in (n = 22). The same strategies to those discussed at interview were reported during the survey phase, namely past exam questions and reading published resources.

5.6 Teaching to the A level specification

To investigate whether the views of the interviewed participants were aligned with a greater teaching population, survey participants were also asked for their views on the limits of teacher SMK within the context of the A level chemistry specification. They were invited to respond to statement 5j, given below, using a five-point Likert type scale, explaining their responses afterwards.

"It is an issue if an A level chemistry teacher's subject matter knowledge is limited to the A level specification." (5j)

The responses to this statement are given in Figure 5.7.

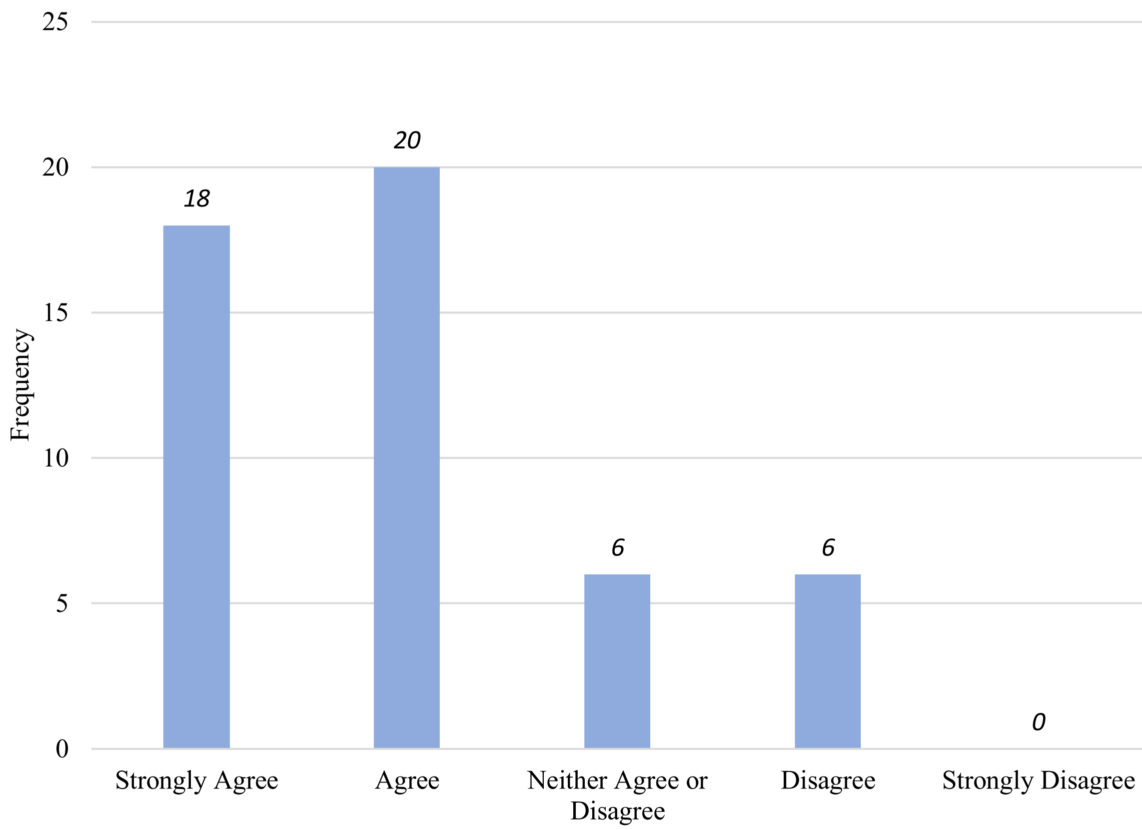

Figure 5.7 Survey participant response to the statement "It is an issue if an A level chemistry teacher's subject matter knowledge is limited to the A level specification" (N = 50).

98% of participants responded to the statement, indicating a good response rate. As was observed during the interview phase of the project, most participants (76.0%, n = 38) declared agreement with statement 5j, whilst only six participants declared disagreement with the statement. Six participants neither agreed nor disagreed with the statement, with three of them commenting that although a wider understanding of the subject is beneficial, it is not necessary, aligning with the responses provided by Gerald and Ethan. Additionally, one of these six participants stated that "a good teacher will make links outside the [specification] anyway", whilst another commented that it "depends on the teacher and what they are prepared to do to reach that level of umbrella understanding to teach the subject as a whole rather than as different topics".

Of the six participants who disagreed with statement 5j, two of them referred to A level examinations in their responses. Their comments are depicted below.

"You need to be firstly an expert in the knowledge required to pass the exam."

> *"In terms of exams, I don't think it is a problem. Students can still be taught well, and further information can be gained from books/the web if the inclination is there."*

These participants place emphasis on students being able to pass the examination, which ultimately is how their knowledge of the A level course is assessed. If a teacher's principal focus is ensuring that students pass their examinations, then this is an understandable perspective to possess. However, these comments solely deal with their beliefs regarding examinations, and do not further delve into the other aspects of teaching; for example, can the same be said regarding understanding of the material, and should a teacher have an appreciation of how the content of the specification can be applied in a real-world context? Irrespective of these teachers' perceptions on these matters, the importance of examinations should not be ignored and is critical to consider when discussing where the level of a teacher's SMK should lie. No other prominent themes were identified in the responses of those who disagreed with statement 5b, although four of these participants were chemistry specialists.

As was observed in the interview responses, the importance of being able to 'stretch and challenge' students beyond the specification was the most common theme identified (n = 28). Some representative comments are included below.

> *"They cannot easily respond to unexpected questions from students. It is also difficult to make connections to other subjects such as physics or biology. Enthusiasm has to be conveyed as well as confidence in you as a teacher. This would not be very likely if only the specification is known."*

> *"You need to be able to think where a concept is heading and stretch pupils in that direction."*

> *"Chemistry is more than just A level. How can you inspire pupils to go to study in areas that involve Chemistry if you know nothing about it? How can you extend their knowledge? How can you adequately prepare them for University applications? You have no further knowledge to link what the pupils are meant to learn with real life applications to help them understand."*

The last of these comments concentrates on the fact that chemistry is wider than the A level specification and that this context must always be appreciated when teaching the subject.

To quote one experienced participant, only having knowledge up to the limits of the specification is "like saying that someone can teach a tennis player to serve effectively if all they can do themselves is serve. You need to know how it fits into the game as a whole in order to produce a serve that is really effective".

Seven participants discussed the importance of confidence and enthusiasm in the subject matter in their responses. Two representative comments are included below.

> *"They will lack the confidence to answer questions students might raise or give enrichment examples."*

> *"Interested pupils need a confident teacher who possesses solid subject knowledge."*

These comments refer to those students who are interested in chemistry and ensuring that their queries can be answered by their teachers, also discussed by Hannah, Gerald, and Kenneth during the interview phase. These comments further highlight the importance of ensuring that A level chemistry teachers are as confident in their SMK as they can be, and that they possess knowledge of relevant contexts to maintain student interest.

Four participants declared agreement with statement 5j as they believed it important for teachers to be able to make links to other areas of science, both within and beyond chemistry itself. One of these participants noted that a teacher "should be able to relate the topics to each other and understand how chemistry fits together as a whole", remarking that "the syllabus does not allow for this adequately enough". A further four participants reported that a wider understanding of chemistry is beneficial to teaching chemistry, with one participant noting that "degree level knowledge is more useful and makes more effective A level teachers", aligning with the beliefs discussed by Ethan during the interview phase.

As has been discussed previously, a strong SMK allows for chemistry teachers to be more prepared when changes are made to the A level specification. Two participants remarked that it is necessary for teachers to possess SMK beyond the specification as specification changes often result in the addition of new content, and very rarely result in content leaving. One of these participants also referred to PCK, noting that "it is also difficult to have good pedagogical content knowledge if your pure content knowledge is limited", lying in agreement with previous studies (Rollnick et al., 2008; Van Driel et al., 2014). One other participant commented on the role of models in A level chemistry teaching, noting that if teachers fail to recognise this "and [are unable] to explain why these models are as they are (by having a more sophisticated understanding), then [teachers] can lead [students] down blind alleys". The use of models, namely the octet rule and Le Chatelier's principle, is discussed further in Chapter 5.7.

Three participants who agreed referred to examinations in their responses to statement 5j. These comments are given below.

> *"I think it's important for teachers to have a knowledge of chemistry broader than that presented in exam specifications. The specification is what students can be asked about in exams, but shouldn't be the limit of what is taught."*

> *"It would be difficult to fully explain the content and application-based exam questions in addition to being able to answer student questions if the subject knowledge were limited to A level."*

> *"In the current exams series, you need to draw on all your experiences when dealing with application questions."*

These responses demonstrate how certain questions in the A level examination require application of knowledge to unfamiliar situations, and as such teachers should have strong SMK to support their students with these more difficult questions, as was also observed in the interview responses provided by Martin and Rebecca.

In Chapter 4.8, the views of Martin, Richard, and Roland with respect to the role of SMK and examinations within the chemistry A level were also discussed. To investigate whether their views were shared by other teachers, survey participants were invited to respond to statement 5k, given below, using a five-point Likert-type scale, and asked to briefly explain their responses.

> *"Generally, I feel that I am teaching my students to understand chemistry rather than teaching them how to answer exam questions." (5k)*

The responses to this statement are shown in Figure 5.8.

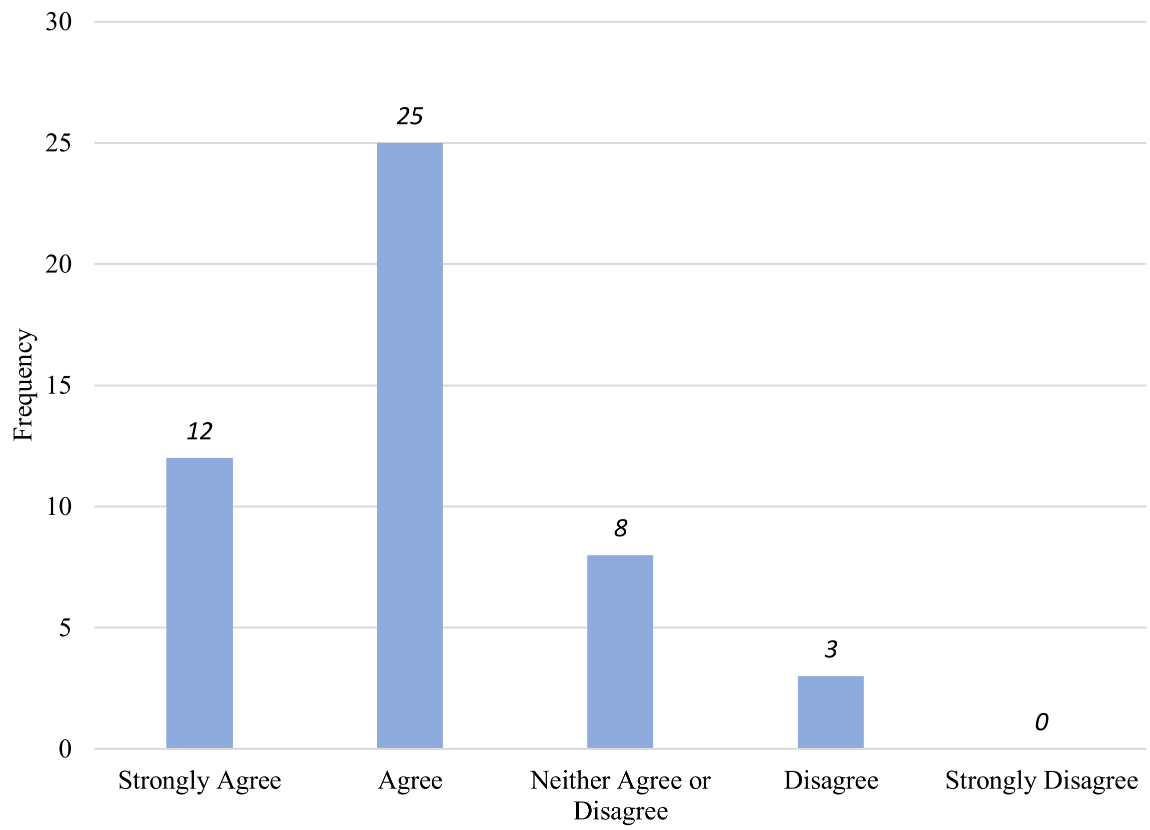

Figure 5.8 Survey participant response to the statement "Generally, I feel that I am teaching my students to understand chemistry rather than teaching them how to answer exam questions" (N = 48).

94% of participants responded to statement 5c, indicating a good response rate. Most participants (77%, n = 37) agreed or strongly agreed that they feel they are teaching their students to understand chemistry as opposed to teaching them how to answer exam questions. Only three participants disagreed with the above statement, whilst eight participants neither agreed nor disagreed. Of those who selected the "neither agree or disagree" option, five participants commented on the necessity of both in A level chemistry teaching. One of these participants expressed positive feeling towards this, commenting that "the more rounded you can be outside the syllabus the greater chance the student has of being able to confidently [answer] A* questions", whilst two of these five participants provided responses indicating a negative feeling towards this matter. Their comments are included here.

> *"As teachers are purely measured on their students' results and not on their teaching, you have to drill the students to regurgitate typical answers."*

"Sadly important to do both - exam technique gets them grades but knowledge gets them engaged."

In addition to these concerns, three of the participants who selected the "neither agree or disagree" option commented on school pressures, with one participant reporting that "the most important concern of colleges is retention and achievement, which is how schools and colleges are judged". A further participant commented on the time constraints of the A level qualification, noting that "there simply is not time with the amount of content in a specification to explore ideas".

Of the three participants who declared disagreement with statement 5k, two of them discussed the influence of student interest. Their comments are included below.

"There is not enough time to teach outside the spec and students are reluctant to listen to things they think they don't need to know."

"The majority of my students are not going onto a chemistry degree, therefore they are only really interested in getting as good a grade as possible."

These participants' comments demonstrate the perception that the students lack interest in the subject, and that their sole interest lies in passing the examination. It is, of course, very important for students to pass their examinations, but this attitude may lead towards an emphasis on rote learning and other ineffective learning strategies, potentially causing detriment to students' later education regardless of the subject they study at undergraduate level. In contrast, the other participant who disagreed with statement 5k noted that in teaching A level chemistry, they ensure that their students have both a good understanding of the chemistry and a strong awareness of exam technique, ensuring that they can apply their knowledge effectively and "succeed in the papers". All three participants who disagreed with statement 5k were chemistry specialists and all had at least four years of experience teaching the A level course.

Of those who agreed or strongly agreed with statement 5k, nineteen participants reported that in their teaching of A level chemistry, they consider student understanding to be more important than directly focusing on the examinations, with many also commenting that a deep understanding leads to a strong ability to answer questions, as was previously noted by Martin during the interview phase. Some representative comments are included on the next page.

> *"It is not possible to cover every eventuality with questions so the underlying principles are most important."*

> *"If you can understand the chemistry, you can answer the exam questions. Sure, there are occasional exam board idiosyncrasies, but these aren't that common. When students talk about wanting to understand better what the mark scheme wants they are often missing the point. It's their own understanding of the topic that actually needs improving. The mark scheme stuff will then take care of itself."*

As was noted by those who disagreed with statement 5k, five participants who agreed also commented on the students' interests, particularly in ensuring that they pass the examination, potentially leading to a disregarding of understanding. Some representative comments are included below.

> *"My teaching is mainly based on a deeper understanding of the concepts required and the best ways to teach them. They want me to teach them to pass the exam but that's not why I went into teaching."*

> *"This was always my intention, bringing the exam technique in as a polish rather than the foundation. Increasingly, though, more students want to know the answer on the mark scheme than understand how to get there (and so prepare for similar but subtly different questions in future)."*

These comments highlight the concerns discussed previously, in that due to the nature of assessment, students have been observed by their teachers to develop unfavourable strategies towards learning the content. Conversely, four of the agreeing participants reported that they try to go beyond the specification in their teaching, in order to help their students understand the specification content to a greater extent. All four of these participants had at least four years of experience teaching A level chemistry, with three of them possessing over sixteen years of experience, possibly demonstrating a higher level of curriculum knowledge and PCK with experience (Magnusson et al., 1999; Van Driel et al., 2001).

Two participants referred to rote learning in their responses, and its negative impacts in A level chemistry. Their responses are included on the next page.

"Now I can teach them to understand the mechanisms, whereas I just memorised them."

"I think real excellence can only be achieved my instilling an understanding. A level Chemistry is very difficult if a student relies on rote learning rather than developing the ability to think and problem solve."

These comments lie in agreement with previous research. Problem-solving is a crucial aspect of A level chemistry, with numerous references being made by participants to examination questions that require students to apply their knowledge to a novel situation. Equally, beyond the A level, the role of a chemist in research or industry can be expected to rely on a significant amount of problem-solving. As was noted by Hilgard et al. (1953), students who develop a deeper understanding of a subject can apply their knowledge to problem-solving activities with a higher degree of success than those who have learnt by rote, whilst Henderleiter et al. (2001) demonstrated that rote learning may cause students to develop misconceptions in organic chemistry.

5.7 Models, analogies, and limitations

Based on the responses from participants during the interview phase of the project, a set of deeper questions were asked during the survey phase of the project to investigate A level chemistry teachers' use of models and analogies in their teaching, specifically in the topics of the octet rule and Le Chatelier's principle. Further rationale for this further investigation is included below.

5.7.1 The octet rule

One model commonly used in teaching A level chemistry is the octet rule. The octet rule can be generally attributed to both Gilbert Lewis and Walther Kossel, who both suggested that in atoms of the noble gases, an eight-electron outer shell is more stable, whilst elements with atomic numbers close to those of the noble gases will tend to achieve these electron configurations when bonding (Kossel, 1916; Lewis, 1916). Although this model is useful, it does not always hold true (Gillespie and Silvi, 2002); numerous compounds, including phosphorous pentachloride (PCl_5) and sulfur hexafluoride (SF_6), do not exhibit this phenomenon, and form what are termed hypervalent molecules (Musher, 1969).

The existence of hypervalent molecules, where the central atom is said to 'expand its octet', can cause problems in A level chemistry education. Fundamentally, the octet rule is one of the first things to be taught on an A level chemistry course, as it allows for the student to gain an appreciation of atomic structure and chemical bonding. The existence of exceptions to this rule can therefore be problematic for students, with issues potentially arising from the methods through which it is explained. Taber (1995) noted that the octet rule is a common cause of misconceptions in chemistry students.

As there is limited discussion of why most compounds form structures with a complete octet, the use of anthropomorphic language is often used by both teachers and students to explain this phenomenon, e.g. "a sodium atom is *lending* chlorine one of its electrons"; "fluorine's *being greedy trying to grab* two electrons" (Taber and Watts, 1996). The use of anthropomorphic language can lead to the development of misconceptions, such as the belief that a reaction will proceed simply because the species involved 'want a full outer shell' (Taber, 1998).

Based on the fundamental nature of this model in the teaching of A level chemistry, and to see whether teachers had an awareness of the issues with this model, it was deemed valuable to ask survey participants whether they believed that the octet rule had any limitations (Table 5.7), and if so, what those limitations are.

Response	**Number of Respondents**
Yes	*48*
No	*0*
Not sure	*2*

Table 5.7 Survey participants' responses to the question "Personally, do you feel that there are any limitations to the octet rule?" (*N* = 50).

98% of participants responded to this question, indicating a good response rate. Nearly all of the survey participants believe there to be limitations to the octet rule, whilst the two participants who reported that they were not sure explained that they did not understand the question. Both of these teachers were experienced chemistry specialists.

Survey participants were required to explain their answers to the question above, and their responses were coded thematically. Most participants (n = 38) commented on the inconsistencies with the octet rule and the many exceptions to it, with specific reference made to hypervalent molecules and those which do not satisfy the rule (e.g. BF_3). Thirteen participants referred to the discrepancies between the GCSE and A level specifications. On GCSE specifications, the octet rule is applied to the bonding of elements with atomic numbers equal to or lower than calcium ($Z = 20$), with limited to no discussion of the exceptions to the rule. On A level specifications, students are required to understand that some elements can 'expand their octet' when bonding. As one participant wrote, "students learn that this is true for all elements…and then have to unlearn that" when they study the A level course, which can result in the development of misconceptions.

Eight participants made direct reference to misconceptions or an incorrect understanding in chemical bonding in their responses. Some exemplary comments are included below.

> *"It prevents students from truly understanding the role of electrostatic attraction in bonding. They don't understand what a chemical bond is if they have been taught using the octet rule."*

> *"The octet rule has to be dismissed very early on, otherwise it can limit students understanding of spd notation for example."*

One of these eight participants further noted that the use of the octet rule as an indisputable law also leads to the "personification of particles, with students saying that they 'want' to have eight electrons in their outer shell", further endorsing the findings of Taber and Watts (1996).

It is positive to see that most participants are aware of the issues involved in teaching the octet rule, displaying an awareness of previous research, and highlighting an understanding of misconceptions that could be introduced through teaching this model. If the octet rule is being used to solve problems and explain bonding theory, therefore, an understanding of the limitations of the model is required. As a result, survey participants who agreed that the octet rule has limitations were asked to respond to two statements (5l and 5m) using a five-point Likert-type scale, reporting whether they believed that the limitations of the rule should be taught and discussed at both GCSE and A level, respectively (Figure 5.9). These statements are given in full below.

"The limitations of the octet rule should be taught and/or discussed at GCSE level." (5l)

"The limitations of the octet rule should be taught and/or discussed at A level." (5m)

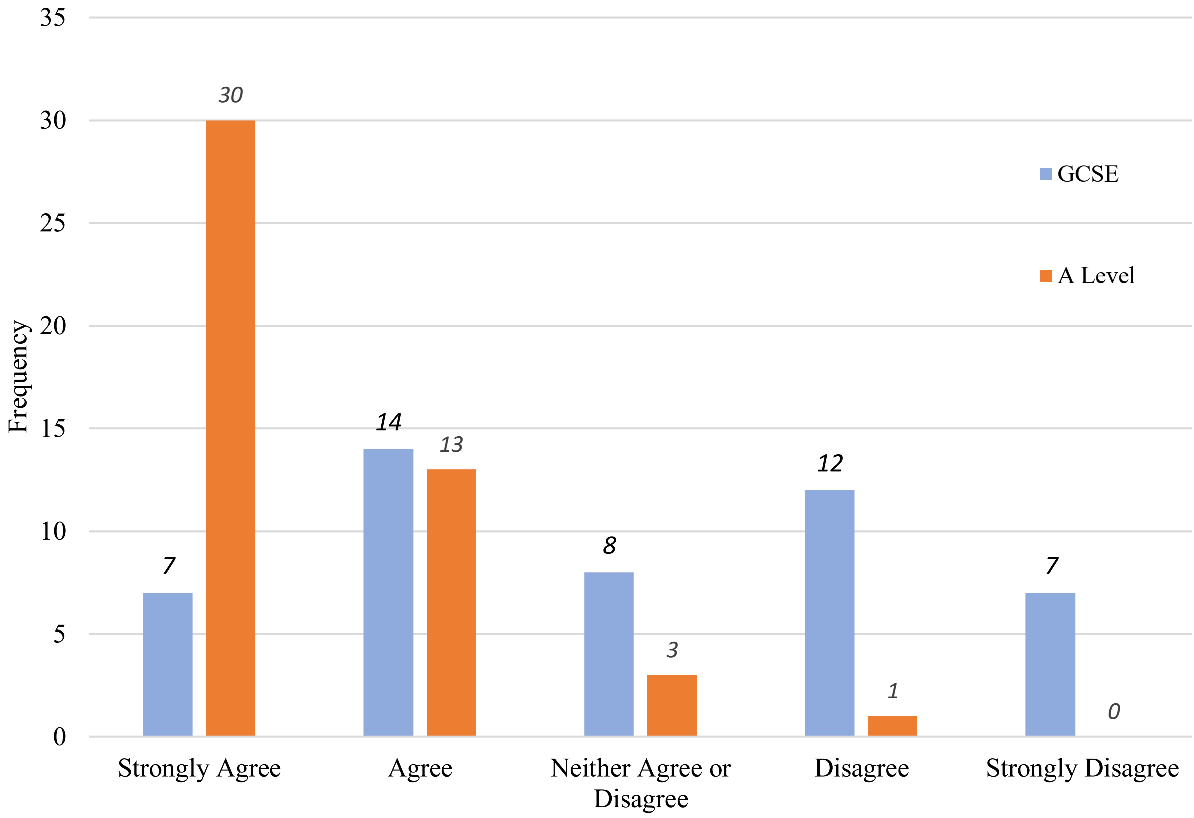

Figure 5.9 Survey participant response to the statements "The limitations of the octet rule should be taught and/or discussed at **GCSE level**" (N = 48) and "The limitations of the octet rule should be taught and/or discussed at **A level**" (N = 47).

100% of eligible participants responded to statement 5l, whilst 98% responded to statement 5m, indicating an excellent response rate. Though it is immediately noticeable that most participants (91.5%, n = 43) agree that the limitations of the octet rule should be discussed at A level, only 21 participants (43.7%) agreed that they should be discussed at GCSE level.

Of those 21 respondents, sixteen commented that at both GCSE and A level it is important for students to realise that the models used to explain chemical concepts have limitations. The general view of these respondents is that the limitations of the octet rule should simply be mentioned at GCSE, without going into specific details, whilst at A level limitations should be discussed in more depth and further explained. Fourteen participants noted that exceptions and expansions to the theory behind the octet rule should be included in A level teaching. Furthermore, one participant noted that when teaching chemical bonding at A level, they do not teach the octet rule. As a result of this, this participant reported that "[the students] get a proper understanding of bonding [and the teacher does] not have to undo everything at A level".

Two participants commented that although the limitations of the model should be discussed at GCSE and A level, this should not necessarily be assessed. Although this is a reasonable suggestion, if these limitations were not assessed, they may not appear on A level specifications. If a teacher's knowledge is limited to the A level specification, then they would be unaware of these limitations, and so this could cause issues and lead to the development of misconceptions if left unconsidered. This provides further support for the assertion that a teacher's SMK should lie beyond the specification.

Of the nineteen participants who disagreed or strongly disagreed that the limitations of the octet rule should be discussed at GCSE level, ten explained that this would be too difficult or confusing for students at this level. Further to this, seven participants reported that these limitations are not relevant to most of their students, as only a small number go on to study chemistry at A level (and possibly beyond), whilst two participants stated that there is already too much content to consider at GCSE level. Sixteen of the nineteen participants who disagreed with statement 5l proceeded to declare agreement with statement 5m, whilst two of them later selected the "neither agree or disagree" option. The other participant also disagreed with statement 5m, commenting that most teachers would "point out that a thermodynamic preference leads to bonding".

5.4.2 Le Chatelier's principle

As was discussed in Chapter 2, there are numerous misconceptions surrounding the topic of chemical equilibrium. Some of these misconceptions may derive directly from Le Chatelier's principle, which states that if a change is applied to a system in chemical equilibrium, the equilibrium (or position of equilibrium) will shift to counteract the change. Gold and Gold (1985) reported that the way in which the principle is written can invoke different meanings and could therefore lead to the development of misconceptions. For example, the word 'counteract' in the definition given here is sometimes replaced by the word 'minimise', two words with similar but not identical meanings. Similarly, Pedrosa and Dias (2000) observed that the terminology used to describe Le Chatelier's principle in chemistry textbooks in Portugal could be one of the main caused for misconceptions, as was also noted in the context of electrochemistry (Sanger and Greenbowe, 1999).

Benedicks (1922) commented on the conceptual problems that may be caused through teaching using Le Chatelier's principle, whilst other notable scientists remarked that the principle lacks precision and can be ambiguous in its use (Ehrenfest, 1911; Planck, 1934). These concerns, coupled with the findings reported in Chapter 2.4, strongly indicate that there are limitations associated with using Le Chatelier's principle to explain chemical equilibrium. Although the principle allows for a person to predict how the position of equilibrium will shift when a change is enacted on a chemical system, it does not provide an explanation of why this shift occurs.

Le Chatelier's principle is often used in teaching chemical equilibrium at A level and is mentioned explicitly on the specifications of two of the four major specifications in the United Kingdom (OCR, 2014a; OCR, 2014b; AQA, 2015; Pearson, 2016). Based on its prevalence in teaching the subject, and given its issues, it was deemed valuable to ask teachers whether they believed that Le Chatelier's principle had any limitations (Table 5.8), and if so, what those limitations are.

Response	**Number of Respondents**
Yes	*28*
No	*12*
Not sure	*10*

Table 5.8 Survey participants' responses to the question "Personally, do you feel that there are any limitations to Le Chatelier's principle?" (*N* = 50).

98% of participants responded to this question, indicating an excellent response rate. The response to this question differs greatly to the response regarding the octet rule, with only 56.0% of respondents (n = 28) declaring awareness of the limitations of Le Chatelier's principle.

The most prevalent theme amongst the responses of those who felt that there were limitations was that the principle is not always applicable, and that there can be exceptions to its use (n = 13). One participant expands on this comment, stating that it "does not apply to certain systems" and that "going through *Q* [the reaction quotient] is so much better". The use of mathematics in explaining equilibrium processes was noted by one other participant, who remarked that "a better understanding is developed by looking at the mathematics".

Four participants commented that even though it is a method of predicting what will happen, it is often used as an explanation or cause of the processes involved in equilibrium changes. As was observed with the octet rule, one participant noted the issue of anthropomorphism in misapplication of Le Chatelier's principle. Their response is included below.

> *"It is only a means to predict outcomes, it does not explain. 'High temp favours endothermic direction' suggests that the molecules discuss what they should do!"*

Four participants referred to how particular aspects of the principle can influence the development of misconceptions. Two of these participants discussed how the wording of the principle can cause confusion, aligning with the assertions of Gold & Gold (1994) and Pedrosa & Dias (2000). One participant also remarked that the definition of a closed system can also cause confusion for students.

Of the twelve participants who felt that Le Chatelier's principle does not have any limitations, eight of them reported that it is suitable for the A level standard as it is, implying that the limitations should only be appreciated when coming to study chemical equilibrium at undergraduate level. One of these participants commented that "students seem to struggle with this principle", but "sees no limitations in what [they] are required to teach", although they did not elaborate on what particular aspects their students struggled with. No other prominent themes were observed amongst these participants. Four of these twelve participants were non-specialists.

Four of the ten participants who responded that they were "not sure" to the question above reported that they had not encountered any limitations in their learning and teaching so far, although one of them commented that chemical equilibrium is "very abstract". One other participant noted that students sometimes forget that kinetics also play a role in chemical equilibrium, because this does not tend to be discussed at A level. A further participant noted that the principle is suitable for both GCSE and A level teaching but did not elaborate further on their response. Five participants who stated that they were not sure whether Le Chatelier's principle has any limitations were non-specialists, whilst three participants could be described as relatively inexperienced (<3 years).

Based on the findings reported in Chapter 2.4, it is not surprising to see that only a small majority of participants are aware of the limitations of using Le Chatelier's principle in teaching chemical equilibrium. It is also notable that most of the non-specialist participants in this study selected either "no" or "not sure" as their answers, further indicating that resources or CPD discussing the limitations of models and minimising student (as well as teacher) misconceptions would be of value in the topic of chemical equilibrium.

Based on the findings above, survey participants who agreed that Le Chatelier's principle has limitations were asked to respond to two statements (5n and 5o) using a five-point Likert-type scale, reporting whether they believed that the limitations of the rule should be taught and discussed at both GCSE and A level, respectively (Figure 5.10). These statements are given in full below.

"The limitations of Le Chatelier's principle should be taught and/or discussed at GCSE level." (5n)

"The limitations of Le Chatelier's principle should be taught and/or discussed at A level." (5o)

100% of eligible participants responded to these survey items, indicating an excellent response rate. The responses to statements 5n and 5o show a similar distribution to the responses to statements 5l and 5m, indicating a general agreement that the limitations of Le Chatelier's principle should be discussed at A level but not at GCSE level. Of the thirteen participants who disagreed with statement 5n, six commented that it would be too difficult to discuss this concept at GCSE level, with some noting that "confusing GCSE students too much" should be avoided.

A further four participants noted that Le Chatelier's principle gives students a "good starting point" that can then be built upon at A level. One of these participants commented that it is good that "a qualitative approach [is] taught at GCSE, which can be built on quantitatively at A level".

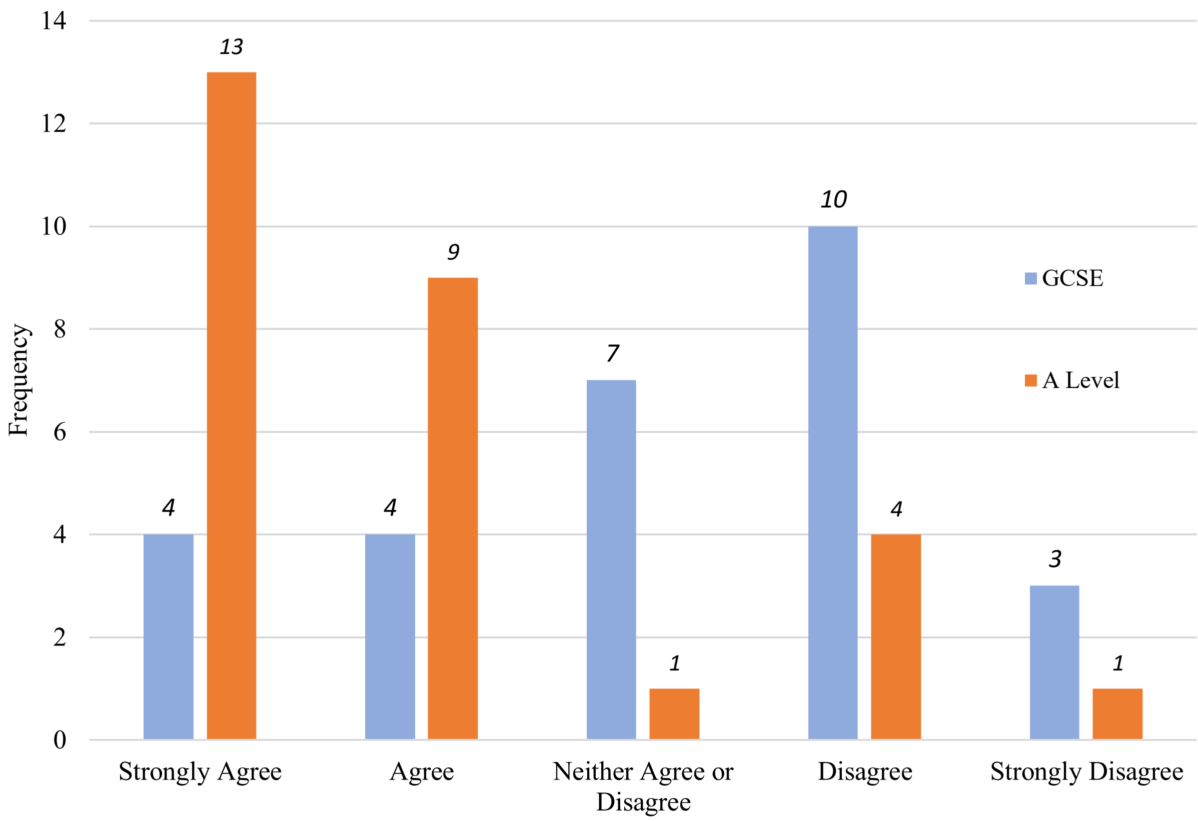

Figure 5.10 Survey participant response to the statements "The limitations of Le Chatelier's principle should be taught and/or discussed at **GCSE level**" (N = 28) and "The limitations of Le Chatelier's principle should be taught and/or discussed at **A level**" (N = 28).

Three participants stated in their responses that Le Chatelier's principle should be removed from GCSE specifications altogether, explaining that it is too complex and conceptually challenging. One of these participants noted its difficulty for students aiming for a 4-6 grade, whilst another reported that it is too complex for all GCSE students to gain a solid understanding.

Of the eight participants who agreed that the limitations of Le Chatelier's principle should be discussed at GCSE level, four remarked that it is important for students to appreciate the limitations of models. One of these participants further explained that at GCSE level, limitations should only be discussed with "more able" students. One participant summarises this general view succinctly, stating that "if something is just a limited model that permits predictions to be made in limited contexts then it should be explicitly introduced in that way".

Similar to the responses observed above, three of the seven participants who selected "neither agree or disagree" in response to statement 5n reported that the principle is too difficult to discuss at GCSE level, unless they are considered with "more able" students. One participant again noted that although the GCSE model is suitable for its purpose, it should not be considered an explanation, further stating the importance of quantitative considerations when teaching the principle at A level.

22 participants agreed that the limitations of Le Chatelier's principle should be discussed at A level. Analogous to those who agreed with statement 5n, the most common theme noted in explanatory responses was that it is important for students to understand that models have limitations (n = 11). Three participants noted in their responses that discussion of limitations is more sensible to approach with A level students rather than GCSE students, whilst two participants further commented on the importance of taking a quantitative approach to solving problems surrounding chemical equilibrium.

Of the five participants who disagreed with statement 5o, two reported that students may find it too difficult. These participants explained that it is "easier to lose weaker students" when explaining equilibrium and that the principle does not need to be elaborated further if students are not choosing to pursue chemistry beyond A level study. As seen previously, one other participant commented on how developing an understanding of K_c will naturally lead to an awareness of the limitations of Le Chatelier's principle.

5.7.3 Use of analogies in A level chemistry teaching

Models such as the octet rule and Le Chatelier's principle are intrinsic in chemistry A level specifications and are included to ease students into concepts and give them a foundational understanding, allowing for these ideas to be built upon later. Alongside models, analogies are often used by teachers to explain concepts, allowing their students to find abstract ideas more relatable to what they already know. Unlike models, however, analogies tend not to be included in specifications and rather are constructions of teachers themselves, based either on experience or real-time decision making. If analogies are unfit for their purpose, then they may cause the development of misconceptions, such as atoms and molecules having anthropomorphic characteristics (Taber, 2000; 2002).

Based on comments made by participants during the interview phase of the project during discussion of high and low confidence topics, it was deemed appropriate to undertake a brief analysis of teachers' usage of analogies and how they are implemented into their teaching.

Survey participants were asked to respond to statement 5p using a five-point Likert-type scale. The responses are displayed in Figure 5.11.

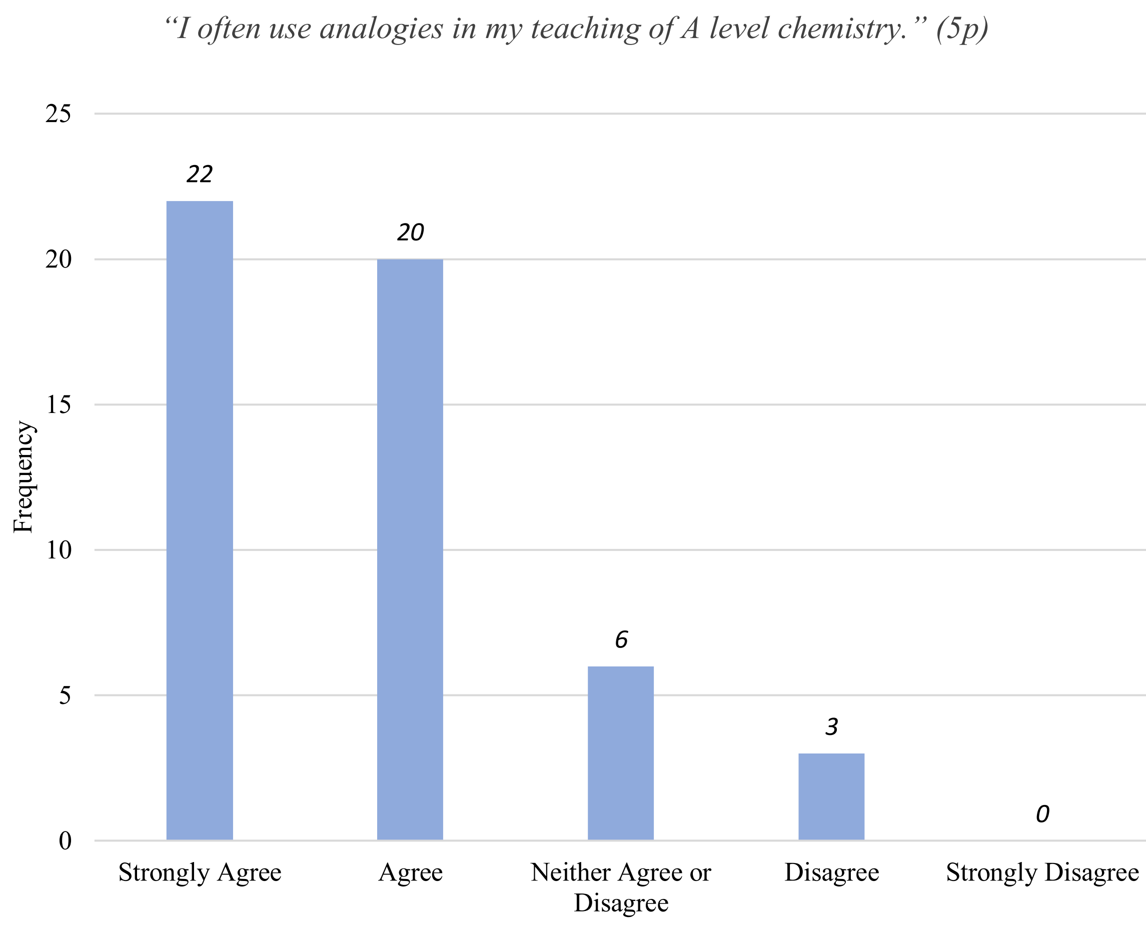

Figure 5.11 Survey participant response to the statement "I often use analogies in my teaching of A level chemistry" ($N = 51$).

100% of survey participants responded to this item, indicating an excellent response rate. Most participants (82.4%, n = 42) reported that they use analogies in their chemistry teaching on a regular basis, whilst only three participants reported that they did not. Those who reported that they did not were all subject specialists but had varying levels of experience, not exceeding ten years.

To investigate whether there were any self-reported patterns between confidence in SMK and usage of analogies, survey participants were required to respond to statement 5q using a five-point Likert-type scale and were invited to explain their responses afterwards. Their responses are displayed in Figure 5.12. Interview participants' discussions of analogy usage are also considered, under the themes identified in the obtained survey responses.

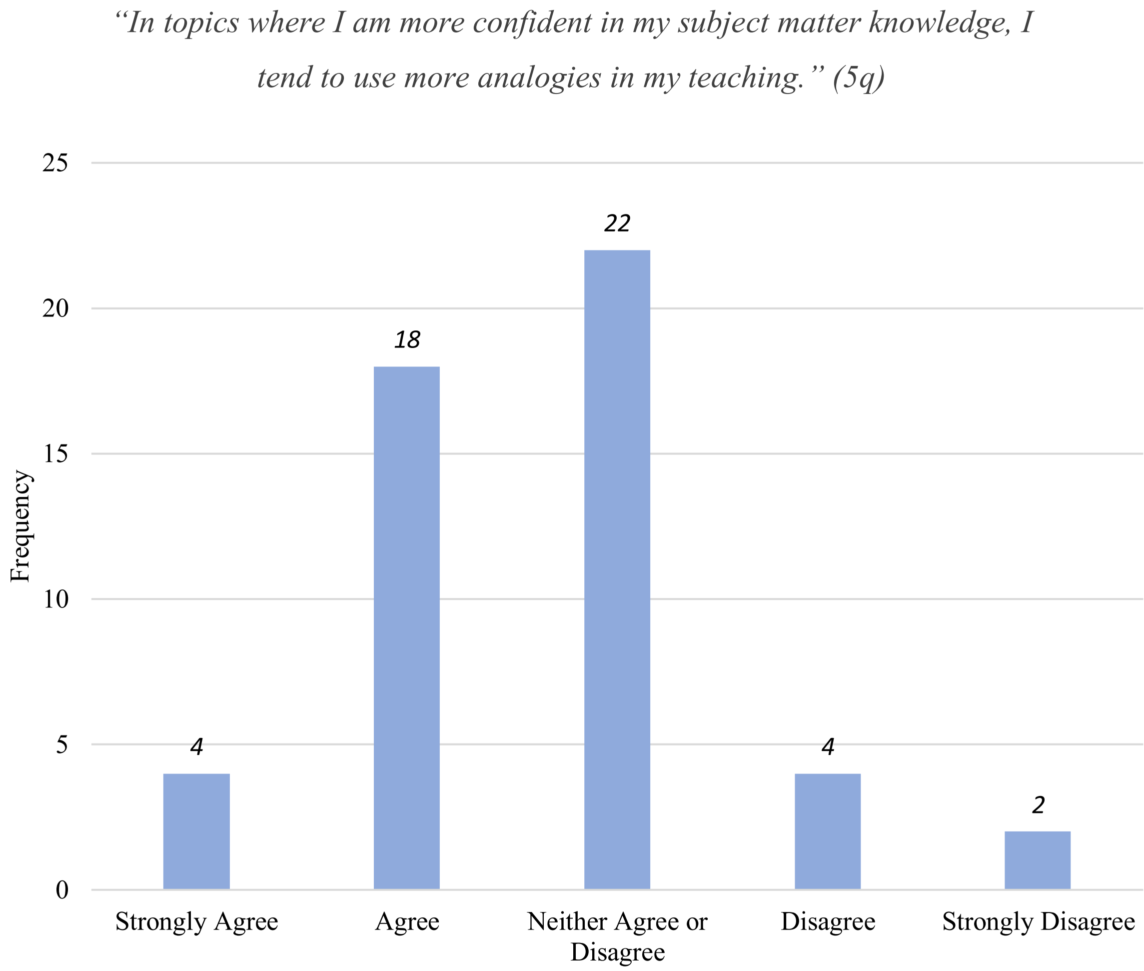

Figure 5.12 Survey participant response to the statement "In topics where I am more confident in my subject matter knowledge, I tend to use more analogies in my teaching" ($N = 50$).

98% of survey participants responded to this item, indicating an excellent response rate. The response to statement 5q was mostly split between the neutral view and an agreement that analogies are used more often in teaching topics of higher confidence, with only a few participants declaring disagreement with the statement. Of the six participants who disagreed or strongly disagreed with statement 5q, two participants commented that they only use analogies when it is appropriate to do so, whilst a further two participants noted that they do not use them in their teaching at all. One of these participants explained that they do not use them as students "get fixated on these ideas and they reflect in their answers, being poor quality, and they can only discuss the analogy".

As was observed with some of those who disagreed, seven participants who responded to statement 5q with "neither agree or disagree" explained that their usage of analogies is not dictated by their confidence, but rather by where they perceived analogies to be most appropriate, as was observed in the interview phase following discussion with Daniel and Gerald. Furthermore, seven participants also reported that there was no correlation between their confidence in their SMK and the topics in which they used analogies, with some participants stating that because they are confident in all areas they cannot otherwise answer this question.

Of the 22 participants who agreed or strongly agreed that they tend to use analogies more in the topics they are most confident with, ten participants reported that this was simply because they were more secure in their SMK, allowing them to select appropriate analogies in their teaching. Additionally, five participants explicitly noted that through being confident in their SMK they felt they had a greater awareness of the different approaches that can be used to convey chemical ideas. These comments demonstrate a level of reflection present in strong PCK, as these teachers can use their high level of SMK to better inform their practice (Kind, 2009a). Some representative responses are included below.

"Subjects I am more confident in tend to be the ones I have a better knowledge of and so am more able to identify analogies and discuss the subject more fully."

'With more confidence of your own knowledge, it's easier to relate to other [scenarios] and also to give things a go without worry of failure."

Three participants who agreed with statement 5q noted that through being confident in their SMK, they were therefore able to identify the limitations of analogies more easily. One of these participants further noted that models like analogies are "only necessary in abstract ideas", aligning with the comments that both Martin and Arthur provided at interview.

Further to the above questions, survey participants were also required to provide examples of analogies that they have used that were effective in their teaching of A level chemistry. The responses were categorised under the ten topics discussed in Chapters 4 and 5, with the quantity of analogies described for each topic noted (Table 5.9). The topics in Table 5.9 are ordered from top to bottom by the ranks assigned in Figure 5.5.

Topic	Number of Examples
Atomic Structure & Molar Calculations	*9*
Bonding & Intermolecular Forces	*6*
Organic Chemistry	*3*
Analytical Techniques	*2*
Energy Calculations	*6*
Acids, Bases, and Buffers	*1*
Chemical Equilibrium	*13*
Kinetics	*10*
Transition Metal Chemistry	*0*
Electrochemistry	*0*

Table 5.9 Frequency of survey participants' responses to the question "Please provide an example of one or two analogies that have been effective in your teaching of A level chemistry" relating to topics of the A level specification (N = 51).

100% of participants responded to this question, indicating an excellent response rate. The three topics observed to have a relatively high number of analogies reported were chemical equilibrium, kinetics, and atomic structure & molar calculations. These three topics are heavily based around mathematics and focus on abstract concepts, possibly explaining why analogies were described more for these topics. Interestingly, the two topics generally held to be low confidence topics were the only topics where no participants provided analogies. This is possibly a further indicator of participants' lack of confidence in these topics, aligning with the responses of those who agreed or strongly agreed with statement 5q. However, it may simply be because participants chose to respond to the survey question with analogies that they are confident and comfortable with using.

CHAPTER SIX

~ Conclusions, Implications, and Future Work ~

Following the scoping work outlined in Chapter 2, the primary aim of this study was to investigate A level chemistry teachers' beliefs and opinions regarding the role of subject matter knowledge (SMK) in their teaching of the subject. This study has principally considered the role of the undergraduate degree and initial teacher training (ITT) in facilitating the development of SMK for teaching and how a teacher's confidence in their SMK can influence their teaching. The key outcomes and observations of the study are noted here, organised by the research questions, followed by a consideration of the limitations of this project. This thesis concludes with a discussion of the implications of the research and recommendations for future work that can be undertaken.

6.1 Conclusions: Chemical Equilibrium and PCK

The first phase of the project was guided by two overarching research questions. The first of these has been included below.

Is there evidence to suggest that A level chemistry teachers hold misconceptions related to chemical equilibrium, and if so, what is the nature of these misconceptions? (RQ1)

The results from the focus group sessions demonstrated that teachers of A level chemistry do possess some misconceptions in the field of chemical equilibrium. There was some indication that participants relied too greatly upon Le Chatelier's principle when answering questions, meaning that they did not consider other factors that could affect their results. This was further demonstrated by the limited usage of the equilibrium expression for K_c in the participants' responses.

The nature of the misconceptions observed was similar to that reported by Quílez-Pardo and Solaz-Portolés (1995). Many participants believed that the addition of an inert gas to an equilibrium system would cause no shift in the equilibrium position, further highlighting a lack of consideration of K_p in their responses. Some also assumed that because neon did not appear in the overall equation, then addition of it would have no impact on the equilibrium position, whilst others disregarded that the overall pressure of the system in the scenarios given would remain constant.

The misconceptions observed were related to questions on complicated equilibrium systems, and so are therefore perhaps not reflective of the content on the A level specification. However, if teachers are to support their students with the chemical equilibrium topic, it can be argued that their understanding should extend beyond Le Chatelier's principle, and so it is important to target these misconceptions in future.

These findings link directly to the results obtained in response to RQ2.

How confident do A level chemistry teachers perceive themselves to be in their (a) understanding of and (b) ability to teach chemical equilibrium? (RQ2)

Prior to the focus group session, most participating teachers rated both their confidence in their understanding of and their ability to teach chemical equilibrium highly, which was positive to observe. Following the session, a significant number of participants felt that their confidence in their understanding and ability to teach dropped as a result.

This is an important outcome of this phase of the project as it highlights two important aspects of the teacher's knowledge base. The first of these is that through having their own misconceptions highlighted, this affected their confidence in not only their SMK but also in their pedagogical content knowledge (PCK), demonstrating further the link between the two knowledge bases. The second is that these weaknesses in SMK, in a topic where teachers felt relatively confident, suggested that there could be further weaknesses with A level chemistry teachers' SMK, especially in topics of lower confidence. These findings ultimately led to the change in focus of this research project, as it seemed more pertinent to investigate perceptions towards SMK and how it could be enhanced rather than on the PCK on a specific topic, allowing for a more general and holistic approach to the issue at hand to be taken.

6.2 Conclusions: The Interview Phase

The interview phase of the project sought to answer two overarching research questions (RQ3 and RQ4), with the research into each one guided by three sub-questions. The conclusions related to the sub-questions are discussed first, which feed into the conclusions to the research questions.

6.2.1 How do A level chemistry teachers perceive the influence of their education on their chemistry subject matter knowledge and their confidence in it?

What are the perceptions of A level chemistry teachers regarding the impact of their undergraduate degree on their subject matter knowledge? (SQ3.1)

Most participating teachers agreed that their undergraduate degrees provided them with enough SMK to feel confident teaching A level chemistry, reporting that it encapsulated the content of the A level, allowed for development of practical skills, and provided an awareness of applications and context. Additionally, most participating teachers believed that A level chemistry teachers should be experts in their field, noting the importance of strong SMK and high confidence, which were believed to lead to expertise. It was also noted that participants felt that teachers should not be expected to be experts from the beginning of their career. Experienced teachers were observed to discuss the importance of being aware of misconceptions more than novice teachers, perhaps indicating that experience results in enhanced PCK and aligning with previous research (Grossman, 1990; Magnusson et al., 1999; Van Driel et al., 2001).

Most participant teachers reported that A level chemistry teachers should possess an A level or an undergraduate degree in chemistry or a related subject, remarking that studying a degree provides a deeper understanding and can increase confidence. However, a small number of participants in the interview phase found that despite the fact they had an undergraduate degree, they did not feel that it had prepared them enough, in terms of their SMK, for teaching A level chemistry. These findings highlight the importance of assessing the SMK of preservice teachers and taking appropriate measures to support SMK development.

How do A level chemistry teachers perceive their confidence in their chemistry subject matter knowledge to change during their initial teacher training? (SQ3.2)

Most participating teachers considered themselves to possess strong chemistry SMK before undertaking their ITT, with some reporting that they needed to improve their knowledge in a few weaker areas. Those who perceived themselves to have weaker SMK were typically non-specialists or had worked in another profession between their undergraduate degree and their ITT. Similarly, most participating teachers reported themselves to have high confidence in their SMK before starting their ITT.

Notably, half of the participating teachers noted that their perception of their SMK did not change upon starting teaching. There was then an even split between those participants who had overestimated their knowledge and those who had underestimated it. Those who overestimated their SMK were generally less experienced and found that they knew less than they first thought when encountering particular topics.

Half of the participants found that their confidence in their SMK increased during the ITT process, noting that as they gained experience, this also made them feel more confident. The remainder of the participants found that their confidence in their SMK did not change that much once they had started teaching, though in some topics did increase again due to experience and opportunity to reflect. These findings demonstrate the importance of both ITT and more experience in the classroom on enhancing teacher confidence in their understanding of chemistry topics.

Which methods do A level chemistry teachers use, during their initial teacher training, to enhance their chemistry subject matter knowledge? (SQ3.3)

Most participants in the interview phase noted that their ITT addressed SMK development in their programmes, reporting that SMK audits, lectures, and practical work were common methods of facilitation. Equally, most participants engaged with self-directed activities to enhance their SMK during their training. Textbooks, chemistry websites, and past examination papers were observed to be the most-used resources in self-directed SMK enhancement.

Through the findings gained in response to the sub-questions SQ3.1, 3.2, and 3.3, it can be said that the participating teachers held their education, through undergraduate degree and ITT, to have a significant impact on their SMK and confidence going into teaching. Notably, as may have been expected, confidence appeared to be enhanced as experience in the classroom increased. Similarly, those who engaged in self-directed SMK development were also seen to gain confidence in their SMK and their ability to teach as a result. This finding demonstrates the need for further early career CPD that specifically targets areas of SMK. Additionally, these findings provided further guidance to the questioning in the survey phase, where information regarding how continued professional development (CPD) could be delivered was sought from the wider A level chemistry teaching population. A further discussion of the implications is included later in this chapter.

6.2.2 Are there differences in the ways that A level chemistry teachers approach teaching topics where they are confident in their SMK compared to those topics where they are not?

Are there particular topics within the A level chemistry syllabus that A level chemistry teachers are generally less confident with their knowledge of? (SQ4.1)

The topics of atomic structure & molar calculations and bonding & intermolecular forces were observed to be topics of high confidence amongst most of the participants in the interview phase, due to the fundamental nature of these topics in the teaching of A level chemistry. Confidence rankings in organic chemistry were observed to be polarised between very high and very low, with participants commenting that this was primarily based on their experience with the topic. Non-specialist teachers who rated organic chemistry a low confidence topic remarked that it was a broad topic and that it was difficult to remember, suggesting that some non-specialists approach organic chemistry with a tendency to use rote memorisation, noted by Grove and Bretz (2012) to hinder understanding and attainment. Topics that appear prominently on both GCSE and A level specifications were typically rated with a higher confidence ranking than those that do not. Some teachers noted low confidence with the topic of kinetics due to issues with specification changes and mathematical understanding. Based on these findings, it can be said that providing SMK support to those with low confidence in their SMK when changes are made to specifications is an essential practice.

Transition metal chemistry was generally considered by participants to be a topic of low confidence. Transition metal chemistry was considered to be a topic of low confidence due to its presentation on the A level specification, with emphasis on qualitative observations and little discussion of the sub-microscopic processes behind them. Differences between A level specifications and the clarity of language required in answering examination questions were also cited as causes for low confidence. Additionally, non-specialists are unlikely to have encountered this topic during their undergraduate studies. These findings suggest that developing resources to enhance teachers' SMK and understanding of transition metal chemistry would be a valuable undertaking.

Electrochemistry was also commonly ranked as a topic of low confidence, with participants most commonly citing struggles during their personal studies and a lack of understanding as the reasons for this. Most participants only felt confident in their electrochemistry SMK up to the limits of the A level; in other topics, participants were noticeably more comfortable in their SMK. Participants also reported that their low confidence stemmed from how the topic is covered on A level specifications, where explanations of the underlying principles were considered by some to be unsatisfactory. The terminology used and the overlap with physics were also noted to cause issues, supporting previous research in sources of students' electrochemistry misconceptions (Garnett et al., 1990).

Do teachers of A level chemistry believe it is a problem if the subject matter knowledge of teachers is limited to the A level specification? (SQ4.2)

Most participants believed it to be an issue if a teacher's SMK was limited to the A level specification, citing the importance of stretching students and possessing confidence in the subject matter. Knowledge beyond the specification was deemed by most to be crucial in engaging students within chemistry. The ability to adapt to specification changes and making links to other subjects beyond chemistry were also perceived as essential qualities that can only be possessed if a teacher's SMK is not limited to the A level specification. Those who did not agree reported that a wider understanding is beneficial, but not necessary, and that although being limited to the specification does not make someone a bad teacher, it will probably make them a less effective teacher. One respondent noted that if a teacher's sole aim is for their students to pass the course examinations, then SMK limited to the specification is enough.

Are A level chemistry teachers aware of their usage of models and analogies in particular topics within the A level specification, and are they aware of the limitations of such models? (SQ4.3)

Discussions at interview highlighted that most of the participating teachers were aware of their usage of models and analogies, with some commenting that they were more likely to either use them when teaching more abstract and theoretical concepts or in topics of high confidence. Only one participant discussed the limitations of using analogies at interview, leading to this being further questioned to a wider audience in the survey phase of the project.

Through the findings gained in response to the sub-questions SQ4.1, 4.2, and 4.3, it can be said that there is some evidence to suggest that the approach that teachers take to teaching particular topics are dependent on their confidence in them, with a notable finding being that the teachers generally hold the same topics to be topics of lower confidence. Most participants reported explicit differences between their teaching of high confidence topics and low confidence topics. Most participants reported that their teaching of high confidence topics tended to be more personalised and adaptable, with a higher awareness of student misconceptions. They reported that lessons in low confidence topics were typically more formulaic, with less scope for flexibility from the lesson plan, and a greater reliance on using resources, showing agreement with the findings of Hashweh (1987), Sanders et al. (1993), and Childs & McNicholl (2007). These findings suggest that there is a link between a teacher's SMK and their PCK, lying in agreement with previous studies (Rollnick et al., 2008; Van Driel et al., 2014). A further discussion of the implications is included later in this chapter.

6.3 Conclusions: The survey phase

Are the results obtained from the participants in the interview phase of the study indicative of the wider population of A level chemistry teachers? (RQ5)

Generally, the results from the survey phase aligned with the results obtained in the interview phase of the project, with many of the same themes arising in both phases of the study. Some important points or issues that were raised during the interview phase of the project were looked into further during the survey phase as a result, with the key conclusions also reported here.

Participants in the survey phase also generally felt that their education had a positive impact on their SMK and their confidence in it. Unlike in the interview phase, in the survey phase of the project the majority of participants felt that upon starting teaching, their perception of their level of SMK changed. The majority of those whose perception of their level changed reported that the weaknesses in their SMK were exposed and that they had overestimated their knowledge, causing them to feel that their SMK was not as strong as first thought. Given that most participants felt their SMK was of a high level, this may imply the presence of the Dunning-Kruger effect, as was observed in undergraduate chemists by Pazicni and Bauer (2014). Additionally, this has further potential implications for the role of the undergraduate degree in developing students' SMK. Additionally, in the survey phase a small number of participants reported a confidence decrease during their ITT, explaining that this was because they did not feel that their SMK was good enough and that it needed to be improved.

Some slightly different results were obtained between the interview and survey phases regarding SMK development during ITT. Fewer than half of the survey respondents noted that their ITT addressed SMK development in their programmes, whilst those that did reported that SMK audits, lectures, and practical work were common methods of facilitation. Those who undertook limited to no SMK development during their ITT remarked that the main focus of training sessions was on pedagogy. Despite this, most participating teachers reported that they participated in self-directed activities to enhance their SMK during their ITT, most commonly citing the usage of textbooks and past examination papers, as was observed in the interview phase.

Most of the teachers participating in this study agreed that ITT providers should offer more SMK development support during the ITT programme. Responses indicated that many participants had experience of colleagues or other teachers who possessed undeveloped SMK, whilst others noted the importance of supporting non-specialists in areas where they possess weaker SMK. A small number of teachers noted the importance of making links between curriculum concepts.

After it was raised as a potential issue during the interview phase, in the survey phase almost half of the participating teachers admitted to worrying that they do not stretch their students enough in topics of lower confidence, highlighting a further potential difference in teaching methods between high and low confidence topics. Those who did not worry mainly reported that they were confident enough in their SMK or that their confidence did not affect their ability to prepare lessons or source difficult questions. Participants who stated that they worry they cannot stretch their students reported a lack of confidence in applying their own knowledge to unfamiliar situations, as well as noting that planning appropriate lessons was difficult. This finding lies in agreement with Kind's (2009a) research, noting that stronger SMK can support a teacher's PCK development and enhance their ability to select appropriate teaching resources.

Others reported that they sometimes feared discussing low confidence topics with their students, as they felt they may introduce misconceptions. These findings imply that if a teacher possesses weaker SMK, then they may be less likely to stretch their most able students, and therefore may not be able to instil as strong an understanding as a teacher with strong SMK. There is also evidence to suggest that by enhancing SMK, teacher confidence can be improved, which can in turn lead to a better learning environment for the students.

Following the interview phase of the study, participants in the survey phase were asked specific questions regarding their usage of two specific models (the octet rule and Le Chatelier's principle) and their limitations. Nearly all the participants in the survey believed that the octet rule had limitations, explaining that there are inconsistencies and exceptions to the rule, as well as discrepancies between the A level and GCSE coverage. Just under half of the participating teachers believed that the limitations of the octet rule should be taught at GCSE, whilst nearly all of the participating teachers agreed that these limitations should be taught at A level. Participants generally believed that these limitations should be discussed briefly at GCSE, with a full explanation provided at A level.

Conversely, just over half of the participating teachers believed that Le Chatelier's principle had limitations associated with it, noting that it is not always applicable and that it is often used as an explanation for equilibrium processes where it shouldn't be. 24.0% of participants believed that Le Chatelier's principle did not have any limitations, noting that it was suitable for A level teaching. 20.0% of participants were unsure if the principle was limited, reporting that they had never encountered any limitations before. These findings, in conjunction with the scoping work described in Chapter 2, suggest that many teachers' understanding of chemical equilibrium and Le Chatelier's principle is flawed, as has been observed with students (Wheeler and Kass, 1978; Quílez-Pardo and Solaz-Portolés, 1995; Quílez, 2006) and teachers (Banerjee, 1991; Quílez-Pardo and Solaz-Portolés, 1995) previously. Additionally, a considerable number of those who were unsure or did not believe Le Chatelier's principle to possess any limitations were non-specialists, further highlighting that further SMK development support for non-specialists is valuable.

As was observed with participants' views on the octet rule, participating teachers generally felt that the limitations of Le Chatelier's principle should be taught at A level, but not at GCSE level. Participants explained that it is more sensible to discuss limitations at A level, whilst some noted that a quantitative approach can be taken. Participants generally considered this topic and its associated limitations too difficult and/or confusing for GCSE students and that it would be easier to 'lose them'.

Most participating teachers noted that they use analogies in their teaching of A level chemistry. Half of the participants reported that they were more likely to use analogies with topics that they were more confident in, commenting that because they felt more secure in their SMK they were more able to select appropriate analogies for the content covered, aligning with the findings of Kind (2009a). Some of these participants also noted that they were more aware of potential limitations with analogies in topics of higher SMK, indicating an awareness of Taber's (2001) key principles regarding the use of analogies. Conversely, the other half felt that their use of analogies was not dictated by confidence, but rather by the appropriateness of the analogy. These participants typically reported that they were confident in all topics of the A level.

6.4 Limitations

There are limitations with the methods used in this project. In the interview phase of the project, participants were contacted through a self-selecting mailing list, and as a result their views may not be generalisable to the general teaching population (Burns and Grove, 1997; Freedman et al., 1997). Additionally, although the nationwide survey aimed to make the data generalisable to a larger teaching population, there is no guarantee that this will have been the case.

It should also be reiterated that the data collected in this study are based on participating teachers' beliefs, opinions, and perceptions of the role of SMK in A level chemistry teaching. No quantitative measurements of teachers' understanding of individual topics were undertaken. This study was designed to be exploratory, gauging teachers' feelings to inform further research into this field. Further research could investigate the links between teachers' misconceptions, their quantitative performance in diagnostic SMK testing, and how confident they are in individual topics.

The results obtained in this study would have been strengthened through use of other data collection methods. For example, participating teachers' comments regarding how they taught high and low confidence topics could have been further supported by undertaking lesson observations and noting differences between them, though this was not achievable due to time constraints. It is recommended that observations should be employed if further investigation into how teachers approach topics of varying confidence is undertaken.

Teachers' comments regarding the impact of their ITT on SMK development may also be limited, as these beliefs will be held based on retrospect. If studies are undertaken to investigate the role of ITT in SMK development in future, it is recommended that a longitudinal approach should be taken, working with participants who are currently training and interviewing them regularly. Additionally, when considering the methods used to develop SMK in ITT, data should also be collected from ITT providers to ensure that personal biases are minimised.

6.5 Implications and future work

The identification of transition metal chemistry and electrochemistry as areas of universal low confidence is an important outcome of this project. In future, it is recommended that resources and CPD courses should be developed in order to enhance A level chemistry teachers' SMK in these areas. Further to this, investigations regarding the relationship between the level of a teacher's SMK and their confidence in it could also be undertaken, in order to ascertain further whether improving teacher confidence can have a positive impact on student learning.

Based on the findings presented in Chapters 4 and 5, a set of twelve videos have been planned to enhance teachers' SMK in electrochemistry, covering the fundamental physics involved in electrochemistry, the historical context of the topic, the key concepts that appear on A level specifications, and the modern-day applications of electrochemistry. These videos were planned with an added focus on common student misconceptions and the thought processes involved in solving electrochemical problems. Due to time constraints, the planned resources could not be developed. In future, the development of such a resource should be undertaken and evaluated.

Participating teachers, including both novice and experienced teachers, felt that ITT providers should offer more SMK development support during ITT. Although the nature of ITT involves the coverage of a large amount of information and pedagogical theory, there is a clear desire for trainees to have resources available to them. Participants identified that more focus should be given to topics that are difficult to teach. Given that these topics have been identified in this study, work can be undertaken in future to develop resources to facilitate this focus. Participants also requested to approach topics from different perspectives and focus on common misconceptions, feedback & action plans, and putting concepts in the context of practical work. These factors should be considered in the development and evaluation of any resources created in future.

It can also be argued that more action should be taken during students' undergraduate degrees to develop their SMK for teaching. Although not all undergraduates will pursue careers in teaching, many will choose to pursue careers within their field and it is likely, therefore, that they will be required to explain concepts to colleagues at some point. Investigation of teachers' attainment in their undergraduate degrees, their confidence in their SMK, and their knowledge of individual topics could also be undertaken. This could include further investigation of the misconceptions that they possess.

The findings from the scoping work of this project, discussed in Chapter 2.4, and investigation into the limitations of models and analogies, detailed in Chapter 5.7, provide support to previous research that teachers possess a limited understanding of chemical equilibrium and Le Chatelier's principle (Quílez-Pardo and Solaz-Portolés, 1995). These findings indicate that work should be undertaken to enhance teachers' awareness of the limitations of Le Chatelier's principle, providing support to non-specialists and experienced specialists alike.

Finally, numerous issues discussed by participants in this study related to issues with specialist language and terminology, an issue that has been identified in numerous studies (Garnett et al., 1990; Taber, 2000; Taber, 2002). Further investigation into the aspects of language and terminology that cause difficulty for students and teachers should be considered, in addition to inquiry into the methods that can be used to ameliorate teachers' concerns regarding terminology. If such methods can be identified, it would be beneficial for resources for teachers of all experience levels to be developed that can attempt to tackle these problems.

APPENDIX A

Online Questionnaires

Initial Online Questionnaire

The Role of Subject Matter Knowledge in Teaching A Level Chemistry - Survey

We are seeking teachers to participate in interviews that will last for approximately 60 minutes. Not all respondents to this survey will be interviewed, however all respondents will be contacted via email after participating.

Thank you for indicating your interest in our research. This study is part of a research project being undertaken at the University of Southampton, focusing on the subject matter knowledge of A level chemistry teachers, and the role it plays in chemistry education. The questions within this questionnaire will ask you to provide information about your teacher training and your teacher experience. This questionnaire should take no longer than 10 minutes to complete.
By participating in this survey, you consent to us contacting you via email regarding the organisation of a date, time, and location for an interview. The interview will centre on the topics of teacher training, the A level curriculum, and common misconceptions amongst students. The interview will last for approximately one hour. Please note that not all respondents to this survey will be invited to interview; to ensure the data obtained in this research are valid, teachers of different demographics (e.g. years of experience, location, degree level, type of school, etc.) must be involved in the study, and so interviewees will be selected by the researchers to fit these demographics. Where possible, we will ensure that the interviews take place at your school/college.

We are extremely grateful for your responses, and will be using the findings of the project to develop new methods of improving teacher subject matter knowledge. Thank you very much for expressing an interest in participating in this study and for taking the time to complete this questionnaire.

Steve Barnes and Prof. David Read
Southampton Chemical Education Research (SoCER) Group

Please tick (check) this box to indicate that you consent to taking part in this survey.

1 Introductory Questions

1. Please provide your name.

2. In which part of the UK is your school/college?
   Options: North West, North East, West Midlands, East Midlands, Wales, South West, London, South East

3. Please provide your email address so we can arrange a time for interview.

4. What subject did you study at degree level? (If you have more than one degree, please indicate the first one you undertook).
   Options: Biochemistry, Biology, Biomedical Science, Chemistry, Engineering, Environmental Science, Forensic Science, Medicine, Natural Sciences, Pharmacy, Physics, Other
   (If 'Other' is selected): Please indicate your degree subject.

5. What type of degree was this?
   Options: BSc, MChem, MSci, Other
   (If 'Other' is selected): Please indicate what type of degree this was.

6. Do you have a higher degree? If so, please specify the degree title and subject (e.g. Ph.D. in Organic Chemistry).

7. What is your highest level of study of mathematics?
   Options: GCSE/O Level, A Level, 1st Year Undergraduate, Beyond 1st Year Undergraduate, Other
   (If 'Other' is selected): Please indicate your highest level of study of mathematics.

8. Which route did you follow in training to become a teacher?
   Options: PGCE (or equivalent), GTP, School Direct, TeachFirst, Other (please specify)
   (If 'Other' is selected): Please indicate your teacher training route.

9. In what year did you first train to become a teacher?

10. How long have you been teaching?
    Options: Currently training, < 1 year, 1-3 years, 4-6 years, 7-10 years, 11-15 years, 16-20 years, >20 years.

11. How long have you been teaching A level chemistry?
    Options: Currently training, < 1 year, 1-3 years, 4-6 years, 7-10 years, 11-15 years, 16-20 years, >20 years.

12. What type of school do you currently teach in?
    Options: Comprehensive (LEA), Comprehensive (Academy), FE College, Free School, Independent School, Sixth Form College, State Grammar, Other
    (If 'Other' is selected): Please indicate what type of school you teach in.

13. Do you have any experience working in another field (e.g. chemical industry) aside from teaching? If the answer is yes, please provide details of this work below.

2 A Level Topics

1. Please rate your **confidence in your subject matter knowledge** of the ten A level chemistry topics given below. The drop-down menu indicates the level (GCSE, A Level, first year undergraduate, and beyond first year undergraduate) that you feel confident with your subject matter knowledge of.
    Acids, Bases, and Buffers
    Analytical Techniques
    Atomic Structure and Molar Calculations
    Bonding and Intermolecular Forces
    Chemical Equilibrium
    Electrochemistry
    Energy Calculations
    Kinetics
    Organic Chemistry
    Transition Metal Chemistry

2. Please rate your **confidence in your ability to teach** the ten A level chemistry topics given below from 1 – 10, with 1 being the topic you feel **most confident** teaching and 10 being the topic you feel **least confident** teaching.

    Acids, Bases, and Buffers
    Analytical Techniques
    Atomic Structure and Molar Calculations
    Bonding and Intermolecular Forces
    Chemical Equilibrium
    Electrochemistry
    Energy Calculations
    Kinetics
    Organic Chemistry
    Transition Metal Chemistry

Secondary Online Questionnaire

The Role of Subject Matter Knowledge in Teaching A Level Chemistry – Pre-Interview Survey

Thank you for indicating your interest in our research. This study is part of a research project being undertaken at the University of Southampton, focusing on the subject matter knowledge of A level chemistry teachers, and the role it plays in chemistry education. The questions within this questionnaire will ask you to provide information about your teacher training, your teacher experience, and your perceptions on the nature of science. This questionnaire should take no longer than 20 minutes to complete.

You must complete this survey **before** your interview, as your responses to the survey will inform the discussion of certain topics at the interview. The interview will centre on the topics of teacher training, the A level curriculum, and common misconceptions amongst students. The interview will last for approximately one hour.

We are extremely grateful for your responses, and will be using the findings of the project to develop new methods of improving teacher subject matter knowledge. Thank you very much for expressing an interest in participating in this study and for taking the time to complete this questionnaire.

Steve Barnes and Prof. David Read
Southampton Chemical Education Research (SoCER) Group

Please tick (check) this box to indicate that you consent to taking part in this survey.

1 Subject Matter Knowledge

1. Please provide your name.

2. In your opinion, how do you define **science** and the **nature of science**?

3. How is scientific knowledge produced?

4. What was your perception of your level of subject matter knowledge before you started teaching?

5. Were you confident in your subject matter knowledge before you started teaching?

6. When you initially started teaching, did your **perception of your level** of subject matter knowledge change? Explain your answer.

7. When you initially started teaching, did your **confidence** in your subject matter knowledge change? Explain your answer.

8. At this point in your teaching career, do you feel that your level of subject matter knowledge has changed since the beginning? Explain your answer.

9. At this point in your teaching career, do you feel that your confidence in your subject matter knowledge has changed since the beginning? Explain your answer.

APPENDIX B

Interview Questions

INTERVIEW STRUCTURE

Hello, if you could please state your name for the recording.

And can I confirm that you have signed the consent form and that you fully consent to this interview being recorded and used for our research project.

Section 1: Teacher Training

These questions will primarily focus on your teacher training, and its influence on your subject matter knowledge.

Which aspects of your degree, if any, helped to develop your subject matter knowledge for teaching?

To what extent did your teacher training address subject matter knowledge development during your training period? Please provide an outline.

Did you engage in any self-directed activities to develop your subject matter knowledge while you were training, which were not formally part of your training? Please provide an outline.

What do you remember about the impact of the subject matter knowledge activities you engaged in during your training on your *confidence* in your subject matter knowledge of chemistry?

Section 2: The Role of SMK in Teaching

These questions will primarily focus on what you think makes a good teacher, and how a teacher's subject matter knowledge can influence that.

Broadly speaking, what do you believe makes an effective teacher of any subject?

Broadly speaking, what do you believe makes an effective teacher of chemistry specifically?

How important do you believe a chemistry teacher's level of subject matter knowledge is in their teaching? Please explain your response. Do you think a teacher should be an expert in their field?

Do you feel that your teaching of chemistry is limited by any external factors (things you personally don't have control over)? *If so, how is it limited? What would you change?*

In an ideal world, how would you personally like to teach chemistry? Under what circumstances would you personally like to teach chemistry? How might your approach and your practice differ?

Section 3: The A Level Curriculum

These questions will primarily focus on your opinions of the A level chemistry curriculum.

Do you personally engage in any activities outside of school (e.g. wider reading, watching television, listening to the radio, museums, science centres etc.) to expand your knowledge of chemistry? Please provide examples.

If a student asks you a question relating to content that lies outside the A level specification, how do you approach this situation? Can you give an example of when this occurred?

How often do you find yourself teaching content that lies outside the A level specification? How do you go about teaching this content?

What should the scope of a chemistry teacher's subject matter knowledge be? Do you personally believe it to be an issue if a teacher's subject matter knowledge is limited to the A level specification?

Section 4: Common Misconceptions

These questions will primarily focus on specific topics in the A level, and the potential issues involved in both teaching and understanding them.

In the pre-interview survey, you stated that <TOPICS> were the topics where you felt the most confident in your subject matter knowledge. What is it in particular about these topics that make you feel more confident in your subject matter knowledge of them? We'll start with <TOPIC>.

How do you approach teaching these topics?

In the pre-interview survey, you stated that <TOPICS> were the topics where you felt the least confident in your subject matter knowledge. What is it in particular about these topics that make you feel less confident in your subject matter knowledge of them? We'll start with <TOPIC>.

How do you approach teaching these topics?

Reflect on the approaches you take between teaching the concepts you feel less confident with to those you feel more confident with. What differences are there between these approaches?

Chemical Kinetics and The Arrhenius Equation

The next few questions centre on the A level topic of kinetics.

What support do you get for subject-specific CPD?

As part of the A level reforms of 2015, the Arrhenius equation has been reintroduced to all A level specifications. How have you adapted to the reintroduction of the Arrhenius equation to the A level syllabus?

Do you feel confident teaching this concept?

To what extent do you feel that you and your students understand the mathematical processes involved in Arrhenius calculations?

To what extent do you feel that you and your students understand the application of the Arrhenius equation to further understand chemical kinetics?

Structure and Bonding

The next few questions centre on the A level topic of atomic structure and bonding.

This is how students and teachers responded to a question regarding structure and bonding in the past. Why do you think that these are the typical responses?

Le Chatelier's Principle

The next few questions centre on the A level topic of chemical equilibrium.

This is how a group of teachers responded to a question regarding chemical equilibrium in the past. Why do you think that these are the typical responses?

Final Comments on Misconceptions and Models

Having considered the problems presented to you, do you believe that the limitations of chemical models and analogies should be taught at GCSE and/or A level? Please explain your response.

That's all of the questions I have for you today, thank you for your time.

APPENDIX C

Interview Phase – Ethics and Consent Forms

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ERGO application form – Ethics form

All mandatory fields are marked (M*). Applications without mandatory fields completed are likely to be rejected by reviewers. Other fields are marked "if applicable". Help text is provided, where appropriate, in italics after each question.

1. APPLICANT DETAILS

1.1 (M*) Applicant name:	Stephen Barnes
1.2 Supervisor (if applicable):	Prof. David Read
1.3 Other researchers/collaborators (if applicable): *Name, address, email, telephone*	**N/A**

2. STUDY DETAILS

2.1 (M*) Title of study:	The role of subject matter knowledge in teaching A level chemistry
2.2 (M*) Type of study (*e.g. Undergraduate, Doctorate, Masters, Staff*):	Doctorate
2.3 i) (M*) Proposed start date:	20/12/2017
2.3 ii) (M*) Proposed end date:	31/12/2018

2.4 (M*) What are the aims and objectives of this study?
The aim of this study is to investigate teachers' opinions of their subject matter knowledge and the role it plays in the teaching of A level chemistry. In addition to this, we will be investigating how the limits of A level chemistry teachers' subject matter knowledge impacts on their teaching, and hence student understanding, of three particular topics (chemical bonding, kinetics, and chemical equilibrium). Investigating this will provide key insight into common issues that teachers have, and therefore allow us to develop strategies to alleviate these issues in future.

2.5 (M*) Background to study (*a **brief** rationale for conducting the study*):
In recent years, there has been an increased research focus on pedagogical content knowledge (PCK) and the role it plays in science education. PCK is a term first coined by Lee Shulman in 1986, and refers to a type of knowledge possessed by teachers that is "based on the manner in which teachers relate their pedagogical knowledge (what they know about teaching) to their subject matter knowledge (what they know about what they teach)" (Cochran, 1997). Without a good level of subject matter knowledge (SMK), a teacher will have difficulty in developing their PCK. Although recent studies have investigated science teachers' SMK and how it influences their teaching, the focus has primarily been on the biological and mathematical sciences. Hence, there is scope for the role of SMK in the teaching of the chemical sciences to be explored.

2.6 (M*) Key research question (*Specify hypothesis if applicable*):

UNIVERSITY OF Southampton

What are A level chemistry teachers' opinions of their own subject matter knowledge and the role it plays in the teaching of A level chemistry?

2.7 (M*) Study design (*Give a **brief** outline of basic study design*) *Outline what approach is being used, why certain methods have been chosen.*
Participants will be required to answer a short online survey. The responses given to this survey will allow for demographic information to be obtained. Based on the demographic information (e.g. years of teaching experience, subject studied at degree level, the type of institution they work in), a small group (20-30) respondents will be selected for interview and will be sent a follow-up online survey. The questions involved in this survey will guide the discussion to certain questions in the interview. Both of these online surveys will take no longer than fifteen minutes to complete. The participants will then take part in a one-hour semi-structured interview with the primary researcher, which will be recorded. The recorded interview will then be transcribed, and the responses to each question analysed by means of thematic/content analysis, such that the main themes of the participants' responses can guide the subsequent stages of the research project. Comparison of the responses between the different demographic groups (e.g. experienced vs. inexperienced teachers) will be made to draw additional conclusions from the data.

3. SAMPLE AND SETTING

3.1 (M*) How are participants to be *approached*? *Give details of what you will do if recruitment is insufficient. If participants will be accessed through a third party (e.g. children accessed via a school) state if you have permission to contact them and **upload any letters of agreement to your submission in ERGO**.*
The chemical education research group at the University of Southampton has a self-selecting mailing list of UK chemistry teachers and university staff who are interested in participating in activities here. An email will be sent to this group, and they will be encouraged to share it with their colleagues and teaching contacts (if possible). If recruitment is insufficient via this method, teachers will be approached through their schools.

3.2 (M*) Who are the proposed sample and where are they from (e.g. fellow students, club members)? *List inclusion/exclusion criteria if applicable. NB The University does not condone the use of 'blanket emails' for contacting potential participants (i.e. fellow staff and/or students).* *It is usually advised to ensure groups of students/staff have given prior permission to be contacted in this way, or to use of a third party to pass on these requests. This is because there is a potential to take advantage of the access to 'group emails' and the relationship with colleagues and subordinates; we therefore generally do not support this method of approach.* *If this is the only way to access a chosen cohort, a reasonable compromise is to obtain explicit approval from the Faculty Ethics Committee (FEC) and also from a senior member of the Faculty in case of complaint.*
The proposed sample are teachers of A level chemistry in the United Kingdom. We hope to interview teachers of different demographics, i.e. based on their teaching experience, their level of degree, the subject they studied at degree level, etc.

3.3 (M*) Describe the relationship between researcher and sample (*Describe any*

UNIVERSITY OF Southampton

relationship e.g. teacher, friend, boss, clinician, etc.)
There is no relationship between the researcher and the sample.

3.4 (M*) Describe how you will ensure that fully informed consent is being given: (*include how long participants have to decide whether to take part*)
Participants will be provided with a consent form and an information sheet when they attend the interview. A 'Welcome Statement' is also included at the beginning of each of the online surveys.

4. RESEARCH PROCEDURES, INTERVENTIONS AND MEASUREMENTS

4.1 (M*) Give a brief account of the procedure as experienced by the participant *(Make clear who does what, how many times and in what order. Make clear the role of all assistants and collaborators. Make clear total demands made on participants, including time and travel).* ***Upload any copies of questionnaires and interview schedules to your submission in ERGO.***
The study is self-selecting. If the participant wishes to take part in the study, they will respond to the online survey sent to them via email and respond to the questions. If the participant is selected for interview (based on demographic information), they will be invited to respond to a second online survey, and will be invited to plan a time and place for interview. In all possible instances, the interview will take place at the teacher's own school or college, and the researcher will travel from the university to them in an effort to encourage greater participation. They will also be provided with the information sheet at this point. Upon attending the interview, the researcher will provide them with a pen, a piece of paper, a copy of the information sheet, and a consent form. The interview will then be conducted and recorded, with reference made to the participant's responses to the online surveys provided previously. The interview will take approximately one hour.

5. STUDY MANAGEMENT

5.1 (M*) State any potential for psychological or physical discomfort and/or distress?
There is no potential for psychological or physical discomfort/distress.

5.2 (M*) Explain how you intend to alleviate any psychological or physical discomfort and/or distress that may arise? (if applicable)
N/A

5.3 Explain how you will care for any participants in 'special groups' *(i.e. those in a dependent relationship, vulnerable or lacking in mental capacity)* **(if applicable)?**
N/A

5.4 Please give details of any payments or incentives being used to recruit participants (if applicable)?
N/A

UNIVERSITY OF Southampton

5.5 i) How will participant anonymity and/or data anonymity be maintained (if applicable)? *Two definitions of anonymity exist:* *i)* Unlinked anonymity - *Complete anonymity can only be promised if questionnaires or other requests for information are not targeted to, or received from, individuals using their name or address or any other identifiable characteristics. For example if questionnaires are sent out with no possible identifiers when returned, or if they are picked up by respondents in a public place, then anonymity can be claimed. Research methods using interviews cannot usually claim anonymity – unless using telephone interviews when participants dial in.* *ii)* Linked anonymity - *Using this method, complete anonymity cannot be promised because participants can be identified; their data may be coded so that participants are not identified by researchers, but the information provided to participants should indicate that they could be linked to their data.*
Linked anonymity. There is no way for anyone other than the primary researcher (Stephen Barnes) to connect the data we receive to any individuals, as he will be interviewing the participants and will be able to identify voices from the recordings. The interview recordings, and any data analysis of these recordings, will be stored on a password-protected computer that only the primary researcher and supervisor (Prof. David Read) have access to.

5.5 ii) How will participant confidentiality be maintained (if applicable)? *Confidentiality is defined as the non-disclosure of research information except to another authorised person. Confidential information can be shared with those who are already party to it, and may also be disclosed where the person providing the information provides explicit consent.*
N/A

5.6 (M*) How will personal data and study results be stored securely during and after the study? *Researchers should be aware of, and compliant with, the Data Protection policy of the University. You must be able to demonstrate this in respect of handling, storage and retention of data.*
All data will be saved on to a password protected computer that only the primary researcher (Stephen Barnes) and supervisor (Prof. David Read) can access.

5.7 (M*) Who will have access to these data?
Stephen Barnes (smb1g12@soton.ac.uk) and Prof. David Read (D.Read@soton.ac.uk)

N.B. – Before you upload this document to your ERGO submission remember to:

1. Complete ALL mandatory sections in this form

2. Upload any letters of agreement referred to in question 3.1 to your ERGO submission

3. Upload any interview schedules and copies of questionnaires referred to in question 4.1

December 2017

Risk Assessment Form for Assessing Ethical and Research Risks

- Please see Guidance Notes at the end of this document.
- *Students*: Please make sure you have discussed this form with your supervisor!

Researcher's name:	STEPHEN BARNES
In case of students:	
Supervisor's name:	PROF. DAVID READ
Degree course:	PhD CHEMICAL EDUCATION

Part 1 – Research activities
What do you intend to do? (*Please provide a* <u>*brief*</u> *description of your study and details of your proposed methods.*) **Participants will be required to answer a short online survey. The responses given to this survey will allow for demographic information to be obtained. Based on the demographic information (e.g. years of teaching experience, subject studied at degree level, the type of institution they work in), a small group (20-30) respondents will be selected for interview and will be sent a follow-up online survey. The questions involved in this survey will guide the discussion to certain questions in the interview. Both of these online surveys will take no longer than fifteen minutes to complete.** **The participants will then take part in a one-hour semi-structured interview with the primary researcher, which will be recorded. The recorded interview will then be transcribed, and the responses to each question analysed by means of thematic/content analysis, such that the main themes of the participants' responses can guide the subsequent stages of the research project. Comparison of the responses between the different demographic groups (e.g. experienced vs. inexperienced teachers) will be made to draw additional conclusions from the data.**
Will your research involve collection of information from other people? (*If yes, please provide a description of your proposed sample.*) **Yes, information will be collected. Participants will be self-selecting. All participants will be teachers of A level chemistry in the United Kingdom.**
If relevant, what locations are involved? (*Please specify which country/region/place you will be working in, and details of where data collection activities will take place (e.g. public or private space).*) **The study will take place at the schools and colleges of the participating teachers. The interviews will be conducted in a private space at the institution.**
Will you be working alone or with others in the data collection process?

Alone.
Part 2 – Potential risks to YOU as the researcher
Please specify potential <u>safety issues</u> arising from your proposed research activity. (*Give consideration to aspects such as lone working, risky locations, risks associated with travel; please assess the likelihood and severity of risks.) If you have already completed a departmental H&S risk assessment, this may be attached to cover these aspects.* **The interviews will be taking place at the teachers' own schools and colleges. There are no potential safety issues.**
What precautions will you take to minimise these risks? **N/A**
Please specify potential <u>distress or harm to YOU</u> arising from your proposed research activity. (*Give consideration to the possibility that you may be adversely affected by something your participants share with you. This may include information of a distressing, sensitive or illegal nature.*) **No potential for distress/harm to the researcher.**
What precautions will you take to minimise these risks? **N/A**
Part 3 – Potential risks to YOUR RESEARCH PARTICIPANTS
Please consider potential <u>safety risks</u> to participants from taking part in your proposed research activity? (*Give consideration to aspects such as location of the research, risks associated with travel, strain from participation, and assess the likelihood and severity of risks.) If you have already completed a departmental H&S risk assessment, this may be attached to cover these aspects.* **The interviews will be taking place at the teachers' own schools and colleges. There are no potential safety issues.**
What precautions will you take and/or suggest to your participants to minimise these risks? **N/A**
Please specify <u>potential harm or distress</u> that might affect your participants as a result of taking part in your research. (*Give consideration to aspects such as emotional distress, anxiety, unmet expectations, unintentional disclosure of participants' identity, and assess the likelihood and severity of risks.*) **Participants may use a pen and paper during the interview and will be answering questions aloud. The questions do not deal with sensitive information, and hence there is very minimal likelihood of distress.**
What precautions will you take and/or suggest to your participants to minimise these risks? **N/A**

Part 4 – Potential wider risks
Does your planned research pose any additional risks as a result of the sensitivity of the research and/or the nature of the population(s) or location(s) being studied? *(Give considerations to aspects such as impact on the reputation of your discipline or institution; impact on relations between researchers and participants, or between population sub-groups; social, religious, ethnic, political or other sensitivities; potential misuse of findings for illegal, discriminatory or harmful purposes; potential harm to the environment; impacts on culture or cultural heritage.)* **No, there are no additional risks based on the sensitivity of the research or the nature of the population involved.**
What precautions will you take to minimise these risks? **N/A**

CONTINUED BELOW …

Part 5 – International Travel
If your activity involves international travel you must meet the Faculty's requirements for Business Travel which are intended to: 1. Inform managers/supervisors of the travel plans of staff and students and identify whether risk assessment is required. 2. Provide contact information to staff and students whilst travelling (insurance contact details, University contact in case of emergency etc.) Full details are provided in the Faculty H&S Handbook in the **Business Travel** section. Selecting **Business Travel** from the Contents list will take you straight to the relevant section.

Departmental H&S risk assessment attached (for Part 2/3)	**NO**	**(Delete as applicable)**
Business Travel and Risk Filter Form attached (Part 5)	**NO**	**(Delete as applicable)**

CONSENT FORM Version 1

Study title: The Role of Subject Matter Knowledge in Teaching A Level Chemistry

Researcher name: Stephen Barnes
Ethics reference: 31216

*Please **initial** the box(es) if you agree with the statement(s):*

I have read and understood the information sheet (Version 1, 28/11/2017) and have had the opportunity to ask questions

I agree to take part in this research project and agree for my data to be used for the purpose of this study.

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected.

I consent to having my voice audio recorded.

I agree to the use of anonymised drawings and quotes in any publications.

Data Protection
I understand that information collected about me during my participation in this study will be stored on a password-protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of participant (print name)..

Signature of participant...

Date..

THE ROLE OF SUBJECT MATTER KNOWLEDGE IN TEACHING A LEVEL CHEMISTRY

INFORMATION SHEET (V1)

As part of our research, we are investigating the role of subject matter knowledge in the teaching of A level chemistry, and teachers' opinions on its importance. Hence, we will be interviewing a number of A level chemistry teachers in order to gauge these perceptions and inform not only our future research, but also the measures that can be taken to improve subject matter knowledge in chemistry.

This interview consists of four sections, and will last approximately 60 minutes. The responses you provided to the online survey will inform some of the questions asked to you today. These sections focus around the following four topics:

- Teacher Training
- The Role of Subject Matter Knowledge in Your Teaching
- The A Level Curriculum
- Common Student Misconceptions at A Level

The final section will require you to answer some questions about A level content aloud. For each question in the interview, please answer as thoroughly as you feel is necessary, and express your own personal opinions.

The audio of this interview will be recorded, and the researcher will collect all writing and drawing undertaken during the interview. Please ensure that you answer all questions clearly and audibly. All collected data will be anonymised and your responses cannot be traced back to you.

Please feel free to ask any questions you may have about the study.

Stephen Barnes and Prof. David Read

Southampton Chemical Education Research (SoCER) Group

University of Southampton

APPENDIX D

Nationwide Survey Questions

The Role of Subject Matter Knowledge in A Level Chemistry Teaching

As part of our research at the University of Southampton, we are investigating the role of subject matter knowledge in the teaching of A level chemistry, and teachers' opinions on its importance. Hence, we are surveying a number of A level chemistry teachers in order to gauge these perceptions and inform not only our future research, but also the measures that can be taken to improve teacher subject matter knowledge in chemistry.

This survey consists of four main sections, and will take approximately 45 to 60 minutes to complete. These sections focus around the following four topics:

- Impact of Teacher Training
- Subject Matter Knowledge for Chemistry
- The A Level Curriculum and Beyond
- What Makes a Good Teacher?

We are extremely grateful for your responses, and will be using the findings of the project to develop new methods of improving teacher subject matter knowledge. By ticking the box below, you are showing that you fully consent to participating in this research project.

If you wish to complete this survey in more than one sitting, then you are able to save your progress. If you do save your progress, you will be required to recall the code provided to you in order to continue the survey. **Please make a note of this code if you wish to continue the survey later.**

Thank you very much for expressing an interest in participating in this study and for taking the time to complete this questionnaire.

Note that this study has been granted ethical approval by the University of Southampton.

Stephen Barnes and Prof. David Read
Southampton Chemical Education Research Group
University of Southampton

Please tick (check) this box to indicate that you consent to taking part in this survey.

Demographic Information

In which part of the UK is your school/college? (*East Anglia, East Midlands, London, North East England, North West England, Northern Ireland, South East England, South West England, Wales, West Midlands, Other*)

What type of school do you currently teach in? (*Comprehensive (LEA), Comprehensive (Academy), FE College, Free School, Independent School, Sixth Form College, State Grammar, Other*)

Which A level chemistry specification do you currently teach? If you do not teach A levels but instead teach alternative qualifications at the same level, please select 'Other' and provide details of the qualification(s) below. (*AQA, CCEA, Edexcel, Eduqas/WJEC, OCR A, OCR B Salters, Other*)

Have you taught any other A level chemistry specifications during your career? If so, please list them below.

What subject did you study at undergraduate level?

What type of degree was this? (*BA, BSc, MChem, MSc, Other)*

Do you have a higher degree? If so, please specify the degree title and subject (e.g. Ph.D. in Organic Chemistry).

If your degree is NOT explicitly titled 'chemistry', please indicate your highest level of study of chemistry. (*GCSE (or equivalent), A Level (or equivalent), 1st Year UG, Beyond 1st Year UG, Other*)

What is your highest level of study of mathematics? (*GCSE (or equivalent), A Level (or equivalent), 1st Year UG, Beyond 1st Year UG)*

Impact of Teacher Training

Which route did you follow in training to become a teacher? (*PGCE (or equivalent), GTP, School Direct, TeachFirst, Other (Please Specify)*)

In what year did you first start training to become a teacher?

How long have you been teaching? (*Currently Training, <1 yr, 1-3 yrs, 4-6 yrs, 7-10 yrs, 11-15 yrs, 16-20 yrs, >20 yrs*)

How long have you been teaching A level chemistry? (*Currently Training, <1 yr, 1-3 yrs, 4-6 yrs, 7-10 yrs, 11-15 yrs, 16-20 yrs, >20 yrs*)

What was your perception of your **level** of chemistry subject matter knowledge before you started training to become a teacher?

Were you ***confident*** in your chemistry subject matter knowledge before you started teaching?

When you initially started teaching, did your perception of your ***level*** of chemistry subject matter knowledge change? (*Yes* / *No* / *N/A*)

Briefly explain your response to the question above.

When you initially started teaching, did your ***confidence*** in your chemistry subject matter knowledge change? (*Yes* / *No* / *N/A*)

Briefly explain your response to the question above.

Was chemistry subject matter knowledge development a compulsory part of your teacher training? (*Yes* / *No* / *N/A*)

> If yes, please indicate ***how*** your teacher training enhanced your chemistry subject matter knowledge.

Did you undertake a subject knowledge enhancement (SKE) course prior to or during your teacher training? (*Yes* / *No* / *N/A*)

> If yes, please indicate ***how*** the SKE course enhanced your chemistry subject matter knowledge.

Did you engage in any **self-directed** activities to develop your chemistry subject matter knowledge while you were training that were **not** formally part of your training? (*Yes / No*)

If you answered yes to the question above, please indicate which resources you used.

My degree provided me with enough chemistry subject matter knowledge to feel **confident** teaching **GCSE** chemistry. (*Strongly Agree* → *Strongly Disagree*)

My degree provided me with enough chemistry subject matter knowledge to feel **confident** teaching **A level** chemistry. (*Strongly Agree* → *Strongly Disagree*)

Briefly explain your responses to the two questions above.

Training providers should offer more subject knowledge enhancement support during teacher training. (*Strongly Agree* → *Strongly Disagree*)

Briefly explain your response to the question above.

Subject Matter Knowledge for Chemistry

Please rate your **confidence in your subject matter knowledge** of the ten A level chemistry topics given below. The drop down menu indicates the level (GCSE, A Level, first year undergraduate, and beyond first year undergraduate) that you feel confident with your subject matter knowledge of. (*Acids, Bases, and Buffers; Analytical Techniques; Atomic Structure and Molar Calculations; Bonding and Intermolecular Forces; Chemical Equilibrium; Electrochemistry; Energy Calculations; Kinetics; Organic Chemistry; Transition Metal Chemistry*)

Please rate your confidence in **your ability to teach** the ten A level chemistry topics given below from 1 – 10, with 1 being the topic you feel **most** confident teaching and 10 being the topic you feel **least** confident teaching. (*Acids, Bases, and Buffers; Analytical Techniques; Atomic Structure and Molar Calculations; Bonding and Intermolecular Forces; Chemical Equilibrium; Electrochemistry; Energy Calculations; Kinetics; Organic Chemistry; Transition Metal Chemistry*)

Please provide an explanation why the topics you rated 1 and 2 are the topics you feel most confident teaching in the boxes below. (*Two separate answer boxes*)

Please provide an explanation why the topics you rated 9 and 10 are the topics you feel least confident teaching in the boxes below. (*Two separate answer boxes*)

Reflect on your approaches to teaching high-confidence topics and low-confidence topics (e.g. lesson planning, lesson structure, teaching methods used, etc.). What differences are there between these approaches (if any)?

Do you have any experience working in a non-teaching field (e.g. chemical industry)? If the answer is yes, please provide details of this work below, with reference to both chemistry-related and non-chemistry-related jobs.

> Do you feel that **not** having other work experience has had an impact on your teaching, compared with those who have other work experience? Briefly explain your answer.
>
> Do you find yourself drawing on your other work experience(s) in your chemistry teaching? Briefly explain your answer.
>
> I believe that having other work experience, aside from teaching, has helped me to become a better teacher. (*Strongly Agree → Strongly Disagree*)
>
> Do you feel that having other work experience, aside from teaching, makes you a better teacher than those who have **not** had any other work experience? (*Yes / No / Not Sure*)
>
> Briefly explain your response to the question above.

Having at least an A level qualification in chemistry (or equivalent) is **necessary** for teaching A level chemistry. (*Strongly Agree → Strongly Disagree*)

Having at least an undergraduate degree in a chemistry-related subject is **necessary** for teaching A level chemistry (note that the term "chemistry-related subject" is defined here as any degree with a considerable number of chemistry modules, e.g. chemistry, biochemistry, natural sciences, etc.) (*Strongly Agree → Strongly Disagree*)

Briefly explain your responses to the two questions above.

A teacher of A level chemistry should be an expert in their field. (*Strongly Agree* → *Strongly Disagree*)

Briefly explain your response to the question above.

I worry that I don't stretch my students enough in topics where my subject matter knowledge is more limited. (*Strongly Agree* → *Strongly Disagree*)

Briefly explain your response to the question above.

The A Level Curriculum & Beyond

It is an issue if an A level chemistry teacher's subject matter knowledge is limited to the A level specification. (*Strongly Agree* → *Strongly Disagree*)

Briefly explain your response to the question above.

The next two questions relate to the 2015 A level specification changes. If you were not teaching prior to 2015, please answer with 'N/A' to the questions below.

I have found it easy to adapt to the increased mathematical weighting within the chemistry A level. (*Strongly Agree* → *Strongly Disagree, N/A*)

I have found it easy to adapt to the reintroduction of the Arrhenius equation to the chemistry A level. (*Strongly Agree* → *Strongly Disagree, N/A*)

My students **can answer exam questions** involving the Arrhenius equation. (*Strongly Agree* → *Strongly Disagree, N/A*)

My students **understand the mathematical processes** involved in answering exam questions including the Arrhenius equation. (*Strongly Agree* → *Strongly Disagree, N/A*)

Briefly explain your responses to the two questions above (optional).

Generally, I feel that I am teaching my students to understand chemistry rather than teaching them to answer exam questions. (*Strongly Agree* → *Strongly Disagree, N/A*)

Briefly explain your response to the question above, commenting on the extent to which you agree with the statement given.

In an ideal world, if you could make any changes to the current chemistry A level curriculum, what would you change (if anything)? Please explain your response.

Personally, do you feel that there are any limitations to the octet rule? (*Yes, No*)

Briefly explain your response to the question above.

Personally, do you feel that there are any limitations to Le Chatelier's principle?

Briefly explain your response to the question above.

The limitations of chemical models should be taught and/or discussed at **GCSE**. (*Strongly Agree* → *Strongly Disagree*)

The limitations of chemical models should be taught and/or discussed at **A level**. (*Strongly Agree* → *Strongly Disagree*)

Briefly explain your responses to the two questions above.

What Makes a Good Teacher?

What qualities do you believe are essential in good teaching of **any subject**? Provide as little or as much detail in your response as you wish.

What qualities, in addition to those discussed above, do you believe are essential in good teaching of **chemistry** specifically? Provide as little or as much detail in your response as you wish. If you have already provided these qualities above, feel free to leave this response box blank.

I often use analogies in my teaching of A level chemistry. (*Strongly Agree* → *Strongly Disagree*)

Please provide an example of one or two analogies that have been effective in your teaching of A level chemistry.

Have you tried using an analogy in your teaching of A level chemistry but found it to be ineffective? (*Yes* / *No* / *N/A*)

> If you responded 'yes' to the question above, please provide an example of one or two analogies that were not effective in your teaching of A level chemistry.

In topics where I am more confident in my subject matter knowledge, I tend to use more analogies in my teaching. (*Strongly Agree* → *Strongly Disagree, N/A*)

Briefly explain your response to the question above.

Closing Questions

In your opinion, what can teacher training and CPD providers do in order to support A level chemistry teachers with their subject matter knowledge development **during teacher training**?

In your opinion, what can teacher training and CPD providers do in order to support A level chemistry teachers with their subject matter knowledge development **after they have qualified**?

If you are interested in hearing about the outcomes of this research project, please provide us with your email address.

APPENDIX E

Survey Phase – Ethics Forms

FEPS Ethics Committee
FEPS Ethics Application Form   Ver 2

Refer to the *Instructions* and to the *Guide* documents for a glossary of the key phrases in **bold** and for an explanation of the information required in each section. The *Templates* document provides some text that may be helpful in preparing some of the required appendices.

Replace the highlighted text with the appropriate information.

Note that the size of the text entry boxes provided on this form does **not** indicate the expected amount of information; instead, refer to the *Instructions* and to the *Guide* documents in providing the complete information required in each section. Do **not** duplicate information from one text box to another. Do not otherwise edit this form.

Reference number: **ERGO/**FEPS**/**48103	Submission version: 1	Date: 2019-03-04
Name of **investigator**(s): Stephen Barnes		
Name of supervisor(s) (if student **investigator**(s)): Prof. David Read		
Title of study: The role of subject matter knowledge in A level chemistry teaching		
Expected study start date: 2019-03-25	Expected study end date: 2020-07-31	

Note that the dates requested on the ERGO Submission Questionnaire refer to the start and end of *data collection*. These may *not* be the same as the start and end dates of the study, above, for which approval is sought. (A study may be considered to end when its final report is submitted.)

Note that ethics approval must be obtained before the expected study start date as given above; retrospective approval cannot be given.

Note that failure to follow the University's policy on Ethics may lead to disciplinary action concerning Misconduct or a breach of Academic Integrity.

By submitting this application, the investigator(s) undertake to:

- Conduct the study in accordance with University policies governing:
  Ethics (http://www.southampton.ac.uk/ris/policies/ethics.html);
  Data management (http://www.southampton.ac.uk/library/research/researchdata/);
  Health and Safety (http://www.southampton.ac.uk/healthandsafety);
  Academic Integrity (http://www.calendar.soton.ac.uk/sectionIV/academic-integrity-statement.html.
- Ensure the study Reference number ERGO/FEPS/xxxx is prominently displayed on all advertising and study materials, and is reported on all media and in all publications;
- Conduct the study in accordance with the information provided in the application, its appendices, and any other documents submitted;
- Submit the study for re-review (as an amendment through ERGO) or seek FEPS EC advice if any changes, circumstances, or outcomes materially affect the study or the information given;
- Promptly advise an appropriate authority (Research Governance Office) of any adverse study outcomes (via an adverse event notification through ERGO);
- Submit an end-of-study form if required to do so.

REFER TO THE <u>INSTRUCTIONS</u> AND <u>GUIDE</u> DOCUMENTS WHEN COMPLETING THIS FORM AND THE <u>TEMPLATES</u> DOCUMENT WHEN PREPARING THE REQUIRED APPENDICES.

STUDY DETAILS

What are the aims and objectives of this study?
The aim of this study is to investigate teachers' opinions of their subject matter knowledge and the role it plays in the teaching of A level chemistry, with reference to their undergraduate degree, teacher training, and their teaching methods. Investigating this will provide key insight into the common issues that teachers have, and will therefore allow us to develop strategies to alleviate these issues in future.

Background of the study (*a brief rationale for conducting the study)*
In recent years, there has been an increased research focus on pedagogical content knowledge (PCK) and the role it plays in science education. PCK is a term first coined by Lee Shulman in 1986, and refers to a type of knowledge possessed by teachers that is "based on the manner in which teachers relate their pedagogical knowledge (what they know about teaching) to their subject matter knowledge (what they know about what they teach)" (Cochran, 1997). Without a good level of subject matter knowledge (SMK), a teacher will have difficulty in developing their PCK. Although recent studies have investigated science teachers' SMK and how it influences their teaching, the focus has primarily been on the biological and mathematical sciences. Hence, there is scope for the role of SMK in the teaching of the chemical sciences to be explored.

Key research question *(Specify hypothesis if applicable*)
What are A level chemistry teachers' opinions of their own subject matter knowledge and the role it plays in the teaching of A level chemistry?

Study design *(Give a **brief** outline of the study design and why it is being used*)
Participants will be required to respond to an online survey. The survey consists of five main sections: demographic information; impact of teacher training; subject matter knowledge for chemistry; the A level curriculum and beyond; and 'what makes a good teacher?'. The questions in the survey relate to the participants' beliefs regarding the influence of certain factors on their subject matter knowledge (SMK) of chemistry, in addition to how important they perceive SMK to be in their teaching. An online survey has been chosen as the method of data collection in order to distribute it nationally, in addition to maximising participation amongst UK teachers.

PRE-STUDY

Characterise the proposed **participants**
The proposed participants are teachers of A level chemistry in the United Kingdom. We hope to obtain responses from teachers of different demographics, i.e. based on their teaching experience, level of degree, the subject they studied at UG degree level, etc.

Describe how **participants** will be approached
If any e-mail lists are used, including FEPS distribution lists, justify their use *here* The chemical education research group at the University of Southampton has a self-selecting mailing list of UK chemistry teachers and university staff who are interested in participating in activities here. An email will be sent to this group, and they will be encouraged to share it with their colleagues and teaching contacts (if possible). Colleagues at other UK universities have similar mailing lists for teachers interested in chemical education research projects, and we will encourage our contacts in other universities to distribute the survey as well.

Describe how inclusion / exclusion criteria will be applied (if any)
N/A

Describe how **participants** will decide whether or not to take part
When opening the survey link, participants will be presented with a 'Welcome Statement' describing the survey. If they wish to participate, they will tick a box stating that they consent to participating in the survey, and will proceed to respond to the survey.

Participant Information (Appendix (i))

Provide the **Participant Information** in the form that it will be given to **participants** as Appendix (i). All studies must provide **participant information**.

Consent Form/Information (Appendix (iii))

Provide the **Consent Form** (or the request for consent) in the form that it will be given to **participants** as Appendix (iii). All studies must obtain **participant** consent. Some studies may obtain verbal consent (and only present consent information), other studies will require written consent, as explained in the *Instructions, Guide,* and *Templates* documents.

DURING THE STUDY

Describe the study procedures as they will be experienced by the **participants**
Participants will tick the box to indicate that they consent to participating in the study. Following this, the participants will proceed through the pages of the online survey answering Likert scale questions, multiple choice questions, and open-answer questions. This will take approximately 45 – 60 minutes. Upon completion, a screen will appear saying 'Thank you for completing this questionnaire'.

Identify how, when, where, and what kind of data will be recorded (not just the formal research data, but including all other study data such as e-mail addresses and signed consent forms)
The data will be stored in the form of responses to the online survey, using the university's own survey website (isurvey.soton.ac.uk), and will only be accessible to the investigators. This data will be collected only through the online survey. The data will be downloaded from the server for analysis upon the completion of data collection, where it will be stored on a password-protected computer in possession of the primary investigator. None of the data collected is personal data. Primarily, the data collected will be in the form of responses to Likert scale, multiple choice, and some open-answer questions. The open-answer questions typically require respondents to either discuss their experiences or to elaborate on the responses given to the Likert scale and multiple choice questions.

Participant questionnaire/data gathering methods (Appendix (ii))

As Appendix (ii), reproduce any and all **participant** questionnaires or data gathering instruments in the exact forms that they will be given to or experienced by **participants**. If conducting less formal data collection, or data collection that does not involve direct questioning or observation of participants (eg secondary data or "big data"), provide specific information concerning the methods that will be used to obtain the data of the study.

POST-STUDY

Identify how, when, and where data will be stored, processed, and destroyed
If the Study Characteristic M.1 applies, provide this information in the **DPA Plan** as Appendix (iv) instead and do *not* provide explanation or information on this matter here See Appendix (iv).

STUDY CHARACTERISTICS

(L.1) The study is funded by a commercial organisation: **No** If 'Yes', provide details of the funder or funding agency *here.*

(L.2) There are **restrictions** upon the study: **No** If 'Yes', explain the nature and necessity of the **restrictions** *here.*

(L.3) Access to **participants** is through a third party: **No**

If 'Yes', provide evidence of your permission to contact them as Appendix (v). Do *not* provide explanation or information on this matter here.

(M.1) **Personal data** is or *may be collected or processed: **Yes**
Data will be processed outside the UK: **No**

If 'Yes' to either question, provide the **DPA Plan** as Appendix (iv). Do *not* provide information or explanation on this matter here. Note that using or recording e-mail addresses, telephone numbers, signed consent forms, or similar study-related **personal data** requires M.1 to be "Yes".

(* Secondary data / "big data" may be *de*-anonymised, or may contain **personal data**. If so, answer 'Yes'.)

(M.2) There is **inducement** to **participants**: **No**

If 'Yes', explain the nature and necessity of the inducement *here.*

(M.3) The study is **intrusive**: **No**

If 'Yes', provide the **Risk Management Plan,** the **Debrief Plan,** and Technical Details as Appendices (vi), (vii), and (ix), and explain *here* the nature and necessity of the intrusion(s).

(M.4) There is **risk of harm** during the study: **No**

If 'Yes', provide the **Risk Management Plan**, the **Contact Information**, the **Debrief Plan**, and Technical Details as Appendices (vi), (vii), (viii), and (ix), and explain *here* the necessity of the risks.

(M.5) The true purpose of the study will be hidden from **participants**: **No**
The study involves **deception** of **participants**: **No**

If 'Yes' to either question, provide the **Debrief Plan** and Technical Details as Appendices (vii) and (ix), and explain *here* the necessity of the deception.

(M.6) **Participants** may be minors or otherwise have **diminished capacity**: **No**

If 'Yes', AND if one or more Study Characteristics in categories M or H applies, provide the **Risk Management Plan,** the **Contact Information**, and Technical Details as Appendices (vi), (vii), & (ix), and explain *here* the special arrangements that will ensure informed consent.

(M.7) **Sensitive data** is collected or processed: **No** If 'Yes', provide the **DPA Plan** and Technical Details as Appendices (iv) and (ix). Do *not* provide explanation or information on this matter here.

(H.1) The study involves: **invasive** equipment, material(s), or process(es); or **participants** who are not able to withdraw at any time and for any reason; or animals; or human tissue; or biological samples: **No** If 'Yes', provide Technical Details and further justifications as Appendices (ix) and (x). Do *not* provide explanation or information on these matters here. Note that the study will require separate approval by the Research Governance Office.

Technical details

If one or more Study Characteristics in categories M.3 to M.7 or H applies, provide the description of the technical details of the experimental or study design, the power calculation(s) which yield the required sample size(s), and how the data will be analysed, as separate appendices.

Appendix (iv): **DPA Plan.**

DPA Plan

Ethics reference number: **ERGO/**FEPS**/48103**	Version: 1	Date: 2019-03-04
Study Title: The role of subject matter knowledge in A level chemistry teaching		
Investigator: Stephen Barnes		

The following is an exhaustive and complete list of all the data that will be collected (through questionnaires, interviews, extraction from records, etc): email addresses.

Providing an email address is optional for participants. Participants can provide their email addresses if they are interested in the outcomes of the research project, such that the investigators can contact them with this information in future. Participants' names will be collected.

The data will be processed fairly because the participants will have given explicit consent for their survey responses to be used in the research project.

Data will be stored on the investigator's laptop, which is password protected, and will only be accessible to the investigators involved in the project (S. M. Barnes and D. Read). The data will be held in accordance with University policy on data retention.

The data will be processed in accordance with the rights of the participants because they will have the right to access, correct, and/or withdraw their data at any time and for any reason. Participants will be able to exercise their rights by contacting the investigator (e-mail: S.M.Barnes@soton.ac.uk) or the project supervisor (e-mail: D.Read@soton.ac.uk).

Appendix (v): Evidence of permission to contact (prospective) **participants** through any third party.

N/A

Appendix (vi): **Risk Management Plan**.

N/A

Appendix (vii): **Debrief Plan**

N/A

Appendix (viii): **Contact Information**

N/A

Appendix (ix): Technical details of the experimental or study design, the power calculation(s) for the required sample size(s), and how the data will be analysed.

N/A

Appendix (x): Further details and justifications in the case of: **invasive** equipment, material(s), or process(es); **participants** who are not able to withdraw at any time and for any reason; animals; human tissue; or biological samples.

N/A

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