In what ways can a subject-specific professional development programme support beginning science teachers in their teaching of physics

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A Research & Development Project

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In what ways can a subject-specific professional development programme support beginning science teachers in their teaching of physics?

Abstract

Supporting beginning teachers in the early stages of their career has been acknowledged as an important factor in resolving the current teacher retention crisis as demonstrated by the introduction of the Department for Education Early Career Framework. Given that physics teacher retention is a particular and persistent concern, despite the implementation of numerous initiatives to remedy the problem over decades, this practitioner-led action research project piloted a programme aimed to support the transition between ITT and the NQT year with a series of physics specific interventions. This small-scale study explores beginning teachers' perceptions about key areas for development in their physics teaching and, given their experience of professional learning, what they perceived to be the most effective strategies to develop their subject knowledge and pedagogical content knowledge. The findings demonstrate that sharing the wisdom of practice of experienced teachers in a research-informed subject specific, six-week online support programme was perceived to increase the SMK and PCK of both specialist and non-specialist beginning teachers, and that translating generic epistemological ideas into physics specific examples for classroom practice was highly valued. The affective domain was also enhanced, and, by applying the analytical lens of self-determination theory, changes in competence, autonomy and relatedness were also noted and explored. Furthermore, the structure of the online course was perceived to be particularly effective in its resonance with the theory of how beginning teachers learn. The implications of these findings are discussed in the context of designing a new national programme to support NQT and RQT science teachers who will be teaching KS3 physics in the next academic year.

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1.Rationale and introduction

> 'Physics is a way of seeing—the spectacular and the mundane, the immense and the minute—as a beautiful, thrillingly interwoven whole.' (Lewin et al., 2012)

The pivotal role of the teacher in stimulating such an appreciation of physics in their students and encouraging a desire for further study cannot be underestimated (Woolnough, 1994; Mutjaba & Reiss, 2013), yet the fact that many non-specialist teachers who have responsibility for teaching the subject approach it with 'dread' (de Winter, 2011:9) signals a real issue for physics education.

The shortage of physics teachers is a well-documented and long-standing concern (Smith, 2010; Hillier et al., 2013) and in the current teacher recruitment and retention crisis in England, physics is the subject most affected. Data from the Department for Education (DfE) Initial Teacher Training (ITT) Census 2019-20 shows that physics has the lowest percentage of recruitment against target at only 43%. This figure is particularly concerning given that bursary payments of up to £28,000 are available to attract eligible graduates. Coupled with the fact that exit rates are extremely high in the early stages of a teacher's career, with only 50% of physics specialists remaining in state-funded schools after five years (Sibieta, 2020), this means that the issue is a huge concern for those involved in both physics education and physics teacher education.

In addition to early career teacher attrition, The National Foundation for Education Research (NFER) found that more experienced teachers are also leaving the profession with 62% of secondary teachers aged 50-59 retiring early (Worth et al., 2018), thus making the recruitment and retention of beginning teachers even more important. The loss of experienced teachers may also add pressure onto new recruits in two ways; firstly, by removing valuable mentoring and collaborative learning opportunities which can be provided by working with experienced colleagues (Williams, 2001; McNicholl et al., 2013) and secondly, by placing a burden of extra responsibility on early career physics specialists who may find themselves the only subject

specialist within their department. Many newly qualified teachers (NQTs) have found that being the only physicist in their department can prove to be very isolating (Hillier et al., 2013) and in my professional experience, this can also lead to an increased workload in terms of providing physics specialist input for curriculum planning.

In order to remedy this situation, I would argue that it is vital to support our beginning teachers particularly as the crisis may be exacerbated with secondary pupil numbers set to increase again, by 19% between 2017 and 2026 (DfE, 2017), further increasing the demand for teachers.

The current recruitment and retention problem is not a purely contemporary phenomenon, indeed, the issues raised seem part of a long-established problem (Smith, 2010) despite numerous attempts by policy makers to find a solution. The introduction of the Early Career Framework (ECF) (DfE, 2019) which was announced in January 2019, for early roll out in September 2020 and national implementation a year later, forms part of the government's response to the potential crisis in teacher provision in England as described above. It makes the provision of a supportive induction process mandatory for all state-funded schools in England. However, although secure subject knowledge is acknowledged as helping 'teachers to motivate pupils and teach effectively' (DfE, 2019:19), it does not specify any detailed subject specific support for teachers. Physics support is available from The Institute of Physics (IoP) via a plethora of free online resources and continued professional development (CPD) events. Additional support is also provided by The Ogden Trust, a charitable trust that exists to promote the teaching and learning of physics, through their Early Career Teacher Development programme which aims to support beginning physics teachers in their subject knowledge and pedagogical development (Ogden Trust, 2018). Less support is available for non-specialists who find themselves teaching physics, however many teachers have found the DfE funded Teacher Subject Specialism Training (TSST) course useful, with 90% of participants stating they would recommend the course (Coldwell et al., 2017), but this scheme is scheduled to end in March 2021 and as yet future provision has not been confirmed.

I find this particularly concerning as, based on my professional experience of delivering physics subject knowledge enhancement courses for trainee and practising teachers, I have recognised that there is a need for additional subject specific support, especially in the early years of teaching. The beginning teachers that I have worked with in recent years have voiced concerns that the input they have received to support their teaching of physics has been insufficient and, as a result, have expressed doubts about their self-efficacy in this area. This was confirmed in my Part 1 assignment research. In light of the current recruitment and retention crisis, it seems important to address these perceptions as evidence suggests that self-efficacy links to job satisfaction which can subsequently affect retention rates (Skaalvik & Skaalvik, 2010; Hobson & Maxwell.,2017).

In my current role working for a national charitable trust for physics education I have responsibility for CPD provision for a network of over 500 schools throughout England, which includes the development of a national programme of sustained physics support for trainee and novice science teachers (hereafter, referred to as beginning teachers). Having responsibility for such schemes bestows a level of obligation on two counts; firstly, to ensure that the financial investment provided by the charitable trust is used effectively and secondly, that the teachers who commit their time to the CPD scheme receive high-quality provision that is relevant and supportive. To that end, I plan to conduct an action research study with the aim of gaining valuable insights to both improve my practice as a teacher educator and to inform the design of the new professional development scheme for beginning teachers. This seems particularly pertinent as the current cohort of beginning teachers have had a significant reduction in their teaching practice due to the COVID-19 school closures.

Given the context above and my own CPD role this research and development work is an action research study which, in a reconnaissance phase, explores beginning teachers' perceptions about key areas for development in their physics teaching and, given their experience of professional

learning, what they perceive to be most effective strategies to develop their subject matter knowledge (SMK) and pedagogical content knowledge (PCK). From the beginning teachers' perceptions elicited in the reconnaissance phase, an intervention was designed and its effectiveness investigated.

The literature review will explore some key themes in order to shape my action research project. As the study has been prompted by the retention issues outlined earlier, I will start by reviewing the literature regarding teacher retention with a particular focus on beginning teachers and recommendations from the findings of related studies. I will then explore teacher growth and the factors that may affect this, including a consideration of the issues and challenges of teaching out of specialism. In order to inform the planning of my professional development intervention, I will move on to consider teacher learning and what constitutes effective CPD in terms of both participant experience and facilitator input. As the study is looking at the perceptions of beginning teachers which may go beyond purely cognitive aspects, I will also explore the broader qualitative aspects of the affective domain.

2. Literature review

2.1 What can we do to aid retention?

The teacher recruitment and retention crisis is currently of utmost concern in science education as outlined in the rationale, however, the problem is a long-standing one and numerous strategies have been implemented to remedy it (Smith, 2010; Hillier et al., 2013) so we have to question whether the introduction of the Early Career Framework (DfE, 2019) could prove to offer an effective solution. The Framework aims to resolve the retention issue in two ways; firstly, by reducing workload in the first two years of teaching and secondly, by mandating CPD during this induction period.

Reduction of workload is beyond the scope of this study so I will now consider what the literature suggests with regard to professional development having a positive influence on retention.

The second strand of the new initiative, improving access to CPD, is strongly endorsed in a recent meta-analysis of professional development with Fletcher-Wood & Zuccolo (2020) claiming that professional development can make the difference between remaining or leaving the teaching profession and, of particular interest to my study, subject specific CPD was found to have a significant effect in early career science teachers (Allen and Sims, 2017). This, coupled with the findings of research on the impact of Science Learning Centre courses (Wolstenholme et al., 2012), indicates that subject specific support could be a key factor in tackling the retention challenge in science.

There is also evidence to suggest that *effective* professional development influences job satisfaction (Sims, 2019) and as a dramatic drop in job satisfaction is noticeable before a teacher leaves the profession (Walker et al., 2018) it is of paramount importance to understand what characterises effective CPD and this will be considered in section 2.6.

Providing opportunities for collaboration constitutes part of the DfE Standards for professional development (DfE, 2016) and this is underpinned by much research evidence (see for example Burn, 1997; Hargreaves & O'Connor, 2018; McNicholl et al., 2013). The nature of such collaborative learning was explored further by Williams et al., (2001) who found that working collaboratively with experienced colleagues in a 'spontaneous' way was the 'most powerful development tool' (p.265) when considering induction for NQTs as it provides responsive and ongoing support. Due to the shortage of physics teachers this may prove problematic and many schools will need to work with external partners to provide such opportunities, but a constraint of this system is that the collaboration is more structured in nature. However, this disadvantage can be counterbalanced by the value of learning from external partners, and such learning has been noted as a powerful tool to aid retention by Sims (2019). The advantage of learning from

experienced teachers was echoed in the findings from the evaluation of the TSST courses (Coldwell et al., 2017) which were provided for non-specialist teachers working outside of their specialism in the shortage subjects of physics and mathematics.

The important role that external partners can play was noted by Coe et al., (2014) in their research across multiple subjects, which found that the provision of alternative perspectives and challenge to current practice could prove advantageous. The value of this kind of collaboration between teachers and external voices aligns with Clarke and Hollingsworth's 'interconnected model of professional growth' (2002: 951) and what Cordingley et al., (2015:8) refer to the value of 'critical friendships'. External support of this kind can also provide beneficial networking opportunities for beginning teachers by broadening their informal and professional support networks (Walker et al., 2018) and reducing feelings of isolation (Hillier et al., 2013).

To conclude, this section argues that effective CPD, and in particular subject specific CPD, provided by external experts may provide some solutions to the retention problem and should therefore, be addressed in my action research study.

2.2 How do teachers develop in the early career stage?

Having established that providing subject specific CPD can be beneficial for beginning teachers, understanding how we can support their development must be our critical starting point and research into the stages of teacher development can provide valuable insights for shaping this support. Kraft and Papay (2014) investigated how teachers improved over time by plotting their effectiveness (based on mathematics achievement of their pupils) against their experience and the data show that over the first two years their effectiveness increased rapidly, with a very steep initial learning curve which gradually flattens then plateaus (Figure 2.2.1). The shape of this graph mirrors the development trajectory described by Berliner (2004) in his stage theory of teacher

expertise. Unsurprisingly, the findings show that teacher development takes time, and data from both studies suggest that competence may take three to five years to achieve.

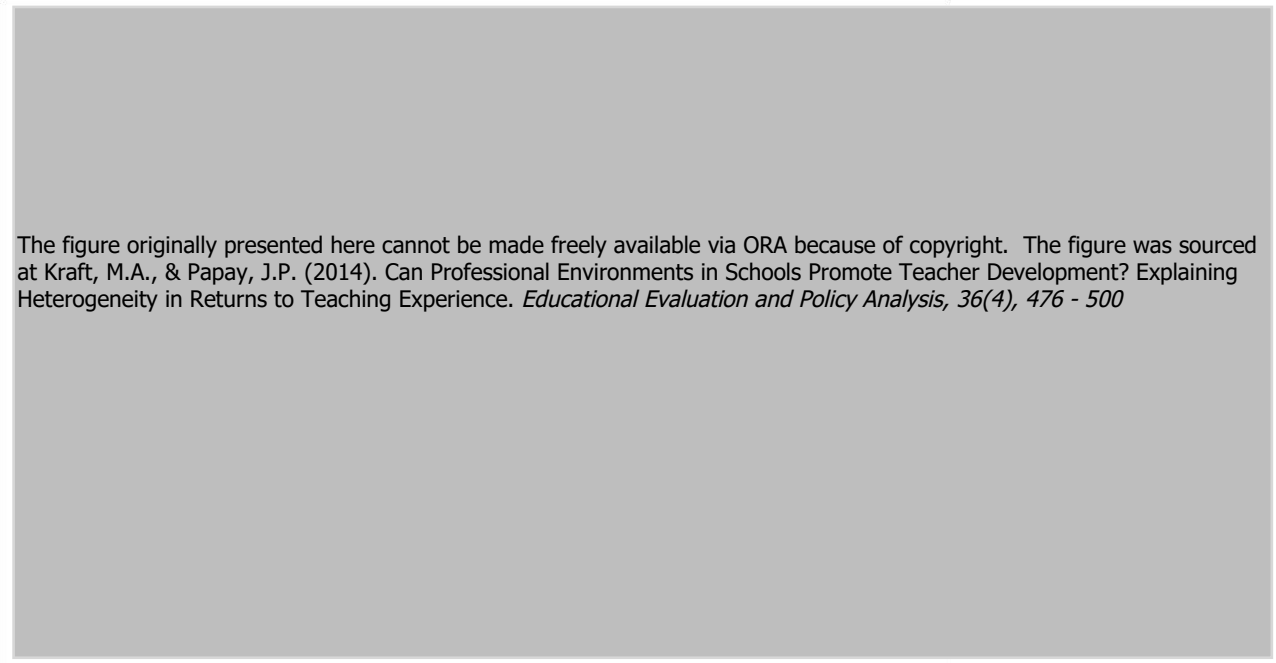


Figure 2.2.1 Teacher development (Kraft & Papay, 2014)

However, there is evidence to suggest that suitable interventions can accelerate the development of expertise in beginning teachers (Maandag, 2017; Heritage, 2008) and as (Scutt, 2020) posits a cyclical relationship between job satisfaction, retention, effectiveness and self-efficacy, it seems important to uncover the key features of such interventions with a particular focus on the early career stage.

Although the early career stage is a period with potential for immense growth, this intense period of knowledge growth can also be a period of uncertainty where the beginning teachers feel vulnerable and can lack confidence. Fuller and Brown's (1975) description of the first stage of teacher development as being one of survival is a common theme in the literature (Etkina et al., 2017; Williams et al., 2001), and the term survival implies that perceptions of competence and self-efficacy may be low at this initial stage, positioned as they are at the base of a steep learning

curve. Henson (2001) found that more effective teachers tended to have greater self-efficacy, therefore, it can be argued that any intervention that accelerates a teacher's progress up the learning curve will lead to increased self-efficacy. Higher levels of self-efficacy were found to increase job satisfaction and retention rates (Skallvik and Skallvik, 2010) and we need to act to provide support that will allow beginning teachers to flourish rather than just survive at the crucial early stage of their career when the drop-out rate is particularly sharp (DfE, 2019; Middleton, 2020). The recent teacher recruitment and retention strategy document confirms this reasoning stating, 'not enough teachers receive the high-quality support and development they need at the outset of their career when the learning curve is steepest' (DfE, 2019:19). Allen and Sims (2018) argue that a step-by-step approach is needed in order to aid the ascent up the learning curve, but this is judged to be at odds with our current front-loaded teacher training system and for many this stage can prove daunting, and a perceived lack of competence can be demotivating.

Many writers argue that effective professional development needs to be ongoing and sustained (Cordingley et al., 2015; Clarke & Hollingsworth, 2002) and, as such, ITT must be seen as just the first step into teaching. Simon et al., (2011:19) define professional development as 'a complex process, beginning with the pre-service teacher's experience and continuing throughout a teaching career' and there seems to be a growing awareness of the need for more homogeneity between ITT and ongoing support provided to promote teacher growth in the early years of teaching (see for example, McIntyre et al., 2009, Hobson et al., 2008).

Kraft and Papay (2014) investigated variations in the rate of teacher growth and found a positive correlation between a strong professional environment and a faster rate of progression. They categorised the constituents of such an environment and the features relevant to my study were peer collaboration, highly qualified teachers and high-quality professional development. Coldwell (2017) offers further support for the emerging high profile of CPD by suggesting that effective

professional development causes an increase in confidence and self-efficacy which in turn makes it more likely for teachers to stay in the profession.

In summary, this section reinforces the importance of CPD which is sustained beyond initial teacher training to ensure that the beginning teachers grow and maintain their upward trajectory yet feel supported through a period of vulnerability.

2.3 Professional development

The evidence suggests that professional development could provide part of the possible solution to the long standing retention problem, but as stated earlier, numerous policy-led programmes and initiatives have been implemented over the past few decades with varying degrees of success (Smith, 2010; Hillier et al., 2013), so what can we learn from the literature to ensure that any new initiative will have a positive effect?

For clarity, as teachers learn and develop in many different ways through experience and interaction, for the purpose of this study I will focus on the aspect of professional development that occurs as a result of organised learning interventions (Maandag, 2017).

Professional development is often broadly defined to be any activity which promotes teacher growth *after* initial teacher training (Creemers et al., 2013; Caena, 2011), but this definition could provide an insight into the problem, in that it makes a distinction between pre-service and in-service training. The lack of coherence and continuity between these career stages has been identified as a problem for beginning teachers making this transition (Hobson et al., 2008). A unique university-led programme, Early Professional Development (EPD) (McIntyre al., 2013) sought to alleviate the problem and this project seemed to resonate with my research. They

identified the following five principles to underpin their intervention to enhance the experience of the beginning teachers:

- coherence of provision with early career CPD forming a 'bridge' (p.6) and building on pre-service training
- allow time and support for reflective practice
- provide individualised support
- address the emotive and affective side of teacher development
- provide trusted and sustained networks

In addition, the importance of a growth environment within their schools was identified which is akin to the findings of Burn et al., (2010) and a key characteristic of Kraft and Papay's (2014) strong professional environment.

These findings struck a chord as they place the emphasis on the personal and social domains as opposed to the more cognitive approach that seems to traditionally typify teacher education literature and the next section looks to explore this area further.

2.4 Self-Determination theory (SDT)

The broader qualitative aspects of teacher education are not a new consideration with work by Bell & Gilbert, (1996) and Loughran, (2006) looking beyond cognitive concerns to the affective domain. As argued above there is evidence that seems to show that the emotional and affective side of beginning teacher development needs to be properly addressed (McIntyre et al., 2009).

SDT provides an analytical framework to examine the affective domain of individuals in their professional setting, by categorising the three 'psychological nutrients required for optimal motivation, engagement, and well-being' (Legault,2017:7) as being autonomy, competence, and

relatedness. Educational research by Allen & Sims, (2018) found that the framework can be applied to the teaching profession and a recent report by (Worth & Van den Brande, 2020) shows that these three domains can lead to intrinsic motivation in teachers which subsequently results in the desired outcome of job satisfaction and retention.

For a broad and simplistic overview of these three basic psychological needs we may consider the following descriptors of these categories (Legault, 2017):

- *Competence* relates to self-efficacy in the sense of showing and improving our abilities
- *Relatedness* is a feeling of being closely connected to or cared for by others
- *Autonomy* is having choice and control over one's actions

So how can we apply this framework to supporting beginning teachers?

Competence: the importance of attending this need in the early stages of teacher development has been identified and discussed in Section 2.2 and will be explored further in section 2.5.

Relatedness: the value of providing a supportive network to nurture the beginning teachers and pre-empt feelings of isolation has also been mentioned previously (Section 2.1) and this resonates with the findings of the EPD study (McIntyre al., 2013) described in section 2.3.

Autonomy: studies by Kagan (1992) and Bowe & Gore (2017) recognise that autonomy can aid professional growth, yet the extent of this influence can be context dependent (Scutt, 2020). Furthermore, Worth & Van den Brande, (2020) found evidence that autonomy over professional learning opportunities had the greatest effect on increasing job satisfaction and the intention to remain in teaching, albeit with a caveat that such autonomy does not necessarily mean total freedom. Beginning teachers may need guidance to consider the relevance of the professional development to their individual needs or the wider needs of the school and its pupils. This research suggests that providing some element of choice could be beneficial in a support

intervention for beginning teachers and again there is resonance with the EPD study which suggests that providing individualised support can enhance the experience of beginning teachers.

The analytical framework of SDT was also used by Hobson and Maxwell (2017) in their secondary analysis of four empirical studies to conceptualise the factors that form the affective domain for the well-being of beginning teachers. Although secondary analysis can be critiqued on the grounds of lacking contextual information and being incompatible with the research aims, the researchers took precautions to mitigate these. As the studies under scrutiny included a project which looked at ITT and early professional development and a physics enhancement programme their findings were of particular interest. They report that beginning teachers' perceptions of relatedness, competence and, to a lesser extent autonomy, had a positive impact on their wellbeing. It would, therefore, make sense to ensure that consideration of these psychological needs was integrated into any support intervention for beginning teachers.

Hobson and Maxwell (2017) also report that factors beyond SDT such as environment and context also had an effect and, of particular interest for my research, the highest rated factor in promoting teacher well-being was identified as support for professional learning and development.

2.5 What knowledge do teachers need to teach?

Having established the importance of CPD in the early career and highlighted the significance of attending to the psychological needs of beginning teachers, research also shows that we need to develop the teacher knowledge base of these teachers. This ties in with the competence aspect of SDT, as supporting their knowledge development, particularly for those teaching out of specialism, can lead to increased perceptions of self-efficacy and competence (Coldwell, 2017), which in turn, can affect job satisfaction and retention (Worth & Van den Brande, 2020). It is, therefore, of paramount importance that teacher educators unpick the key components of the teacher knowledge base, in order to design and deliver impactful CPD; this opinion is backed up by Stender

et al., (2017: 1) who describe understanding what teachers need to know as 'the holy grail of teacher education research'. This section will focus on two key aspects of the teacher knowledge base: PCK and SMK as they are particularly relevant to my study which is centred on novice and non-specialist teachers.

2.5.1 Pedagogical content knowledge (PCK)

There is a vast amount of literature which explores the main aspects of this knowledge base (see for example Lee & Luft, 2008; Shulman, 1986; Berry et al., 2015) with SMK and general pedagogy providing the cornerstones and the influential construct of PCK providing a bridge between the two with Shulman (2015:8) describing it as:

> That special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding.

PCK has been adopted widely as a useful tool to develop our understanding of teachers' professional practice however, individual researcher's interpretations of PCK vary greatly. Academic reviews found the following two components, which are consistent with Shulman's original conception, are common to most interpretations (Kind, 2009; Lee & Luft, 2008:1346):

- representations and instructional strategies which includes using illustrations, analogies, explanations and demonstrations to transform SMK into an accessible form for students
- knowledge of students' subject specific learning difficulties such as misconceptions, preconceived ideas, barriers to learning, connections to other concepts and problem-solving strategies

Many consider PCK to be the essence of good teaching; encapsulating everything that beginning teachers need to aid their development as illustrated by the bold claim that 'if you could bottle it

and administer it to a novice, they would become an expert overnight' (Kaiser & Reid, 2020). Other researchers support this view with Lee and Luft (2008: 20) identifying the need to 'capture the knowledge that is held by science teachers' and Schneider and Plasman (2011) concluding that an explicit focus on PCK is necessary in their review of science teachers' development. Furthermore, many models of the knowledge base of teachers use the concept of PCK as a way of understanding the professional practice of teachers, however, due to its 'elusive nature' (Kind, 2009:198) it can be difficult to reveal and section 2.6.1 will focus on suggested techniques for teacher educators to use.

In short, it is about taking SMK and translating it into a form that is accessible to learners, and unsurprisingly, a recent study commissioned by the DfE identified that this is an area that many novice teachers find difficult and therefore, need support with (Walker et al., 2018:20):

> New teachers' confidence in their own knowledge of a topic appears to be greater than their confidence in their ability to teach that knowledge which, in turn, is greater than their confidence in their ability to develop teaching materials on the topic.

Whilst PCK is a well-respected construct there are some additional aspects of the teacher knowledge base which are not featured in the framework that can be illuminating when trying to unpick the development of beginning teachers. An alternative lens to analyse how SMK is revealed in teaching is provided by The Knowledge Quartet (KQ) (Rowland et al., 2005 and Rowland, 2013), which was originally used in mathematics education. The KQ comprises four broad bases of teacher knowledge: foundation, transformation, connection and contingency. The foundation base incorporates teacher beliefs and SMK, whereas the transformation base has many commonalities with PCK as it covers representation and strategies and an insight into learner difficulties and misconceptions.

The connection base aligns closely with knowledge of goals, curriculum organisation and assessment; components of PCK identified by Lee and Luft (2008). This area can present problems for both beginning and non-specialist teachers as they can be unsure about topics and sequencing (Schenider and Plasman, 2011; Childs and McNicholl, 2007).

Contingency may prove even more challenging for beginning teachers as it involves reacting spontaneously yet educatively in the moment with confidence, and this knowledge-in-interaction often relies on experience and expert knowledge, indeed Berliner (2004:203) describes such 'fluid expertise' as a key feature of the adaptive expert teacher.

2.5.2 Subject matter knowledge (SMK)

Most science education research does not integrate SMK with PCK (Loughran at al., 2001; Carlsen, 1999) because PCK is predominantly concerned with the transformation of SMK, however, Kind's review of PCK in practice (2009:187) concludes that 'SMK is a prerequisite for developing effective PCK'. Nonetheless, SMK and PCK may not be quite as distinct as this suggests with Kinach (2002) proposing that relational SMK questions should be interleaved with PCK strategies, therefore, as teacher educators we must not neglect the development of SMK.

Lack of SMK in pre-service teachers can lead to some serious issues in their transmission of information and narrowing their input, with Childs and McNicholl's (2007) finding that teaching out of specialism can be 'unadventurous and lacking cognitive challenge' (p.5) resonating with de Winter's view that non-specialists have a 'restricted breadth of understanding' (2011:161). Whilst this may be detrimental to the students they teach, it can also reduce teacher efficacy (Bandura,1977) and consequently reduce their desire to remain in the teaching profession (Donaldson & Johnson, 2010). The level of SMK required for a particular age group is also an important consideration (Kind,2009) with many beginning teachers struggling to make the

'transition' from their own advanced level of understanding and requiring guidance on the distinction between academic science and school science (Kind and Taber, 2005:187).

The literature also highlights the importance of addressing teachers' misconceptions in teacher education programmes as research has shown that non-specialist teachers who may lack SMK can hold misconceptions similar to those of their students (Gomes-Zweip, 2008 and Sadler & Sonnert, 2016). One surprising claim from Karal and Alev (2016) suggests that this lack of SMK can be used as a development opportunity, by taking the teachers' personal experiences of the challenge of understanding unfamiliar topics, and using it to help with their PCK development, in so much that they are able to predict students difficulties in areas where they had decreased SMK, however, this view is a minority one and is strongly countered by Abd-el-Khalick & Lederman's (2010:670) claim that 'teachers cannot possibly teach what they do not understand'.

The implications for teacher education are that simply signposting common misconceptions to learner teachers i.e. using a 'teaching by telling' model as described by Knight (2004:41) is insufficient and adopting a more constructivist approach is suggested (Larkin, 2012; Palmer, 2005; Treagust, 1988) in order to refute and reconstruct the correct understanding in the teachers, and also to model how to translate this effectively into their classroom practice.

2.6 What makes effective CPD?

2.6.1 Pedagogical reasoning

As the literature posits that supporting beginning teachers by providing quality professional development may accelerate their learning trajectory (Maandag, 2017, Kraft and Papay, 2014), I will now explore what the research recommends in terms of providing a strong professional environment in terms of CPD.

SIms (2019) suggests that effective science CPD should include both subject knowledge and pedagogy in order to improve the quality of science teaching in schools and, as PCK provides the bridge between these two aspects it would, therefore, seem to be key for teacher development. Improving PCK can prove problematic for beginning teachers with limited classroom experience as this 'wisdom of practice' (Shulman, 1986:9) is generally acknowledged to develop with increased teaching practice (Loughran et al., 2008). McNicholl et al., (2013:169) observed that PCK 'gradually emerging through interaction' therefore, in order for teacher educators to deliver effective CPD they must consider how to reveal their tacit knowledge so that beginning teachers can learn from them. Uncovering 'craft knowledge' (Burn & Mutton, 2015:218) can prove challenging for teacher educators and, as a result, they often adopt a transmission or didactic mode of delivery described as the 'recipe' style approach (Crowe and Berry, 2007:31) resulting in the transfer of situated knowledge which can be very context specific. Research suggests that, in order for the CPD to be more effective than show and tell, we should move towards a meta-cognitive style, where the teacher educator provides opportunities for the beginning teachers to be actively involved in the learning process through activity and discussion as it is more likely to cause change and promote sustained teacher learning (Cordingley et al., 2015).

Thus, in order to generate PCK in novice teachers, it seems important for teacher educators to articulate their pedagogical reasoning (Loughran, 1995; Russell & Loughran, 2007). Indeed Korthagen et al., (2006:1036) state that 'learning about teaching is enhanced when the teaching and learning approaches are modelled' by teacher educators. This approach has been used effectively in the Californian 'Physics Teacher SOS' scheme (Baird, 2013) which utilises the craft knowledge of experienced teachers who offer a series of workshops in which they use practical demonstrations to introduce and develop understanding of a particular physics concept; this is often referred to as phenomenological learning (Baird, 2013).

The experienced teachers model how they would perform demonstrations and articulate how they would develop the dialogue with their pupils as well as highlighting problem areas, possible misconceptions, connections and extension questions. They share their wisdom of practice and make their tacit reasoning explicit by providing a commentary of pedagogical reasoning as advocated by Bishop and Denley (2007).

Providing beginning teachers with scaffolding in this way may provide the key to supporting them (Zeichner, 2005; Sims & Fletcher-Wood, 2018) and some researchers (Stender et al., 2017; Zazkis et al., 2009) go further by suggesting the implementation of teaching scripts and other similar approaches. However, it could be argued that this reduces the beginning teachers' autonomy and, as such may prove detrimental to their job satisfaction (see section 2.4). In contrast, if teacher educators focus on developing teachers' ability to choose the most appropriate learning strategy and how to adapt it for different contexts they can be considered to be 'generating PCK' in their work with beginning teachers (Zeichner, 2005 ; Van den Berg, 2015:574).

Shulman (1987) divides pedagogical reasoning into four sub-stages: critical interpretation, representation, selection and adaptation and tailoring and although it may be useful to consider each discrete area separately and provide examples when developing the repertoire of the beginning teacher, Bishop and Denley (2007) noted that highly accomplished science teachers interweave these aspects skilfully and this can be difficult to deconstruct, however translating their professional experience clearly is key for a teacher educator (Goodwin and Kosnik, 2013).

2.6.2 Professional learning environment

Kraft and Papay's (2014) place a strong professional environment at the heart of teacher progress along the learning trajectory. Therefore, I will now look to uncover how this can be applied to CPD settings. Maandag et al., (2017:23) declares that 'adults are motivated to learn when they are in an atmosphere that is safe and respectful, when they are related to others, when content is meaningful.' Similar themes are drawn out by Wilson, (2013) who cites nurturing meaningful relationships and building supportive, non-threatening learning environments as essential for professional growth.

In a similar vein, building such an environment is vital to establish 'trust and rapport' (Russell and Loughran, 2007:37) to allow for an honest, yet sensitive, approach when subject knowledge or experience is lacking. The EPD study identified trust as a fundamental feature when working with beginning teachers who may feel vulnerable due to lack of classroom practice, negative feedback or when teaching out of specialism (Knight, 2004). All of these features highlight the importance of emotion in teacher learning and tie in with the psychological need of relatedness described in the section 2.4.

2.6.3 Promoting buy-in

A common theme picked out by many researchers is that CPD needs to be relevant and practice based in order to provide buy-in from teachers (Sims & Fletcher-Wood, 2018; Weston & Hindley, 2019) and that there is a higher likelihood of engagement when CPD responds to need and accounts for preconceptions (Gomez-Zweipp, 2008; Karal & Alev, 2016). It is essential that CPD is perceived to be connected to classroom practice (Korthagen & Kessels, 1999; Schneider & Plasman, 2011) and this personal connection will also attend to the psychological need for relatedness as described earlier. In order to ensure this connection teacher educators can design programmes which afford opportunities to 'think like a teacher' (Crowe & Berry, 2007:39), interact

collaboratively with colleagues (Burn, 1997) and experience activities and methods that are relevant to their own practice (Grangeat & Kapelari, 2015).

2.6.4 Integrating educational theory

Beginning teachers may not always appreciate the relevance of educational theory to their classroom practice and the dilemma of how best to integrate theory and practice in ITT courses has been a long-standing concern (Korthagen et al., 2006). 'Practice shock' (Walker et al., 2018:54) describes a common experience for beginning teachers when they struggle to acclimatise to the reality of being an NQT and lose sight of some of their theoretical knowledge. The problem was explored by Korthagen & Kessels, (1999) when they sought solutions to this problem. They found that trainee teachers were not sufficiently prepared due to lack of integration between the epistemological theory and phronesis, theory which is situation-specific and relevant to their classroom experience. They advocate that synthesis of the two aspects is advisable with their integrated approach or 'realistic teacher education' (p.7). They suggest that the theoretical insights offered by the teacher educator should veer more towards the model of phronesis than be purely epistemological; that is, at a very simplistic level the teacher educator should translate the educational theory into practice, or reframe it, when it is needed and, therefore, relevant. For this to be effective the trainee teacher needs to have had useful experience in the classroom to build a picture and create personal meaning. Once experience has built up, reflection is key to developing logical connections and with skillful guidance from a competent teacher educator a powerful cycle can ensue. However, without reflection time and skilled support it has been argued that a move away from rigorous traditional coverage of theory has led to the reverse problem with teacher training being reduced to just 'learning tricks of the trade' (Korthagen et al., 2006: 1021) which could ultimately hinder professional growth.

This need for professional experimentation is corroborated by Clarke and Hollingsworth (2002) as it underpins their cyclical model of teacher growth. It too suggests a responsive approach in which teacher educators provide opportunities for the teachers to enact change in their professional practice. They advise against one-off workshops with passive participants working on a deficit model of teachers' skills and suggest a shift towards a more constructivist approach, with teachers taking an active part in 'shaping their professional growth through reflective participation' (p948). Salient outcomes have also been seen when theory and practice are not viewed as dichotomous but are interwoven in an integrated approach with Burn & Mutton (2015) perceiving the benefits of such 'research-informed clinical practice' (p.217) extend beyond initial teacher training.

An example of this approach is an initial teacher education programme, the Oxford University Internship scheme (Burn & Mutton, 2015) for secondary trainee teachers which is based on practical theorising which entails trainee teachers synthesizing evidence from both decontextualized education research and personal information from their own professional experience and reflecting on them to develop their professional thinking and practice.

2.6.5 Reflective practice

Reflection is an integral part of each of the approaches described so far in this section and the findings of (McIntyre et al., 2009) show that early career provision should aim to help beginning teachers to become reflective about their practice. Reflective practitioners are likely to take responsibility for their CPD and grow to become adaptive experts who avoid the plateau stage described by Kraft and Papay (2014) and Berliner (2004). However effective reflective practice, that is reflection on practice to inform future practice, does not come naturally to all and, therefore, needs nurturing during beginning teacher education (Loughran, 2002).

2. 7 Online learning

As this research and development project is being conducted during the COVID-19 lockdown period, online provision of the professional development interventions is the only viable option available and additionally, due to the rapid growth in uptake of online CPD and the likely constraints we face due to social distancing in the year ahead, it seems a promising solution to providing sustained CPD (EEF, 2020) for the future, therefore, I will now explore what the literature reveals regarding this mode of delivery.

Research has found that online CPD is subject to the same limitations and challenges of face-to face provision (Fishman et al., 2013), however, we need to dig deeper with regard to the specific modes of interaction within such provision. As my interventions are synchronous workshops with similar structure to those which would be delivered face-to-face, I will not investigate asynchronous provision. Synchronous CPD has been found to be valued by participants with the advantage of responsive interaction over-riding any disadvantages they may encounter due to the rigid time schedule (Yates, 2014). Furthermore, it can be argued that if the platform for delivery is changed but the content remains largely similar, one may not expect different outcomes (Clark, 1983), but given the practical nature of physics there are some constraints on how much can be replicated in an online forum. One alternative tool that has been trialled successfully is to embed videos of practical work which align with the aims of the session (Blomberg et al., 2013).

Mirroring the metacognitive approach described in section 2.6.1, online learning has been proved to be more successful (Sims, 2003) if participants are more actively engaged, and online facilitators are advised to orchestrate participation by encouraging discussion in order to overcome any discomfort that participants could feel due to unfamiliar protocols and interactions Salmon (2006). In this respect, Salmon (2002) promotes the importance of building relationships in her online

teaching and learning model that resonates with the importance of the supportive learning environment described in section 2.6.2.

Having reviewed the literature relating to developing a sustained, subject-specific professional development programme to support beginning science teachers, I will carry out a small-scale action research project with the following research questions:

RQ1: What do the beginning teachers perceive to be key areas for development in their physics teaching?

RQ2: Based on the professional development they have received so far, what strategies do they perceive to be most effective in developing their subject knowledge and pedagogical content knowledge?

3. Overall Methodology

3.1 Context

This study was conducted with a cohort of trainee science teachers who were in their last term of their ITT course and about to transition to their first teaching posts. The ITT programme in question is a collaboration between countywide secondary schools who work together in a school centred initial teacher training provider. It offers several routes into teaching including Qualified Teacher Status with Post Graduate Certificate in Education (PGCE) in partnership with a local University and School Direct. The physics provision consists of two full days and four twilight sessions, and I lead the twilight sessions.

The study was centred on an optional physics CPD project which aimed to provide a coherent transition between ITT and the NQT year with the aim that supporting this transition might address the issues of retention raised in the introduction.

The study took place during the COVID-19 lockdown and the implications of this were two-fold; firstly, the trainees did not complete their final school placement which significantly reduced their teaching practice and secondly, the data collection and intervention sessions were all conducted online.

3.2 Action research – why?

This research project is a small-scale practitioner led action research study to support beginning teachers to develop their physics SMK and PCK and, in so doing, bolster their cognitive and affective self-perception so as to smooth the passage from ITT to being an NQT and hopefully support their continued retention in the profession. By doing my research, I also aim to improve my practice in supporting beginning teachers. As a practising teacher who provides physics CPD for both trainee and early career teachers, in recent years I have found that it has become increasingly obvious that the teachers have significant concerns about the quantity of physics input during their training. My Part 1 research, in conjunction with the findings of my literature review, confirmed this (McIntyre et al., 2009 and de Winter & Airey, 2020) and this is the problem I want to tackle. When contemplating the design frame for my research and development project, I was prompted to consider action research as Denscombe (2002: 27) describes it as a way 'to tackle a problem or enhance the performance' through changes to the way practitioners operate and Bell (2005) states that it is carried out by practitioners who have identified a need for change or improvement.

Further reading reinforced my decision to use action research as the design frame with several writers describing it as a response to an identified problem (Rapoport, 1970; Cohen & Manion, 1994). The subsequent reflective cyclic processes and evaluation inform the practitioner and allow them to develop a better understanding of the problem, so as to design and implement interventions which are formulated to provide solutions to the problems identified, monitor and

evaluate these by systematic analysis and modify where appropriate in order to achieve improved outcomes (Opie, 2004 and Thomas, 2017) which aligns well with what I hope to achieve.

Lewin (1946) is often attributed to be the founder of the action research cycle and his cyclical model seems appropriate to adopt (Figure 3.2.1) as it provides a suitably simple framework to scaffold my research and design project around:

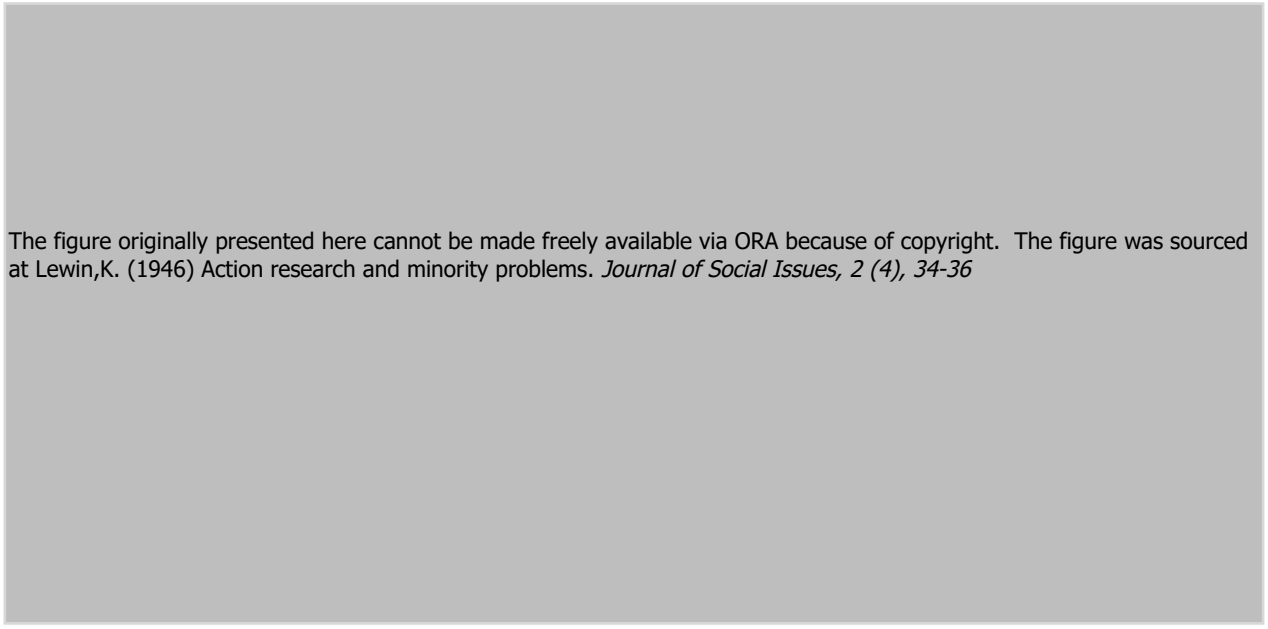


Figure 3.2.1 Lewin's (1948) Action research cycle

The structure synthesizes the key features described in most action research models; providing a continual refinement of practice based on collecting evidence and reflection, yet it retains a simplicity suitable for the environment that I will be working in.

Whilst action research appears to be a good approach to take, there are certain drawbacks which will need to be considered: because it is practitioner-led there could be a tendency that familiarity may limit objective thinking and in some cases action research may be highly relevant to the situation but may not be scalable (Wilson, 2013).

The first of these issues is more relevant to my project as it involves interpretive qualitative research and my personal and professional perspectives and beliefs could influence my interpretations, so I will need to consider my positionality and acknowledge my subjectivity in my findings (Thomas, 2017 and Opie, 2004).

Leading on from this, whilst there are debates in the literature about whether practitioner action research can be called research as the practitioner is an insider, it can be argued that this type of research can have an equally valid purpose (Elliott, 2009) and, as the purpose of my project is to test out ideas to change and improve my practice and evaluate these changes, it fits with the principles of professional action research described by Wilson (2013).

3.3 Phases of the research

Table 3.3.1 details the structure of my design frame in line with Lewin's model (Figure 3.2.1).

Phase	Lewin's model	Research & development project	Timing
Reconnaissance	Identifying a trend or initial idea	Professional experience, field notes and discussions – ITT Physics Pathways and TSST sessions with NQTs Literature review	April 2019 – March 2020
	Reconnaissance or fact finding	*Initial interviews – finding the baseline* Research questions: *What do the trainee teachers perceive to be key areas for development in their physics teaching during the last term of their initial teacher training year?* *Based on the professional development they have received so far, what strategies do they perceive to be most effective in developing their SMK and PCK?*	March 2020
Action research cycle 1	Planning	Analysis of qualitative data Designing 3 workshops: • Forces • Electricity • Earth & Space	March – April 2020
	First action step	Intervention online workshops (see above)	March – April 2020

	Evaluate	*Second interviews – to evaluate intervention 1 and to identify further needs* *RQ1: In what ways did the interventions meet the perceived cognitive needs of the trainee teachers with regard to developing their physics PCK and SMK?* *RQ2: In what ways did the trainee teachers perceive that the structure and delivery of the interventions met their needs in terms of the affective domain as identified in the reconnaissance phase?*	May 2020
Action research cycle 2	Amended plan	Analysis of qualitative data Designing 3 workshops: • Cognitive Science in the Physics Classroom, • The Slightly Awesome *Physics* Teacher • Improving Secondary Physics – translating the EEF recommendations for use in the physics classroom	May 2020
	Second action step	Intervention 2 - online workshops (see above)	May- June 2020
	Evaluate	Final interviews – *to evaluate intervention 2 and ascertain key strengths of the support programme to inform future practice* Research questions: *RQ1: In what ways did the interventions meet the perceived cognitive needs of the trainee teachers with regard to developing their physics PCK and SMK?* *RQ2: In what ways did the trainee teachers perceive that the structure and delivery of the interventions met their needs in terms of the cognitive and affective domain as identified in the reconnaissance phase?*	June 2020

Table 3.3.1 Phases of the research

3.4 Collaboration

3.4.1 With the participants

The very nature of practitioner-led action research means that collaboration is at the heart of the cyclical process. Sagor (1992) extols collaborative action research as a commitment to thoughtful practice and developing an active professional community. It can be considered a vehicle for using professional expertise to solve real problems and one which reflects the applied nature of teaching (Oja & Pine, 1987). The three-stage interview process, coupled with plenary discussions will provide the impetus for the collaboration in my study and my interpretation and implementation at each stage will subsequently be evaluated by the participants in order to ascertain whether it was responsive to their needs. Although this shared dialogue is being curated to gain insight into the trainee teachers' perceptions of physics teaching and professional development there is some evidence that suggests that the dialogue itself can be a rewarding component of collaborative action research (Levin and Rock, 2003).

3.4.2 With teacher educators

The initial plans for the action research project (pre-COVID-19) involved collaborating with a teaching colleague on the delivery of the intervention sessions. During the lockdown, a combination of managing a new mode of working and providing home-schooling for his children preventing this from happening.

One of the workshops in the second phase of the intervention cycle was co-presented with a fellow teacher educator as his area of expertise matched one of the themes that emerged from the intermediate interviews. However, as he is an English specialist, I decided to plan this session collaboratively with him so that it had the required physics slant, as it was clear from both the literature (Cordingley et al., 2015; Sims, 2019) and the participants' previous responses that subject-specific examples were very important. We worked together to adapt his training session

based on his popular education book, 'The Slightly Awesome Teacher' (Salles, 2016) to incorporate relevant physics examples throughout and we co-presented the session online.

4. Reconnaissance phase

4.1 Research questions for the reconnaissance phase

RQ1: What do the trainee teachers perceive to be key areas for development in their physics teaching during the last term of their initial teacher training year?
RQ2: Based on the professional development they have received so far, what strategies do they perceive to be most effective in developing their subject knowledge and pedagogical content knowledge?

During the reconnaissance interviews I aimed to find the baseline and explore which physics topics and pedagogical approaches that the trainee teachers felt needed extra support and to uncover their individual concerns regarding the teaching of physics. I sought information regarding the strategies that they found most useful from the professional development they had received to date. These insights will be used to inform the design of the support intervention which is the focus of section 5.

4.2 Methodology for the reconnaissance phase

4.2.1 Data collection

As my research questions demonstrate I am seeking to explore the perceptions of the trainee teachers, I will adopt a qualitative approach using semi-structured interviews in order to gain a personal and in-depth insight which could inform my action research interventions and future practice. I appreciate that this approach is limited as data of this type cannot lead to any statistical

claims and the size of the sample is too small to make any generalisations (Cohen & Manion, 1994). However, for my practitioner-led action research it seems an appropriate tool to use due to the adaptability it provides, as ideas can be followed up and responses can be probed, where appropriate, for development and clarification (Bell, 2005). It can provide greater richness of responses than questionnaires as semi-structured interviews allow for 'a depth of feeling to be ascertained' (Opie, 2004: 118) whilst still maintaining an overall shape and structure in contrast to unstructured interviews (Thomas,2017).

Whilst focus groups can also be useful for revealing the beliefs, attitudes and perceptions of participants and the interaction between them can reveal valuable information (Wilson, 2013) they may have the drawback of dominant personalities influencing the discussion disproportionately compared to less assertive members (Bell, 2005). Due to the timing of my research in the COVID-19 lockdown all discussions were been conducted online and, as there can be issues with flow of conversation in group conference calls, individual interviews seemed more appropriate.

The skill of the interviewer is an important factor and there are many facets which need to be considered. Interviewing in this way is a subjective technique and therefore there is danger of bias (Thomas, 2017), particularly when only one researcher is involved (Bell, 2005) and that researcher is an insider. The researcher must avoid placing too much emphasis on facts that they believe to be true and ignoring information that doesn't resonate with their personal beliefs (Miles and Huberman, 1994). Wilson (2013) advises that listening is more important than talking and Opie (2004) encourages pausing for responses and warns against leading questions. In order to mitigate these issues, I designed my interview questions so they were not leading, listened and asked follow-up questions that also didn't lead and asked for clarification e.g. 'can you say more about this?' where necessary. It is important to establish trust, put the interviewee at ease and build a rapport with them (Opie, 2004; Thomas, 2017; Wilson, 2013). As these interviews were conducted

during the COVID-19 lockdown all were carried out remotely via telephone or online audio call and, although I already had a positive professional relationship with the participants, I was careful to always start each session with everyday conversation to put them at their ease in order to build rapport and trust as indicated above.

I conducted a series of semi-structured interviews following a schedule based around my research questions (Appendix 1) with seven trainee teachers from an ITT programme. This represented half of the current cohort and all of those who volunteered to participate in the research were included. Opportunity or convenience sampling in this way may seem restrictive as it will not allow my conclusions to be generalised (Wilson, 2013) but as the project was conducted during the COVID-19 school closures there were external constraints beyond my control. It could be considered purposeful sampling as a range of ages and routes into teaching were present with all three science specialisms represented. Details of the participants can be found in Appendix 3. After the reconnaissance interviews each participant was interviewed on a further two occasions as detailed in table 3.2.1.

4.2.2 Ethical considerations

Ethical issues were considered throughout the investigation, following the BERA guidelines (2011). CUREC clearance was sought and granted (Reference: ED-CIA-20-136) and consent was obtained from the participants (Appendix 2). The participants were informed that that their participation was entirely voluntary and that they had the right to withdraw at any stage. They were informed that all participants would remain anonymous in written reports and that any audio recording would done on a PIN-protected audio recorder, deleted from the audio recorder within a week and that transcriptions of parts of the interviews would be anonymised and stored in password protected files.

Although I provide training as part of the ITT course I am classified as an external tutor and, as such, do not have any influence on the outcome of their assessment and therefore there were no significant power issues to contend with. The interventions that were offered were optional and did not form any part of the formal assessment of the ITT course. As the workshops offered were designed to take account of their perceived needs and were not compulsory, they were not externally imposed and, therefore, again did not present any significant ethical issues.

The interviews were carried out during the testing time of the COVID-19 school closures and some of the participants described feeling vulnerable. Several participants referred to shortcomings of their ITT course provision and I had to ensure that I was empathetic whilst still maintaining a professional stance. For example, one participant shared their opinion that physics provision had been better than the other sciences as there had been more of it, I was able to respond by explaining that the physics support intervention was an optional, extra scheme in order to maintain the reputation of the ITT programme. This was not a poor reflection of the provider but due to wider issues of content and time pressure which was exaggerated by the abrupt end to their teaching practice placements imposed by the COVID-19 lockdown, however, if my findings were to suggest that there are inadequacies in the ITT provision, which needed to be addressed, this must be handled sensitively.

Many of the participants were struggling to adapt to time pressures of completing their course online whilst also providing childcare for their families, therefore, I was particularly aware of minimising my demands on their time and being flexible to fit with their schedule. To that extent, each session was repeated to provide choice. The interviews were also conducted at a time of their choosing and they participated on a voluntary basis.

4.2.3 Data analysis

Having carried out semi-structured interviews with the aim of seeking understanding and insight into the perceptions of the trainee teachers with regard to subject specific CPD and how it can help them to develop their physics teaching, I had collected a large quantity of qualitative data to interpret (all seven participants were interviewed for approximately 30 minutes). Given that I would be taking an interpretivist stance to analysing this data the constant comparative method of coding described by Thomas (2017) and Wilson (2013) seemed to fit with my aims of unveiling the perceptions of the trainee teachers at each stage of the action research cycle by allowing themes to emerge which then form the basis of the analysis. This grounded approach was adopted as opposed to the use of a priori coding in order to elicit the perceptions of the participants.

The application of the constant comparative coding method to my research is detailed here. The research questions for my reconnaissance phase were used in the preliminary interviews. These interviews were audio recorded and some notetaking was performed during the interview to guide my thinking with regard to further questions. After the interview the audio recordings were transcribed, and the coding process was started by reading through the transcriptions and highlighting parts that seemed important. Recurring ideas across the whole data set were picked out as temporary or first order constructs, for example, practical activities and physics identity (see Appendix 4). The data were revisited, and temporary constructs were noted alongside a table of references for any illuminating quotes. Examination of these notes allowed the elimination of some of the temporary constructs which were not reinforced in the rest of the data. For completeness, counter examples were also highlighted and collated. The most prominent features across all seven transcripts were drawn out as second-order constructs, for example, misconceptions and transformation of content into an accessible form for students. The data were

re- examined systematically in light of the new second-order constructs and the emergent themes which encapsulated the essence of the data were identified, for example, the second order constructs described above were combined in the theme of PCK. This systematic approach reveals patterns and enables a large quantity of qualitative data to be crystallised into manageable sections.

4.3 Findings from the reconnaissance phase

The purpose of the reconnaissance phase was to collate the perceptions of the trainee teachers to inform my thinking regarding the design of the support intervention and by using the constant comparative coding method as a systematic analytical tool to interrogate my qualitative data from the semi-structured interviews I was able to identify some dominant themes which emerged from the second order constructs. A summary of these themes in Figure 4.3 provides a broad-brush overview of the findings which will be discussed in the next section.

The dominant themes show that the participants perceive their key areas for development are to improve their SMK and PCK within the paradigm of physics (RQ1). Their references to the affective domain reveal the importance of accounting for this in any intervention strategy. The teacher education theme explores their perceptions in relation to RQ2.

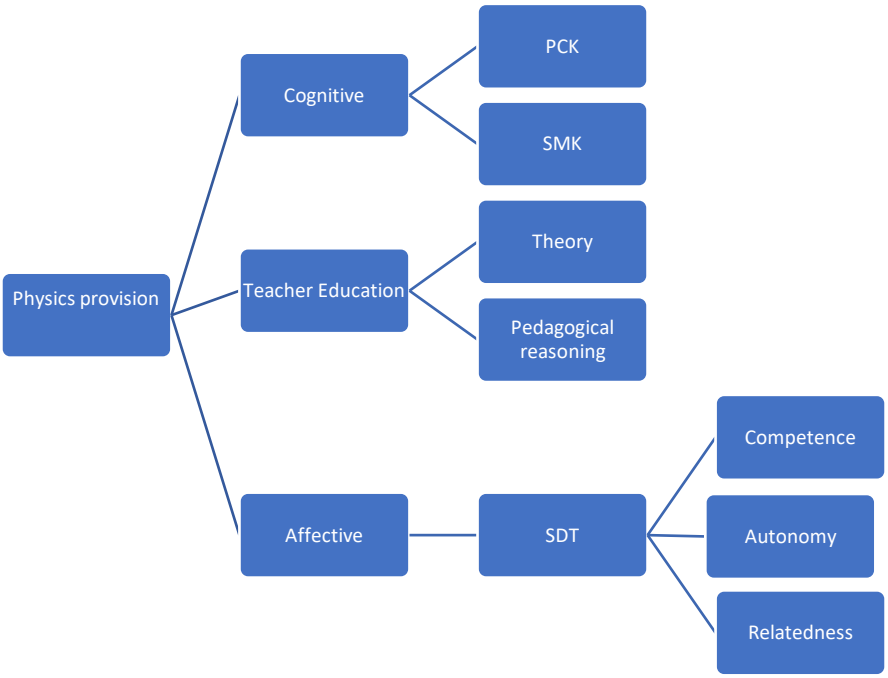


Figure 4.3 Network analysis of emergent themes

4.3.1 Physics specific input

In terms of addressing RQ1 a key area the trainees referred to was in physics. Some typical responses were:

> Any physics CPD - I've lapped it up, but it is too concentrated, too short a period of time. (Respondent 2, R2)

> I feel pretty overwhelmed and I find it (teaching physics), still, pretty overwhelming. (R1)

These concerns of a deficit model of training provision (Clarke & Hollingsworth, 1986) have been backed up by de Winter and Airey (2020:3) in their recent physics education paper which states that 'subject-specific aspects of teacher competence has been limited and fragmented'. In the interviews it also became clear that opportunities to observe physics lessons or work with physics specialists in their school placements had been very scarce and the following quote illuminates this perception:

> I feel frustrated by the lack of observations – I just don't know what physics teaching looks like. (R1)

Having established their perceived need for more physics input I will consider each of the emergent themes in more detail below in order to shape my support intervention.

4.3.2 Pedagogical content knowledge (PCK)

As described in the literature review, Shulman's (1987) concept of PCK comprised of two components: representations and instructional strategies and knowledge of students' subject specific learning difficulties. The first of these components was the most prominent theme in the interviews and most participants mentioned that they felt they needed help to develop ways of making SMK accessible to their students, which chimes with Shulman's statement describing the learning process of teachers (1987: 13):

> -to becoming able to elucidate subject matter in new ways, reorganise and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations so that it can be grasped by the student.

Whilst the participants were able to mention areas that they felt were of particular importance for their development, the responses predominantly featured generic concerns relating to practical ideas and demonstrations with a particular focus on explanations and how to approach topics. This seemed common for both the physics specialists and non-specialists with just slight nuances to be seen at times.

The non-specialists seemed particularly aware of the constraints of their repertoire:

> I want to know how to bring physics to life with practical activities, my imagination doesn't extend to physics practicals. (R6)

> You want to learn what's the best way to teach a topic – what the tips and tricks are. (R2)

The physics specialists had additional concerns about transforming their subject knowledge into an accessible form for their students *at the right level*, for example respondent 3 said:

> I need to be moving from lecture style and avoid going off at a tangent into areas that are too complex
>
> At the start of my ITT year and after 4 years of research into quantum physics my journey of doing teaching – oh, I don't actually remember this thing that a Year 7 is supposed to do. (R5)

This difference of knowledge about science versus school science has been acknowledged previously as something that novice teachers need help with (Kind and Taber, 2005 and Kind, 2009) and would seem, therefore, a valid concern to be addressed in my intervention.

From this data I concluded that my interventions should feature many practical and creative examples of methods to elucidate physics concepts and develop understanding through demonstrations, use of models and analogies with a clear focus on explanations and an emphasis on the level of knowledge expected at each stage.

An area that requires significant time allocation in the intervention design is student misconceptions, a feature of PCK, which is of particular importance as physics is a subject in which misconceptions abound. In the work of Pine et al., (2001) over half of the misconceptions in science identified were physics based, however, although they are prevalent, they are also predictable as much research has been carried out in this field. (Driver, 1981). Both Shulman (1986) and Rowland et al. (2005) place emphasis on the importance of teachers pre-empting problem areas due to student misconceptions. The interviews showed that the trainee teachers had a heightened awareness of this aspect of student learning as they had recently completed a University assignment on student misconceptions, however several acknowledged that they

themselves held the same physics misconceptions as their students, for example respondent 4 said:

> I realised that I didn't understand the real reason why it is hotter here in the summer. I thought it was due to the earth being closer to the Sun – I learnt it myself when I was researching common student misconceptions!

Whilst PCK is a powerful way of unpicking the knowledge base of a teacher, the Knowledge Quartet, (Rowland et al., 2005), has some additional facets beyond those provided in Shulman's PCK model and one of these knowledge bases; contingency, acting educatively in the moment when the classroom dialogue takes an unanticipated turn, featured heavily in the data from the reconnaissance interviews:

> I'm going to have to become comfortable with the challenge when someone asks a good question - I go on too long, talk too quickly when I'm nervous. The CPD sessions are useful to highlight or pre-empt issues that could occur. (R4)

> I'm worried about dealing with questions - I don't know what to say – I find it's really useful when you share your experience. (R3)

It can be difficult for a teacher educator to develop contingency knowledge, but by raising awareness of misconceptions and potential problem areas these skills may be developed and opportunities to prepare for and rehearse contingent moments should be included in the intervention plans.

4.3.3 Subject matter knowledge

When questioned all of the participants held the view that they could work on their SMK independently and would prefer to use any professional development sessions for improving their PCK. The following responses paint a picture of their perception of SMK as being a distinct entity:

> Key Stage 3 science input is not so useful, you can figure that out yourself. As science graduates you can teach yourself any necessary subject knowledge. (R2)

> If it's just content, you can look that up yourself. (R4)

However, I would argue that some of their other responses provide telling insights which contradict these views and suggest that this area can indeed prove problematic, for example, several of them voiced concerns regarding answering questions from students which required explanations that tested their subject knowledge. This resonates with Kind's (2009) belief that SMK is a prerequisite of PCK and the findings that SMK should be interleaved with PCK development (Kinnach, 2002; Karel & Alev, 2016).

In light of this, my own professional experience and research which shows that non-specialist teachers may have a narrow repertoire which is restricted due to their lack of SMK (Childs & McNichol, 2007, de Winter, 2011) it would seem pertinent to ensure that my interventions are underpinned by the development of SMK.

4.3.4 Teacher education

A key theme which emerged in the analysis under teacher education related to RQ2 was the identification of the importance of having the experienced teacher's pedagogical reasoning made clear (Bishop & Denley,2007 and Crowe and Berry, 2007) and one respondent demonstrated a developing awareness of the tacit skills enacted by teachers:

> In teaching practice, you focus on presentation skills in the classroom, that's what's being modelled, you don't see the hidden stuff, it's not overt. (R1)

When probed further it became clear that they valued opportunities to gain insights into the understanding the pedagogical reasoning of practising experienced teachers, in particular, having explanations of how to adapt to different contexts and discussions to evaluate different approaches:

> Showing how you can teach things for the particular age groups, for example, the energy stores and transfers and modelling that with the liquid beaker model was really useful. (R4)
>
> Examples of how to teach certain ideas, going through demonstrations you can use in the classrooms, practical examples of how to teach things with pros and cons - here's what I've done, what's worked, what hasn't so learning from teachers who have taught it .The experience side of teaching is what you learn from. (R5)
>
> You share your experience, give us a leg up, prepare us for that curveball.(R3)

This highlights an issue considered in the literature review; the accumulated, experiential knowledge of an accomplished classroom teacher can be viewed by teachers as providing credibility and value in terms of contemporary insights (Murray and Male, 2005) but it must be counter-balanced with the importance of having teacher educators who have developed the skills and adopted the principles of practice necessary to provide meaningful growth (Cordingley et al., 2015 and Korthagen et al., 2006) to ensure that the provision is more than just passing on 'tricks of the trade' (Childs and McNicholl, 2007:8).

The other aspect of teacher education that emerged in their evaluation of the professional development they had received to date, was the front-loaded input of theory during their induction weeks. The majority of the participants claimed that they had found the input interesting at the time but had not been able to process the information once their school placements began as one described:

> Two weeks of professional studies you just sit and listen, some of it was quite interesting but didn't know how to apply it to teaching, blindly listening - I don't think I've ever gone back to that stuff as once I got in school the rest of the course took over. (R5)

This view of the disconnect between theory and practice is indeed supported by the literature (Korthagen et al., 2006). Further questioning elicited the opinion that although they would like to revisit some of the content of the induction programme, but their more pressing concerns were linked with developing their PCK.

4.3.5 Self-determination theory

In terms of the affective domain linked to RQ2, it became apparent that as well as the overt cognitive needs related to subject knowledge and pedagogy there were also many references to the affective domain and in particular, their feelings towards teaching physics. I will use SDT (Ryan and Deci, 2000) as described in the literature review, as an analytical lens to categorise their perceptions and take account of them when designing the support interventions.

i) Competence

Personal competence was the main cause of anxiety and it encompassed the basic ability to survive (Fuller and Brown, 1975), dealing with contingent moments (Rowland et al., 2005) and a general feeling of unpreparedness due, in part, to the reduction in their teaching practice due to Covid-19.

This small sample is indicative of the large range of concerns expressed by the trainee teachers:

> If I don't use this time, I'm going to drown. (R7)

> I'm flailing around trying to find resources. This course should be two years – I feel unprepared and still find it pretty overwhelming – it's sink or swim! (R1)

> My fear is that a child will come for help for explanation and I won't be able to help - it's such a long time since I did physics, it all feels new. (R6)

These comments resonate with the 'survival' view of the early years in teaching and show how novices must feel at the bottom of the steep learning curve of teacher effectiveness (Kraft & Papay, 2014; Berliner, 2004) but the fact that they had missed the last term of their ITT year lay at the root of most of their concerns.

As this action research study was prompted by concerns regarding the attrition of beginning teachers the interventions must aim to allay these fears as they are significant and could lead to a lack of self-efficacy which is in turn linked to job satisfaction, effectiveness and retention (Henson, 2001; Sims, 2017 and Scutt, 2020).

ii) Autonomy

This domain was interesting to analyse, with two distinct views emerging. The importance of having a choice of approaches, resources and strategies was important to most of the trainee teachers:

> I like having a choice of resources and approaches. (R6)

> I want lots of ideas so you can pick and choose what you think will work. (R2)

Conversely a small number of the teachers alluded to wanting a formulaic approach as they found too much choice was overwhelming.

> I need to make it into a process, I need a formula at which I can become efficient. (R5)

Respondent 1 described the contrast from his previous career:

> My previous profession was very orthodox – there was a certain way of doing things, but with teaching there are so many things to use and try – it's like walking into a supermarket, you don't know what to choose off the shelf. I find that overwhelming.

In my professional opinion, when designing any intervention, it would be dangerous to dictate a set way of teaching a particular topic as this would remove both autonomy and any scope for adapting resources to the individual class context, however, providing examples of frameworks and strategies that can be adapted to suit a range of situations may be helpful to make it seem less overwhelming.

iii) Relatedness

The power of the collective and a feeling of belonging was valued by all of the participants and it seemed particularly important to the younger trainee teachers. They valued the support of the community of peers and found it therapeutic to have a safe space to air their concerns:

> I love the science group – the WhatsApp group chat – we just talk about lesson plans, if someone is unsure, we give ideas, any worries or stressful times, it gives reassurance, everyone in the same position really helps. (R2)

When questioned about their motivation for signing up for the extra physics intervention, after identifying a need for physics help, the most common reason was the familiarity of the existing group and trust in the facilitator:

> I'd have been less keen to sign up if I hadn't known anyone. (R7)

> When I got the email, because it was linked with your course., I thought I'll sign up because I know I can trust your sessions, the things you provide, I don't feel worried about giving up the time. (R4)

It was evident that the feeling of relatedness went beyond the present and several participants were already thinking ahead to their NQT year and how they would feel part of a group:

> There are no other NQTs in my Department so it would be nice to check in with the group again. (R4)

> I'm going to share some ideas with my department. They've liked some of my ideas so far. (R5)

These insights resonate strongly with the findings of the EPD study (McIntyre et al., 2013) and highlight the need to account for psychological needs when designing support interventions so as to build their feeling of competence, provide tools for some level of autonomy and recognise the importance of the group dynamic. The literature on principles of practice supports this affective domain by stressing the importance of a secure, non-threatening environment and teacher education techniques designed to promote teacher growth (Loughran, 2006; Russell & Loughran, 2007, Wilson et al., 2010).

4.4 Summary of findings from the reconnaissance phase:

The network analysis and subsequent consideration of the emergent themes, leads me to conclude that the support interventions should be designed with the following points in mind:

1. Include demonstrations, model and analogies with clear explanations to develop the first aspect of PCK.
2. Focus on diagnosing and refuting misconceptions held by the trainee teachers and offer classroom strategies for incorporating this practice.
3. Explicitly model dialogue, highlight problematic areas and allow time for trainees to rehearse contingent moments.
4. Ensure that SMK is consolidated and developed through the activities incorporated in the intervention.

5. The principles of practice of creating a secure, non-threatening environment conducive to developing their practice as effectively as possible and one in which I make my pedagogical reasoning explicit will be key to the delivery of the intervention.
6. The design of the intervention must have underlying affective foundations to build their competence, provide them with tools to work autonomously and nurture the relatedness that the group provided and they obviously valued.

5. Action research cycles

5.1 Design of intervention in response to findings

The analysis of the qualitative data from the reconnaissance phase, in conjunction with the findings from the literature review and my own professional experience, led me to the following aims for the first intervention cycle:

a) to develop PCK
   - by including demonstrations, model and analogies with clear explanations which addresses the first aspect described by Shulman (1986) of representations and strategies
   - focus on diagnosing and refuting misconceptions held by the trainee teachers and offer classroom strategies for incorporating this practice in line with the second aspect of subject specific learning difficulties

b) to place SMK as an underpinning principle so that it can be consolidated and developed through the activities incorporated in the intervention

c) to ensure that my approach as teacher educator
   - will explicitly model dialogue, highlight problematic areas and allow time for trainees to rehearse contingent moments

- will place key principles of practice at the core of the provision; creating a secure, non-threatening environment and one in which I make my pedagogical reasoning explicit

d) to account for the underlying affective aspects that are essential for self-efficacy and, therefore, linked to retention, are developed throughout the intervention cycle

As described above the general principles found from the reconnaissance phase determined the design of the interventions. The first cycle consisted of a suite of three topic-based workshops on Forces, Electricity and Earth and Space. Each workshop was one hour long and was conducted online (via Zoom, a web-based meeting platform) due to the COVID-19 lockdown.

I decided to delay the emergent theme of revisiting theory from their induction weeks until the second cycle of interventions as my reconnaissance research revealed that there was enough to cover in terms of developing topic based PCK which had featured more prominently in their responses.

Each workshop had some common components and followed a similar format incorporating hooks, SMK summaries, demonstrations, simulations, models, making connections, diagnosing and refuting misconceptions. See Appendix 5 for details of the Electricity workshop.

5.2 Evaluating Cycle 1 -Research questions and methodology

RQ1: In what ways did the interventions meet the perceived cognitive needs of the trainee teachers with regard to developing their physics PCK and SMK?

RQ2: In what ways did the trainee teachers perceive that the structure and delivery of the interventions met their needs in terms of the affective domain as identified in the reconnaissance phase?

The methodology was the same as for the reconnaissance phase and so the justification for the use of the data collection methods remains the same.

The second set of interviews were conducted following cycle 1 of the action research project, with the aim of evaluating the first intervention cycle of online workshops, in terms of whether the trainee teachers perceived their needs had been met with regard to developing their PCK and SMK, which strategies were most effective for them, and what they perceived needed further development in the second intervention cycle. As before the interviews were semi-structured, audio recorded and lasted between 25 – 40 minutes long (see schedule in Appendix 1).

The qualitative data gathered were processed and analysed in the same way as before using the constant comparative coding method described in section 4. A grounded approach was used but it has to be acknowledged that the original themes that emerged in the first phase did influence the data analysis in that the coding and identification of themes were informed by the previous analysis.

5.3 Phase 1 evaluation: findings and adjustments to intervention

5.3.1 *RQ1: In what ways did the interventions meet the perceived cognitive needs of the trainee teachers with regard to developing their PCK and SMK in relation to their physics teaching?*

Analysis of the data shows many areas of SMK and PCK that the trainee teachers perceived met their needs.

Firstly, feedback showed that the strategies put in place to transform the SMK into an accessible form for use in the classroom, that is, my attempts to develop their PCK (Van den berg, 2015; Crowe & Berry, 2007) were particularly valued:

> How you transform what you've got to teach them, it's exactly what I need and why I continue to keep signing up because I found every session invaluable. (R6)

> It is the practicalities of it, I've got physics A-level, but it was a long time ago. I'm quite happy to check my understanding by finding information I need but it's translating it across that's the tricky bit. (R4)

The quote above shows that the foundational belief that SMK is separate to PCK is resistant to change, but as previously described all of the sessions had SMK underpinning the activities as advocated by Kinach (2002) and Kind (2009).

Secondly, diagnosing misconceptions was a key feature of each workshop in response to their preliminary comments and the literature which suggests that many novice and non-specialists teachers hold misconceptions similar to those of their students (Gomes-Zweip, 2008; Karal & Alev, 2016; Sadler & Sonnert, 2016). In line with the recommendations (Treagust, 1988; Palmer, 2005) we looked at ways to refute and reconstruct the correct understanding in the teachers, and to model how to translate this effectively into their classroom practice:

> I now get the phases of the Moon! The black and white ping pong ball model made it so clear – I loved it. (R7)

> Actually, identifying my own misconceptions was really useful. The time to explore and develop understanding has helped me and I will definitely aim to take this approach with my classes. (R6)

Thirdly, making connections to other concepts as referenced in Shulman's (1986) original conceptualisation of PCK and also in the Knowledge Quartet (Rowland et al., 2005) was an emergent theme, with the beginning teachers identifying difficulties with sequencing coherent

paths through topics and recognising the appropriate level of conceptual challenge. This can prove particularly challenging for teachers working outside of their specialism (Childs & McNicholl, 2007). This theme emerged strongly in the evaluation of the first cycle with comments ranging from a position of complete concern:

> I need to know what to do - a lot of the time you don't know what comes next really. (R7)

to a deeper level of resonance with other participants:

> I really liked what you said about starting electricity with static - it just made perfect sense – it reminded me of when I taught photosynthesis. With photosynthesis I was able to re-order the teaching sequence it as it was my specialism, however, out of specialism I can't do that. Now it makes perfect sense. (R6)

> Electricity - you did it in a different way. It was brilliant, so useful the way you explained the link to fields. You explained it in a way the kids could understand and make links with static, to me that's how I would like to teach it. (R3)

Fourthly, the subject specific nature of the training and its development of PCK in physics, identified as a key feature of effective CPD by Cordingley et al, (2015), was frequently described positively many times and was often linked to their perception of needing more physics support from the reconnaissance phase:

> I've had a session on questioning before, but I find it hard to translate it to physics. I had a historian discussing questioning but translating history discussions and comparing it to how to handle a pupil in science is difficult. (R3)

> The pedagogy with the physics slant is brilliant - particularly what I found hard in the past is the translation of the theory into defined stuff for the classroom. (R2)

Finally, another common concern which aligns with elements of PCK identified by Lee & Luft (2008) and the connection aspect of the Knowledge Quartet (Rowland, 2005), was focused on covering exam specifications and providing guidance to develop good examination technique in their students and the discussions often featured underlying references to competence and

performativity. The specific area that most requested was strategies for tackling extended qualitative answers in physics.

5.3.2 RQ2: In what ways did the trainee teachers perceive that the structure and delivery of the interventions met their cognitive and affective needs as identified in the reconnaissance phase?

In relation to the delivery of the intervention, the analysis shows how they perceived their needs had been met; to this end, some of the features of effective CPD revealed in the literature review were identified during the interviews.

Firstly, making my pedagogical reasoning explicit (Loughran, 1995; Russell & Loughran, 2007; Bishop & Denley, 2007) was noted by many as being of particular benefit as the following quote demonstrates:

> I like the visual demonstrations where you model pretty much exactly how you do it in front of the class and explain why you do it, like with the marshmallow in the Pringles tubes. Tapping into your experience counts - that's like gold dust to me. (R3)

Secondly, providing time and support for reflection was highlighted as a benefit by several respondents which is a desirable trait to nurture when working with teachers at any stage of their career (Simon et al., 2011; Nelson et al., 2015). This aligns with one of the findings of McIntyre et al., (2013) in their EPD research.

> Taking time to consider a particular strategy such as using demonstrations to develop explanations and thinking about the purpose of practical work has been good. Sometimes I just did a practical with the class and hadn't thought why I was doing that, what they were learning – I like the 'hands-on, minds-on approach'. (R4)

> I have been told that I need to explain the theory more, during these sessions by looking at using a variety of examples to explain an idea, like the seasons with the torch and the swimming noodles, I was thinking I could model one version and then get them to do the other version and explain the theory using that. (R5)

Thirdly, the participants valued receiving constructive advice in a non-threatening environment which ties in with the principles of practice outlined by Loughran, (2006) and Russell & Loughran (2007). Unfortunately this seemed to resonate most when it was linked with negative feedback they had received during their teaching practice, but it was promising to hear that the intervention sessions had given them scope to adapt and improve their practice in areas where they perceived it necessary, as self-efficacy is linked to competence, one of the necessary psychological needs of SDT (Ryan & Deci, 2000).

> I've got feedback on coming up with more exciting starters and that's another reason why I like your sessions. You have good starters and to use as hooks but then you develop the understanding with them. (R2)
>
> Being able to say which areas I need help with without worrying was so helpful. I feel much more confident about teaching forces now that we have looked at ways of covering it. I now know how to introduce moments – my first lesson on that was a disaster! (R4)

Lastly, supportive communities of practice can provide a powerful weapon in the retention battle (Worth & Van den Brande, 2020; McIntyre et al., 2009) as being part of the group and having a familiar facilitator can attend to their feelings of relatedness (Hobson et al.,2017). Indeed, the importance of this psychological need permeated many of the discussions.

The response below brought out an interesting attitude to the competence aspect of the affective domain which is important to consider:

> I think at the beginning of the course plenty of us would be quite prepared to look stupid as we could say 'physics is not my speciality and I haven't touched this for years', but at this point when you're about to start teaching, people would be more fearful of exposing their lack of knowledge. (R1)

In contrast most of the participants felt differently, identifying the security that the group provided as a positive, as typified by this statement:

> The group ethos helped, there's something nice about keeping the group and seeing familiar faces. I can be quite shy, so for me knowing that people are not going to think I'm silly if I say something I don't know. I know they are not going to make a judgement - I like being in that community. (R3)

In summary, three of the aims of the intervention shaped by the reconnaissance interviews were acknowledged positively in the intermediate interviews: to develop PCK, to enact key principles of practice, and to account for the needs of the affective domain. Overall, the first phase was perceived to have helped with developing the PCK of the trainee teachers and they valued the teacher education approach adopted. Making connections (Rowland et al., 2005; Childs & McNicholl, 2007) appeared to be of particular interest and modelling a range of subject specific examples which are relevant to the classroom were especially popular. Their trust in the credibility of the facilitator also seemed to feature strongly. In the main, the participants still perceived SMK to be a separate entity but it did underpin virtually every activity and strategy used in the intervention (Appendix 5).

The underlying theme of concerns about competence persisted from the reconnaissance phase and it became clear that more support sessions would be necessary to try to bolster this aspect of the affective domain. In order to inform my planning of the second cycle of interventions, I revisited a theme that emerged in the reconnaissance phase when the trainee teachers' perception of effective professional development was explored; the integration of educational theory with classroom practice. Due to time constraints this had not been incorporated into the first intervention cycle.

The findings resonated with research on the disconnect between education theory and classroom practice (Korthagen and Kessels, 1999) with most of the participants questioning their

engagement with, and application of, the theory covered during their professional practice induction weeks.

> Professional development at this start seemed very abstract and it's not until you're in the classroom and you see how the classroom works that you can think it through, but by that time you forgotten what they covered at the start! The theory in our weekly pathway sessions is more relevant. (R2)

> During professional studies at the beginning - I didn't have anything to hang it onto. My brain was closed to it. I couldn't remember it all, some of it comes back but not all of it. (R3)

When probed further about which aspects of this provision they would like to revisit they all chose the cognitive science input and the recommendations from the EEF 'Improving Secondary Science' report (2019). Several expressed a desire to learn more about Rosenshine's Theory of Direct Instruction (2010) as it is an approach that they have encountered in their schools and this quote shows how relevance of CPD provision is linked to buy-in from participants (Sims & Fletcher-Wood, 2018; Weston & Hindley, 2019):

> I've also got in the back of my mind and I have to be careful as the school I'm teaching at is they are quite direct instruction based with quite strict policies on deliberate practice so whatever I'm using there needs to be a real purpose to it. (R4)

As the participants identified this as an area of concern, the theme of translating the theory (episteme) covered at the start of the course and transforming it into a form accessible to beginning teachers, taking account of their pressing concerns regarding popular educational theory, planning, curriculum sequencing and assessment was used to shape the next intervention cycle. It seemed important to maintain the aspects of the first phase that the participants perceived to be useful such as making pedagogical reasoning explicit, allowing time for reflection

on practice and encouraging active engagement in the workshops to allow opportunities to think both like a teacher and a student.

5.4 Phase 2 Intervention

A second suite of three one-hour workshops was designed in response to the findings from the intermediate interviews. This cycle moved away from specific physics topics and took some of the theory that they had covered in their professional studies induction programme as a structure to plan the second phase of the intervention cycle and to provide a coherent narrative or 'logical thread' for each intervention session (Cordingley et al., 2015:8).

The first workshop covered strategies for curriculum planning and assessment and sought to address their concerns regarding how to plan effectively for coherence and to prepare their students effectively for examinations. This anxiety seemed to stem from the culture of performativity that currently pervades schools and could cause a lowering of their perception of self-competence and so a range of strategies was included (Hobson & Maxwell, 2017).

The first part of the workshop focused on using SOLO taxonomy (Biggs & Collis, 1982) as the basis of a learning framework that organises the required curriculum content in a logical progression in terms of physics knowledge and understanding. The second part of the workshop looked at specific examples of strategies to recap knowledge and develop examination technique. They were demonstrated with the teachers acting as students in order to make the process clear and to give them opportunities for active involvement (Grangeat & Kapelari, 2015; Loughran, 2006), the accompanying commentary provided an insight into my pedagogical reasoning (Bishop & Denley, 2007). Cognitive science was embedded so that the theory introduced in their induction weeks

was revisited and translated into physics specific classroom activities and approaches (Burn and Mutton, 2015).

Additional aspects of cognitive science that are currently very popular within the education community and, as such, have been adopted as a requirement for many of the science departments that the trainee teachers have been or will be working in, formed the basis of the next workshop in this cycle. This is designed to promote buy-in from the participants as it is directly relevant to their professional practice (Sims & Fletcher-Wood, 2018; Weston & Hindley, 2019). Ways to incorporate retrieval practice and interleaving of content plus numerous other direct instruction strategies (Rosenshine, 2010) were covered in a workshop run by the author of the "The Slightly Awesome Teacher", (Salles, 2016), a popular contemporary education book. I worked collaboratively with the author to adapt this session to have a physics slant as he is an English teacher and the trainees had previously stressed how important the subject specific aspect of any provision was to them (Sims, 2019; Allen and Sims, 2017).

The final session of the second intervention cycle aimed to translate the recommendations for teachers from the recent Education Endowment Foundation 'Improving Secondary Science' report, (2018) into a subject specific format that was relevant to their classroom practice, that is connecting the theory with the practice as this was a perceived need that arose from the interviews.

5.5 Phase 2 intervention: findings

RQ1: In what ways did the interventions meet the perceived cognitive needs of the trainee teachers with regard to developing their physics PCK and SMK?

RQ2: In what ways did the trainee teachers perceive that the structure and delivery of the interventions met their cognitive and affective needs as identified in the reconnaissance phase?

The final interviews were conducted with seven participants as described in detail in the previous phases for exactly the same rationale and the data were subject to the constant comparative coding treatment as previously described. The same themes from the previous cycle emerged and were explored in greater depth in order to inform the design of a new initiative to support beginning science teachers with their physics teaching and these themes will be discussed now.

5.5.1 *RQ1: In what ways did the interventions meet the perceived cognitive needs of the trainee teachers with regard to developing their physics PCK and SMK?*

Analysis of the data from Cycle 2 interviews showed that developing PCK was still at the forefront of the participants' thoughts, in terms of translating their SMK for student learning and understanding and reinforced the value of providing a range of resources and strategies.

The following quote captures the essence of many discussions alluding to PCK bridging SMK and pedagogy:

> It's not the pedagogy, it's not the physics knowledge, it's the reality, it's the tips that I value a lot. It gives me the feeling that I can do it one day I'll be okay and actually quite good at it. (R1)

However, although the participant mentions tips for teaching, the reality of the provision, as explored below, was not a tips for teaching approach (Crowe & Berry, 2007) but one which sought to *develop* their PCK (Van den Berg, 2015). For example, in response to the participants' specific concerns with regard to improving their students' qualitative examination technique each workshop included a number of simple, yet effective classroom strategies. One approach that was

perceived to be particularly useful was a series of challenge questions based on demonstrations which were enacted as they would be used with a class, developing the dialogue and providing a narrative of my pedagogical reasoning at the same time, akin to the approach adopted by Baird (2013). This was taken further with a 'talking heads' video technique as advocated by Clark & Mayer, (2016) which aligns with online education advice from Bloomberg, (2013). A specific example of this was a video of a remote-controlled car placed on a piece of card sitting on a raft of pencils to provide a low friction surface. The teachers were asked to predict what would happen when the car was set off, and, in line with the principle of providing a non-threatening environment if they felt their subject knowledge was lacking, they were told that they could answer as a student. They were forthcoming with a range of responses and this seems to provide evidence that they felt comfortable within the group to speak out even if they were unsure of the physics involved which indicated to me that the environment was secure and non-threatening in line with the advice from Loughran (2006) and Maandag et al., (2017). The video was played, and the subsequent discussion revealed some misconceptions which were explored and refuted. They were then tasked with writing a model answer which we refined collaboratively. The activity proved very engaging and informative and their views on it show that this technique was useful in many ways from offering samples of teaching techniques:

> It has absolutely changed my approach, lots of specifics such as the car, which can turn into generic techniques that I will apply. I have struggled and this gave me some ideas to help me, for example, the longer answer questions they've always been a problem but thinking in bullet points - yeah that makes a lot more sense. (R5)

to modelling the process explicitly in conjunction with making my pedagogical reasoning clear thus enabling the novice teacher to develop their repertoire:

> The demos and developing dialogue, like the car, was really useful. It's something I've watched people do. People have observed me saying you should try this and the sort of alluding to it, but you kind of made it really clear, which I found really useful. (R7)

and, although the underpinning focus on SMK had seemed tacit previously, the interleaving of it with PCK development was obvious to some as shown in this comment:

> I think you did help with my subject knowledge and the opportunity to ask questions straight away was so helpful. (R2)

Cordingley et al., (2015) argue that a focus on generic pedagogic strategies is insufficient, they need to be rooted in SMK and this opinion was a constant theme in the final interviews:

> Physics specific training is really great in as much as I understand physics, but I think kids can really struggle with physics compared with the other two sometimes, so I think having the techniques on how to teach that and good models had real appeal. (R6)

> The vocabulary ideas were really useful …we have so many in the professional development sessions but if an English teacher is doing it, all of their examples are in English and I do find it hard to translate your own subject. (R2)

A further consideration for SMK was gauging the appropriate level of science knowledge and communicating it in the classroom (Kind & Taber, 2005) and that seemed particularly important to the physicists, as shown in the following comment:

> I sometimes miss out the basics which I think can be quite common when you've got higher understanding - you take bits for granted. It was so useful to hear you explain it. (R3)

In summary, developing SMK and PCK within the paradigm of physics by modelling classroom strategies with an associated commentary of pedagogical reasoning, in a supportive and non-threatening environment which offers opportunities for collaboration and discussion was perceived to be useful by the beginning teachers.

5.5.2 RQ2: In what ways did the trainee teachers perceive that the structure and delivery of the interventions met their needs in terms of the cognitive and affective domain as identified in the reconnaissance phase?

Firstly, I will consider the participants' perceptions of the teacher education practices used in the second intervention cycle.

As before, the participants recognised the value of having the pedagogical reasoning of the teacher educator revealed. With the example of the toy car described above, they identified the power of discussing demonstrations in a CPD session compared to observing a skilled teacher in class, alongside the importance of having some classroom experience to reflect on:

> That video of the car will be really useful, as when you did it you were explaining 'I'm going to do this because they often misunderstand this or they miss out this step in their understanding', so if you watch it with the class you don't get the teacher explaining what they are doing. (R7)
>
> I think it is important for us to have the experience in the classroom because it builds your understanding of the challenges that you personally face, I think you have a filter on your ears. (R3)

Another advantage of this approach is that the participants appreciated the insight of what the students experience during physics lessons as well as benefitting from the pedagogical commentary and modelling (Loughran, 2006):

> The best way I learn how to teach something is to observe someone else teaching to the class - it's really powerful. My observations have been the best learning and that's what you've been doing with the demos. (R2)
>
> I like having the teacher talk modelled - you can kind of know what's going through the kids' heads, by taking the role of student you see the questions you have, and these are probably the questions they have. (R6)

From trialling this video commentary technique and analysing the feedback it became clear that it was a powerful way of blending many of the key features that emerged from the literature review and was perceived to meet the needs of the participants. The phenomenological demonstrations provided a hook on which to deepen physics understanding and the associated commentary mirrored the Physics Teacher SOS scheme (Baird, 2013) and thus seemed to enable the development of PCK (Van den Berg, 2015) and made the wisdom of practice of the experienced teacher clear (Shulman, 1986).

Another area identified for the second phase of the action research cycle was to revisit the educational theory introduced in the induction weeks and translate it into a physics specific form that was relevant to their classroom practice and this was the overarching theme for all of the second intervention cycle. I will now discuss my findings regarding this aspect of the provision, with examples from the third workshop, which was based on the 'Improving Secondary Science' report (EEF, 2019), as they typify the patterns of thought across the suite of workshops.

The majority of the comments alluded to the challenge of putting education theory into practice and several comments chime with research-informed clinical practice (Burn & Mutton, 2015) the interplay between theory and practice is obvious (Korthagen & Kessels, 1999; Schneider & Plasman, 2011):

> I think definitely being able to relate it (the theory) to the classroom experience has been helpful. Some of the sessions at the start of the year, I remember listening but you can't relate it to what you actually do. (R2)

All agreed that having a variety of physics specific examples of how to embed the theory into their practice was beneficial. The idea of the teacher educator providing a bridge between the

theoretical and practical domains resonated with the development of PCK in novice teachers (Kaiser & Read, 2020; Van den Berg, 2015):

> When you went through every recommendation and showed this is how you apply in the physics fashion - it was a bridge between the general ideas and here's how to apply them in physics specifically, which I think was really useful. (R5)

Becoming a reflective practitioner is an important factor for teacher growth and it was encouraging to see the trainee teachers continue to adopt a reflective stance and there seemed to be a more positive shift in their thinking in contrast to the first cycle where reflective comments were generally linked to areas of weakness:

> What you've given me is lot of resources, lots of things to think about to try and find ways to improve my offer to the kids, and to improve the way that I get them to learn physics. The timing has been really good - if it was all up front, I hadn't had an opportunity to put into practice. Now I'm reflecting what I've done I'm starting to see all the holes in it! (R1)

Having considered the teacher educator practices that the participants perceived to be most effective, the next consideration is how it affected their perceptions of themselves in terms of the affective dimension and the three domains of SDT; competence, relatedness and autonomy.

Analysis of the interview data showed that the over-riding feedback of this personal growth was their increase in self-efficacy which is most closely linked to competence, and this was often linked to the extra physics input that the optional interventions provided. The following quotes are just an indicative sample of a large range:

> I'm now more confident teaching physics than the other two which sounds weird because it was definitely my weakest. Physics is my weak point but, because I feel we've had so much extra support in physics and all of this physics focused teaching, I am more confident now teaching physics than I would be the other two. (R7)

> I was very nervous about it and now I feel a lot more confident because although my physics is still rusty and know that if I do a bit of revision will be fine. I've actually found them so useful having the extra physics as my feedback was more physics. (R6)

However, although there was a general pattern of increased confidence, anxiety surrounding their competence when they were responsible for a class was still visible when probed further, indicating a need for sustained support:

> I still don't consider myself a physics teacher, but I feel confident with KS3. I wouldn't feel as confident with the top set Y11 but do feel more comfortable as a result of our course. I've certainly got strategies which makes sense to me which I can then use for them. (R4)

In particular, many participants expressed concerns about being able to think on their feet which resonates with Rowland's (2013) contingency knowledge:

> One of the great risks as a non-physics teacher, for example, what happened today when you got questions from Eve, is taking it in a slightly different direction because they've complicated it - that's what the children will do. You were able to field that really well because of your experience and knowledge of physics, my fear is that would just start to unravel because I don't have sufficient strength. (R!)

In terms of the second aspect, relatedness, feeling cared for and part of a group was valued by many and the feedback was similar to before in terms of this aspect.

> I would have been less keen sign up if I hadn't known anyone – it has made me feel more comfortable. (R7)

The third aspect, autonomy remained dichotomous with the majority valuing an increased repertoire of teaching resources, approaches and techniques and having a choice to match to individual contexts but two of the teachers still described having too much choice as overwhelming which resonates with the findings of Childs & McNicholl (2007) in their study of science teachers teaching out of specialism.

The last area to consider is how the participants perceived the structure and nature of the provision. Although this was dictated to some extent by the constraints of the COVID-19 lockdown, the optional weekly one-hour online sessions had over 85% attendance and appeared to be well-received with all of the participants expressing an interest in continuing the support into their NQT year. The limited scope for informal and small group discussion online was mentioned by several participants and one respondent described it as a 'weird dynamic' but all acknowledged it as a satisfactory alternative during the COVID-19 lockdown. In fact, many identified the advantages of using an online platform for the future when balanced against the difficulties of being released from school, setting cover, travel time and juggling full-time teaching with family life.

The evaluation of the format was illuminating in some respects, for example, having more frequent but shorter sessions reduce the cognitive load, and this was referenced by the non-specialists in particular:

> As a chemist, I found the previous three-hour sessions overwhelming – the amount and the pace. I think I learned a lot more from the one-hour sessions as it was the right amount to take in. (R2)

This resonates with the findings of Willingham (2017) who warns that beginning teachers may be overwhelmed and retain little if too much information is offered in one input.
Furthermore, how we design our input as teacher educators may benefit from the guidance Maandag et al., (2017) regarding teaching adults in light of respondent 7's view:

> We are taught to do interleaving and retrieval practice with our classes but that's not the case when we get taught in our full day sessions!

The literature outlines the many benefits that working with an external expert can bring (Coe et al., 2014; Worth et al., 2017) and this was also acknowledged by several as being a strength of the provision.

> You are in one school where teachers have a certain way of doing things - it's lovely to hear different approaches. (R3)
>
> I'm in a department with no physics specialists so having access to your knowledge has been so useful. (R4)

In summary, the intervention cycles were perceived to have attended to the cognitive needs that the beginning teachers highlighted in the reconnaissance phase, that is, to develop their PCK following Shulman's (1986) categories of representations and strategies and subject specific learning difficulties and to place SMK as an underpinning principle.

This was facilitated through adopting a teacher education approach that placed place key principles of practice at the core of the provision; creating a secure, non-threatening environment making my pedagogical reasoning explicit and allowing time for trainees to reflect on their practice.

Accounting for the underlying affective aspects that are essential for self-efficacy and, therefore, linked to improving retention, also emerged as a key consideration when designing an intervention programme.

The elicitation of the trainee teachers' needs was a vital part of process and the findings from the reconnaissance phase, allowed me to develop a targeted and significant programme that appeared to genuinely meet their needs. The action research showed the real importance of asking your learners what they perceive they need and designing a programme, informed by

professional experience and academic literature, to meet those needs and then building on this as was done in cycle 2.

6. Conclusion and implications

6.1 Conclusion

The findings demonstrate that sharing the wisdom of practice of teacher educators in a research-informed subject-specific, six-week online support programme was perceived to have met the needs of the beginning teachers in both the cognitive and the affective domains as described in sections 4 and 5. In the cognitive domain, the CPD was perceived to increase the SMK and PCK of both specialist and non-specialist trainees and the translation of generic epistemological ideas into physics specific examples for classroom practice was highly valued. The affective domain was also enhanced, and, by applying the analytical lens of self-determination theory (Ryan & Deci,2000), positive changes in competence, autonomy and relatedness were also noted. Furthermore, the structure of the online course was perceived to be particularly effective in its resonance with the theory of how beginning teachers learn (Willingham, 2017). In addition, aspects of the teacher educator approach that were particularly valued were placing key principles of practice at the core of the provision; creating a secure, non-threatening environment in which the pedagogical reasoning of the teacher educator is made explicit and reflective practice is fostered.

Listening to the voices of the beginning teachers was an effective way of eliciting their perceived needs and revealing a range of ways in which they could be supported. Working collaboratively with them in this way to refine the provision appeared effective, and their perceptions of this individualised approach mirrored the findings from McIntyre et al., (2013) which also focused on the needs of beginning teachers.

6.2 Limitations

Before looking at the implications of my findings it is important to consider the limitations of the study. Firstly, as the findings of my action research study are based predominantly on my interpretive analysis of qualitative interviews there may be an innate subjectivity in my interpretation of the data, despite my attempts to remain objective.

Secondly, as this research was practitioner-led the participants may have felt a certain loyalty towards me due to our existing professional relationship, and this may have influenced their perceptions of the intervention programme and its effectiveness or may have influenced what they chose to disclose during the interviews.

A further limitation is that the intervention took place in an unprecedented time of school closures due to the COVID-19 pandemic which meant that the beginning teachers felt under-prepared as their teaching practice had been curtailed and, as a result, they had more time to engage with extra CPD so the findings represent a picture of a very specific point in time, that is dissimilar to the norm. The restrictions also meant that all of the research and intervention activities were conducted online and some of the more subtle nuances of face-to-face interaction may have been lost. The teachers were unable to implement their learning as schools were closed. The sample size was small, and as argued earlier, it may not be representative as convenience sampling was used with all of the beginning teachers who volunteered to participate forming the research group.

6.3 Implications

The implications of the findings of my small-scale study are discussed in the context of designing a new programme to support beginning teachers who will be teaching KS3 physics in the next academic year. The Trust, a national body that I work for which supports the teaching and learning

of physics, is introducing a programme to support over 80 NQT and RQT science teachers as part of its response to the teacher retention crisis outlined in the rationale (Figure 6.1).

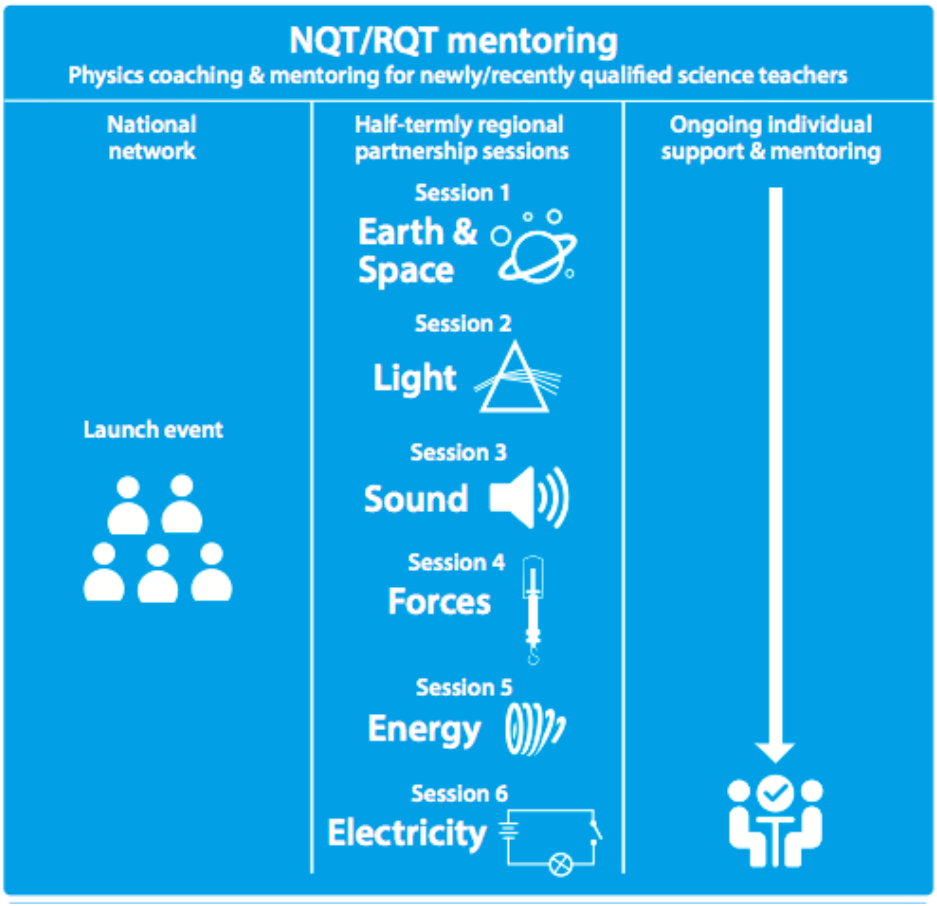


Figure 6.1 The Trust NQT/RQT mentoring programme

The key findings of this small-scale study, combined with other evidence bases such as the literature review and the professional knowledge base of myself and my colleagues, have been used to inform the design of the programme and I will now describe how they are accounted for in the design of the CPD programme.

Firstly, the programme incorporates key features of effective CPD as it provides sustained, subject-specific support with input from external experts. During the mentor training the importance of the teacher educator approach and embedding key principles of practice of good teacher education was emphasised (Loughran,2006; Russell & Loughran, 2007), for example, ensuring a secure, non-threatening environment and making their pedagogical reasoning explicit, a key area

identified in this research. In order to account for findings regarding duration and time pressures that beginning teachers experience each session will be one hour long.

Secondly, in terms of the cognitive domain, the launch event consists of a keynote exposition outlining the fundamental principles behind outstanding physics teaching from an expert in physics teacher education, followed by a series of classroom demonstrations which model these principles in action. The topic based half-termly mentor sessions will have a particular focus on SMK, addressing common misconceptions and transforming SMK into a form that is accessible to students, thus aligning with the two core strands of Shulman's (1986) conceptualisation of PCK: representation and strategies and barriers to learning, and the transformation quadrant of Rowland, (2013). The content will be directly applicable to classroom teaching at KS3 which ensures that the CPD is relevant (Sims & Fletcher-Wood, 2018; Weston & Hindley, 2019).

In addition, the sessions are structured to allow for reflection and discussion time after the topic-based input (Figure 6.2). The remaining time will be used to allow the participants time to seek advice and support for their individual concerns and build a mutually supportive peer community which was shown to be beneficial by Walker et al., (2018). This aims to provide opportunities for collaboration and learning from physics experts as advocated by Coldwell et al., (2017) that may be lacking within science departments due to the physics teacher shortage described earlier.

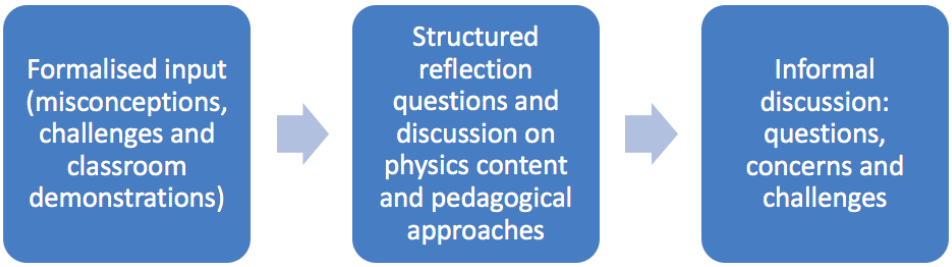


Figure 6.2 Architecture of a mentor-led session

Finally, supporting the affective domain emerged as a dominant theme in the action research and as the literature suggests that it is a key factor in improving teacher retention, it would seem sensible to attend to the needs of affective domain in the programme design. Using the framework of self-determination theory, features are included to build competence through the focus on SMK and PCK, promote autonomy by modelling and evaluating a range of strategies and approaches, and nurture a feeling of relatedness by providing involvement in a national network in addition to an accompanying local mentor and peer support group. Relatedness may also be increased by ongoing individual support from the mentor throughout the year and this responsive and sustained support aligns with the research of Williams et al., (2001).

Although, as described in the limitations, the findings from such a small-scale study cannot be generalised (Wilson, 2013) and taken as robust evidence for scaling to a national project, they have provided useful insights which have informed the design of the new programme. In order to evaluate whether this programme could be effective on a larger scale and have an impact on the retention problem described in the rationale, it would be beneficial to conduct further research. The first research question could be seen as a continuation of the original action research cycle:

- *In what ways and to what extent do the successful features of the CPD intervention work in the wider context of the scaled-up programme?*

The second would require a new longitudinal research study:

- *To what extent does a successful CPD experience, as characterised in this project, have an effect on long term teacher retention?*

My intentions for this research project were to develop a physics support programme for beginning teachers and, whilst initial feedback from the national programme has been positive, the further research suggested could provide valuable insights into the important issue of teacher retention in physics.

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Appendix 1 -Semi-structured interview schedule details

Reconnaissance Phase

Biographical:
Education history
Route into teaching
SKE course?
Previous career/ employment

1. Can you describe some highlights of your ITT year?
2. Have you faced any challenges during this year?
3. Have you had CPD during the year?
4. What has been the most useful aspects of the CPD?
5. What, if anything, has been missing from the CPD that you have received during the year?
6. Which aspects of your teaching have developed most during this year:

   -subject knowledge linked to the curriculum statements

   -transforming your knowledge into an accessible form for your students

   -making connections between prior and future learning

   -thinking on your feet (contingency strategies)?
7. What would you want to see included in an NQT subject specific CPD programme?
   - Is subject knowledge more important to you than pedagogy?

Phase 1 -baseline questioning

1. Which topics from the curriculum would you like support with?
2. Which physics skill development would be most useful to you?
3. Which aspects of your teaching would you like to develop further during this year:

-subject knowledge linked to the curriculum statements

-transforming your knowledge into an accessible form for your students

-making connections between prior and future learning

-thinking on your feet (contingency strategies)?

4. What would you want to see included in an NQT subject specific CPD programme?
5. Is subject knowledge more important to you than pedagogy?

Phase 2 – evaluating and forward planning

1. What has been the most useful aspects of the CPD?
2. What has been the least useful aspects of the CPD?
3. What, if anything, has been missing from the CPD that you have received during the year?
4. How valuable is the networking provided by participating in this course?

Appendix 2 – CUREC Consent form

PARTICIPANT CONSENT FORM

CUREC Approval Reference: ED-CIA-20-136)

Purpose of Study: To determine whether sustained, subject-specific professional development can effectively support early career science teachers

		Please initial each box
1	I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, and without any adverse consequences or academic penalty.	☐
3	I understand that research data collected during the study may be looked at by designated individuals from the University of Oxford where it is relevant to my taking part in this study. I give permission for these individuals to access my data.	☐
4	I understand that this project has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee.	☐
5	I understand who will have access to personal data provided, how the data will be stored and what will happen to the data at the end of the project.	☐
6	I understand how this research will be written up and published.	☐
7	I understand how to raise a concern or make a complaint.	☐
8	I consent to being audio recorded	☐
9	I understand how audio recordings will be used in research outputs	☐
10	I agree to take part in the above study.	☐
11	I agree for my personal data to be kept in a secure database for the purpose of contacting me about future aspects of this study.	☐

Name of Participant	Date	Signature

Name of person taking consent	Date	Signature

Information sheet for participants

To determine whether sustained, subject-specific professional development can effectively support science teachers during their early career.

1. **Purpose of Study:** To research effective ways of supporting science teachers during their early career, design an intervention to support a group of teachers and to evaluate the intervention.

2. **Background of Study:** There is currently a recruitment and retention issue for science teachers, particularly physics teachers. This study aims to find out reasons that may be causing this problem and looks to use the findings to design an effective professional development programme that will support teachers in their first or second year of teaching.

3. **Methods of Study:** The research will start individual interviews to determine your views about your teacher training, the issues and challenges you face as a Newly Qualified teacher (NQT) or recently qualified teacher (RQT) and your views about what makes effective continuing professional development (CPD) and what additional CPD you would like to have. The findings will inform the design and delivery of a more sustained intervention programme which works in addition to the current TSST programme. Field notes and audio recording will be taken during the CPD intervention. Your participation is entirely voluntary and you can withdraw at any time. If you do not wish to participate or you wish to withdraw this will have no effect on your participation in the course. Finally, if you do decide to participate with your permission, the interview with be audio recorded. If you do not wish to be audio recorded then notes will be taken.

4. **What happens to the data provided?** The **research data** will be stored confidentially on the investigator's password protected computer within a separate confidential folder and within a locked cabinet for paper documents.
   Your responses will be anonymised.

5. **Personal / sensitive data** will be stored confidentially using a secure password protected computer within a separate confidential folder and within a locked cabinet for paper documents.

I will ask all participants for their permission to use direct quotes.

All research data and records will be stored for a minimum retention period of three years after publication or public release of the work of the research, in accordance with the University of Oxford's Policy on the Management of Research Data & Records.

6. Will the research be published?

The University of Oxford is committed to the dissemination of its research for the benefit of society and the economy and, in support of this commitment, has established an online archive of research materials. This archive includes digital copies of student theses successfully submitted as part of a University of Oxford postgraduate degree programme. Holding the archive online gives easy access for researchers to the full text of freely available theses, thereby increasing the likely impact and use of that research.
If you agree to participate in this study, the research will be written up as a thesis. On successful submission of the thesis, it will be deposited both in print and online in the University archives, to facilitate its use in future research. The thesis will be published open access.

7. Who has reviewed this study?

This study has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee.

8. Who do I contact if I have a concern about the study or I wish to complain?

If you have a concern about any aspect of this study, please speak to the researcher, [redacted] who will do their best to answer your query. The researcher should acknowledge your concern within 10 working days and give you an indication of how they intend to deal with it. If you remain unhappy or wish to make a formal complaint, please contact the relevant chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter in a reasonably expeditious manner: Chair, **Social Sciences & Humanities Inter-Divisional Research Ethics Committee**; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Wellington Square, Oxford OX1 2JD
If you would like to discuss the research with someone beforehand (or if you have questions afterwards), please contact [redacted] (contact details are provided above).
If you are prepared to participate in this research please complete and sign the Participant Consent Form attached and return by 12th March,2020
Thank you.

[redacted], 17th February, 2020

Appendix 3 – Details of participants

Participant	Subject specialism	ITT Route	SKE course?	Previous career
R1	Chemistry (PhD)	PGCE	Yes	Career in nursing, including training
R2	Chemistry (MSc)	PGCE	No	No
R3	Physics (PhD)	Flexi (part-time) schools direct route	Yes	Science research (lasers)
R4	Biology (BSc)	PGCE	Yes	Research scientist and manager
R5	Physics (PhD)	PGCE	Yes	No
R6	Biology (BSc)	PGCE	Yes	Not disclosed
R7	Biology (BSc)	PGCE (Chemistry subject specialism)	Yes	Not disclosed

Appendix 4 – Data analysis - constant comparative coding summary from interview transcripts

Preliminary interviews								
Constructs (temporary constructs shaded out in right hand column to leave second order constructs to group into emergent themes)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**Emergent themes**
	Quotes from transcripts – number references used							
Motivation		1,8,5	20					
Resources/ repertoire		1,6	17	5,7	3	4	4	PCK – representations & strategies
Tacit/ modelling/ pedagogical reasoning	2,4	2,23	10, 12	12,5		4	4	Teacher education
Concerns (drowning)	3	3,4,5,12, 14,16,29	2,8					SDT -Competence
Employer – waiting for information		7						
Explaining to students		10,19		6	3			PCK – representations & strategies
Lacking CPD		13,21						SDT -Competence
SMK	1	17,26	9,1 1		2	5	2	SMK
Focus on exam/ going off target		18,20		13				PCK – representations & strategies
Practical activities		24,25		4,8		9	2	PCK – representations & strategies
Ideas/ creativity		25	5,1 4	4,8		9	2,7	PCK – representations & strategies
Confidence		26						SDT -Competence
Group (CoP)			1,7, 3			1	3	SDT - relatedness
Front loaded theory			4,6	3,2		1	6	Theory
Subject specific examples and contexts	7		13	1			1	PCK – representations & strategies
Contingency			15	10				KQ - contingency
Tips and tricks	5		17					PCK – representations & strategies
Online provision			18	9	4			
Misconceptions	6			11				PCK – student difficulties

Collaborative planning					5	10	3	Teacher education
Mentoring						2,7		SDT - relatedness

Intermediate interviews (after phase 1 intervention cycle)								
Constructs (temporary constructs shaded out in right hand column to leave second order constructs to group into emergent themes)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	Emergent themes
	Quotes from transcripts – number references used							
Concerns		5,6,7,8		1,11	1,10,17,12,13,14	8,4	1	SDT - competence
Practical activities/ ideas		11		Throughout	5,7,9,10	4,5	2,7	PCK – representations & strategies
Non-specialist							3	SMK
Links		1		7			4	KQ -Connections
Using models							5	PCK – representations & strategies
Modelling/ explaining				6,8	12		6,8	Teacher education - Pedagogical reasoning
Prep for exams/ focus/ 6 mark answers		4					9	PCK – representations & strategies
Front loaded/ realistic					8	6	10	Theory
Motivation							11	
Group		9		13	15,16	7	12	SDT -relatedness
Context						1,3		KQ -Connections
Creativity		2				2,3		PCK – representations & strategies
Ideas vs content						5		PCK – representations & strategies
Transformation		3		2,12	2,3			PCK – representations & strategies

Planning				3				KQ -Connections
My experience		13		4,6				Teacher education
Questioning				5				PCK – representations & strategies
Misconceptions				9,10				PCK- student difficulties
Physics identity					4,6,12,13			
Purposeful practical					11			PCK – representations & strategies
Trust					18			Teacher education – principles of practice

Final interviews (after phase 2 intervention cycle)								
Constructs (temporary constructs shaded out in right hand column to leave second order constructs to group into emergent themes)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	Emergent themes
	Quotes from transcripts – number references used							
SMK	4,9			10	6	1,3,24,		SMK
How to teach			5	7,10	7	2,2b		PCK
Misconceptions	13					4		PCK- student difficulties
Leaning from external/ experience	2	17	9	1,12	5, 17	5	7	Teacher education
Demos and practicals	12	10,11	25		19,20	6	5	PCK – representations & strategies
New school community	11	16	1		12,17	7,23		SDT – relatedness
Pedagogical approach with physics specific examples	16	15	3,7,12		22	8		PCK – representations & strategies
EEF & links	17	14	15	9	11	9q		Theory
Quantity pace						10		Timing/ structure
Planning						11		
External session (Mr Salles)					14	12		Theory
Linking to their own practice	11,14	5,16	10,17, 18,19	8	12,22	13,17, 20	6	Theory
Different presenter	18	9		14		14		Teacher education – principles of practice

Modelling	6,7,9	11	6	6,1	10,20		2,9	Teacher education - Pedagogical reasoning
Timing/ quantity	4	6	23,19, 20	4,5	23,18	15	3	Timing / structure
Identity/ confidence/ feelings	15,1 6	8,10,1 2,18,1 9,23	2,4,16 ,20,24	11,13	2,15,19	16	1,1 1,1 3	SDT – confidence
Motivation	3	7	7		1,3,4	21,22		
Physics input GITEP	8						4,1 2	
Observations	6,8,9			7				
Contingency	5				8		10	KQ -Contingency
Follow up resources			8,22	3	23			
Scaffolding				2	21			PCK – representations & strategies
Group	1,10		21,25		13,16,1 8		12	SDT -relatedness
Interleaving/ revisiting	13,3				4?			Structure
Challenge of ITT				3				SDT – competence

Appendix 5 – Sample workshop structure (Electricity)

Activity	Aims to address from findings stated above			Comments
	a)PCK	b) teacher education	c) SMK	
Hooks: Picture question: what links amber to electricity?	/	/		*-using illustrations, analogies, explanations and demonstrations* Highlighting the power of stories, developing hinterland to support the core curriculum, considering vocabulary
Knowledge recap: Retrieval practice - structure of atom	/	/	/	*-Explicit SMK coverage* Making links with chemistry coverage of this topic plus discussion of how to recap previously covered content
Demonstrations: Static electricity	/	/	/	*-using illustrations, analogies, explanations and demonstrations* Non-threatening as all involved easy to access everyday kit
Computer simulations: PhET Sims – Balloon charging	/	/	/	*using illustrations, analogies, explanations and demonstrations* Signposting web-based simulations and demonstrating how it can be used
Connections: Link static to electric fields to current electricity	/	/	/	*connections to other concepts and problem- solving strategies* Following accepted physics logic for developing understanding of this difficult topic (ASE book0 ref) which is at odds with exam board suggested route
Diagnostics: Spangler stick, MIT bulb challenge	/	/		*Dealing with misconceptions* Engaging yet challenging demonstrations shown and associated dialogue modelled. BEST resources signposted
Signposting resources for practical applications of theory: Flood Alert, Graphite graphing and squishy circuits	/	/		*using illustrations, analogies, explanations and demonstrations* Interesting contexts to apply understanding to unfamiliar situations, mathematical skill development embedded.
Definitions: Critiquing cartoon	/	/	/	*Explicit SMK coverage* Key terms consolidated and discussion of cartoon used to check and develop their understanding
Evaluating Models: Rope and Drude model for circuits	/	/	/	*using illustrations, analogies, explanations and demonstrations* Promoting the importance of critiquing models used. Common yet problematic models discussed (pizza van, clashing currents). IoP suggested models enacted and layers of understanding unpicked.
Plenary: Next time questions (Arbor Scientific)	/	/		*using illustrations, analogies, explanations and demonstrations* A powerful tool for the teacher educator to assess the level of SMK and also to showcase a very effective classroom strategy.