Development of teachers' dialogic using the CoRe framework: planning for transformation and contingency

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Development of teachers' dialogic teaching using the CoRe framework: planning for transformation and contingency

Abstract

This research project focuses on the development of two beginning teachers' practice in physics classrooms over an academic year. Both teachers are in their first three years of teaching and one is a physics specialist while the other is a non-specialist. Within a mentoring relationship with the teacher educator, a framework called Content Representation (or CoRe) (Loughran et al., 2012) was used to develop dialogic teaching in their classrooms. The completion of CoRes by expert teachers had allowed their pedagogical and subject knowledge to be shared with the beginning teachers who had used them to plan for dialogic teaching. Elliott's (1991) model of action research is applied to investigate the research questions set at the start and throughout the study. A qualitative methodology using semi-structured interviews was adopted to explore the beginning teachers' beliefs and practice. This included lesson observations and feedback carried out over each of the three school terms (or phases). During the first phase (phase-1) baseline-data was collected to explore the teachers' practice. In phase-2, data collection aimed to reveal to what extent the CoRe framework was effective in developing dialogic teaching. Also, during this phase, the extent to which my mentoring was effective was explored. Data collection in phase-3 aimed to find out to what extent the CoRe we had modified (CoRe2) was effective in developing dialogic teaching. Lessons were analysed using a framework called the Knowledge Quartet (KQ) (Rowland et al., 2005) and Alexander's five principles of dialogic teaching and related indicators (Alexander, 2017).

The findings suggest that the CoRe framework can support beginning teachers plan for dialogic teaching. In particular, the modified version, CoRe2, had been useful for them to consider activities that encouraged student talk. The findings also suggest that the constructivist-oriented mentoring received by the teachers had allowed them to be involved in their own development in the classroom. These findings will be shared with colleagues at the Institute of Physics (IOP) who are also expert physics practitioners working with teachers to develop their practice. This will have implications for the way we cater for the needs of both specialist and non-specialist novices teaching physics.

1. Introduction, context and rationale

The focus of this study is on developing beginning teachers' dialogic talk in classrooms through mentoring focused around a framework called Content Representation, or CoRe (developed by Loughran et al., 2012). This had developed as a result of exploring and researching issues presented in units 1 to 4 during this MTEd programme. These have linked to my role as teacher educator for the Institute of Physics (IOP) supporting secondary-school science teachers with a wide range of experience in the English system.

In England, national politico-educational initiatives such as the National Literacy Strategy (1998) have placed significant emphasis on 'speaking and listening' in the classroom, however, quality student talk remains rare (Alexander, 1996; Galton et al, 1999). In the latest reprint of *Towards dialogic teaching*, Alexander (2017) discusses the inadequate references to dialogic teaching in these initiatives and in the National Curriculum (DfE, 2014). At the time of writing, more consideration towards developing effective intervention for dialogic teaching has resulted from Alexander's work. For example, his well-known *principles of dialogic teaching* (discussed in 2.1.2) were at the heart of a recent large-scale intervention funded by the Education Endowment Foundation over 20 weeks in year 5 at 38 UK primary schools (Jay et. al, 2017). The evaluation of the project revealed that, 2492 students in the intervention groups were found to have made two additional months' progress in English and science compared to 2466 students in the control group, on average. This evidence supports a move to more dialogic teaching in schools. As such, the opportunity to explore teachers' beliefs about teaching and learning, and science (Author, 2017a) had encouraged me to consider how constructivist approaches, such as dialogic teaching, can impact on classroom practice. Positive outcomes were revealed to be closely

linked to the teacher demonstrating *transformation* and *contingency* during interaction with students (Rowland et al., 2005). These knowledge dimensions were further explored in unit 2 in light of how teachers plan for student talk (Author, 2017b). Both these units also allowed me to explore and compare the classroom practices' of beginning teachers (those in their first three years of teaching - including the training year), and more experienced teachers. This highlighted some general differences that existed between these groups of teachers. A significant finding was that beginning teachers' lack of pedagogical knowledge resulted in planning lessons that were very much teacher-led and focused on classroom management. Typically, lesson planning would lack constructivist approaches such as dialogic teaching (Author, 2017a). For more experienced teachers with a traditional approach to teaching (which is mainly teacher-led) their beliefs about teaching and learning, are more fixed than beginning teachers (Author, 2017b). Such *nested epistemologies* present a challenge for the teacher educator to develop constructivist teaching (Tsai, 2002). A further finding which has influenced this study, was that experienced teachers find it difficult to share their pedagogical knowledge (Author, 2018a; Berliner, 2004). Therefore, a framework such as CoRe, which is designed to capture the knowledge that expert teachers have about teaching their subject can be useful in supporting novice teachers plan for constructivist methods like dialogic teaching.

Finally, my developing knowledge as teacher educator has played a key role in initiating and running this programme of support for the beginning teachers in this study (Author, 2018b). Knowledge of 'teaching about teaching' and 'learning about teaching' are hoped to develop the beliefs and views of practice of these teachers (Loughran, 2006: 1180) to support dialogic teaching.

2. Literature review

This section reviews relevant literature from a cross-section of established peer-reviewed publications. Section 2.1 first focuses on what, in this project, teachers need to learn and develop and, as said, that is enhancing their use of dialogic talk. Section 2.2 then looks at how teacher learning can be supported and begins by arguing that beginning teachers' initial beliefs about the nature of science (NOS) and about teaching and learning are important to take into account when working with beginning teachers (2.2.1). This is followed by a look at the literature which describes stages beginning teachers go through as they learn to teach in order to highlight the context in which the support is provided (2.2.2). Having discussed important issues about what beginning teachers bring to the process of teacher education and how they learn, I will look at the CoRe framework used in this study to facilitate beginning teachers' learning (2.2.3). The section ends with a review of the literature surrounding mentoring which is a key strategy used in this study to develop the teachers' practice (2.2.4).

2.1 What do teachers need to learn?

Here I will consider key literature about the knowledge base of teachers. This includes discussion about a theoretical framework called the Knowledge Quartet which will be used during lesson analyses and feedback of the teachers' lessons in this study. As the focus of these lessons will be to develop dialogic teaching, relevant literature in this area will also be

reviewed. The section ends with a look at key literature on classroom questioning - an important strand of dialogic teaching.

2.1.1 Teachers' knowledge base

SMK and PCK

The quality of teaching and learning 'depends to a large extent on the teacher's own knowledge of the content' (Abe, 2014). In Shulman's (1986) seminal work on teachers' knowledge, three categories of content knowledge are distinguished. They are: knowledge of the subject - or subject matter knowledge (SMK), pedagogical content knowledge (PCK), and curricular knowledge. Science teachers' level of SMK has been shown to influence their confidence in teaching (Harlen and Holroyd, 1997) and their teaching practices (National Research Council, 2007; Sanders et al., 1993). PCK is different from SMK, on the one hand, because of the focus on interaction between the teacher and their students, and from general pedagogical knowledge, on the other, because of the direct relationship with subject matter. Building on Shulman's work, many researchers (e.g. Carlsen, 1999; Grossman, 1990; Loughran et al., 2012) have developed descriptions of PCK, acknowledged as 'a special form of teacher knowledge' (Verloop et al., 2001: 449) which is 'particularly difficult to define and characterise, conceptualising both the link and the distinction between knowing something for oneself and being able to enable others to know it' (Rowland et al., 2005: 255). Shulman (1986: 8) described PCK as constituting 'the ways of representing and formulating the subject that make it comprehensible to others.' This is the general consensus amongst key writers on PCK, which is revealed in Lee and Luft's (2008) review of influential literature in this area. While there are significant differences with what

knowledge bases are thought to make up PCK, the general agreement is that 'representation and strategies' and 'student learning and conceptions' are central to it (ibid.: 1346).

The Knowledge Quartet

Rowland et al. (2005) carried out research on the content knowledge, both SMK and PCK, of 12 primary trainee-teachers of mathematics in the UK. A major objective of the research was to develop an empirically-based conceptual framework that would be simple to use in generating productive discussion between the trainee and their mentors following lesson observations. Using a codification method, they developed four 'dimensions' of teachers' knowledge base, which are presented in a framework called the *Knowledge Quartet (KQ)* – 'a tool for thinking about the ways that subject knowledge comes into play in the classroom' (ibid.: 258). Each of the four dimensions include several subcategories that aid the observer's lesson analysis. The dimensions are: *Foundation* - involving beliefs and knowledge about the subject, influenced by academic experience; *Transformation* - which echoes Shulman's (1987: 15) notion of it being 'the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful'; *Connection* - concerning the coherence of teaching demonstrated across an episode, lesson or series of lessons; *Contingency* - supporting a constructivist view of teaching involving responses to unplanned scenarios in which 'teachers are challenged to deviate from their lesson plan' (Rowland et al., 2011: 71). Three situations that trigger contingency have been identified by Rowland et al. (2011). They are: *responding to students' ideas*, *teacher insight*, and *responding to the (un)availability of tools and resources.* Relevant to this study, the articulation of students' ideas was found to be the most prevalent trigger of contingency.

Through constructivist approaches like dialogic teaching, such situations are likely to occur, providing valuable opportunities for transformation which could be brought about by episodes of contingency. For example, classroom discourse can present scenarios where the teacher is 'taken by surprise, necessitating some kind of improvisation' (ibid.: 72). For beginning teachers, it is to be expected that it is challenging to anticipate and act on such contingent events. Rowland et al. (2011: 72) acknowledge that novice teachers:

> … lack the experience from which (potentially, at least) to learn about how students respond to certain pedagogical stimuli, or even to exemplify in practice (and thereby believe) the 'theory' that they have read, or been told, in their professional training.

Hence, beginning teachers could struggle to consider appropriate resources or strategies (i.e. pedagogical stimuli) to conduct dialogic teaching in their classrooms. Therefore, in planning lessons, the use of a tool like the CoRe (discussed in 2.2.3) could support them in their preparation.

Finally, and relevant to this study, teachers' 'context knowledge' and 'personal knowledge' are key domains identified (Grossman, 1990; Verloop et al., 2001). Context knowledge incorporates knowledge about students, students' community, and school, which is unique for each teacher and built up over time (Grossman, 1990). As well as SMK and PCK, 'personal knowledge' will be determined and 'coloured' by individual teachers' own experiences, personal history (including learning processes) and personality variables (Verloop et al.: 443) and any new knowledge will be interpreted via teachers' own personal knowledge base (Pajares, 1992).

2.1.2 Dialogic teaching

Classroom talk is generally considered as being *authoritative* or *dialogic* (Chin, 2006; Mortimer & Scott, 2003). Mortimer and Scott (2003), in their programme of research in English and Brazilian settings over 10 years, characterise authoritative classrooms as those where the teacher's voice and instructions are dominant with little or no opportunities for students to convey their ideas and opinions which could sway them from the 'science story'. Such educational settings are prevalent internationally, driven by 'monologic' curricula which 'promote a shared and universal meaning' (Nesari, 2015: 643). Science education experts advocate the Vygotskian sociocultural perspective that learning happens in dialogue with others (Mitchell, 2010; Scott 1998). In dialogic classrooms, the teacher encourages students to voice their ideas, and debate and explore points of view (Scott et al, 2006). Drawing on the Bakhtin view of dialogic discourse 'where meanings are neither fixed or absolute' (Alexander, 2017: 25), Nesari (2015) discusses how such concepts are a good starting point for a 'modern and effective theoretical framework' for teaching and learning. He writes:

> In dialogism there is always room for arguing, since questions show everybody's point of view rather than the universal truth. (p.643)

However, extensive research shows that in classrooms this kind of interaction is uncommon (Alexander, 2017; Mercer et al., 2009; Mitchell, 2010; Myhill, 2006; Taylor and Lelliot, 2015). Following a 2.5-year study investigating classroom discourse and its effects on learning in the UK, Myhill (2006: 24) reports that 'teacher talk dominated whole class teaching and teacher-pupil interactions operated in highly conventional discourse patterns'. Similarly,

Mercer et al.'s (2009) research on dialogue between teachers and students during science lessons in 5 primary and 3 secondary schools in England, revealed that the 12 teachers in their study found dialogic teaching difficult to facilitate. These findings are supported across a variety of settings, for example in Australia (Mitchell, 2010) and South Africa (Taylor and Lelliot, 2015). Such difficulty could stem from Alexander's (2017: 31) view that 'dialogic teaching challenges not only children's understanding, but also [teachers'] own' and that teachers need to be confident about their 'conceptual map of a lesson's subject matter' in order to 'give children greater freedom to explore the territory which that map covers'.

In their research mentioned earlier, Mortimer & Scott (2003) characterise how teachers use language to develop students' ideas in science. This is presented as two dimensions: *dialogic-authoritative* - concerned with the extent to which both the teacher and the students' ideas are represented; and *interactive - non-interactive* - which describes the contributions made by both teachers and students (interactive) or situations in which just the teacher speaks (non-interactive).

Criticising such a dichotomy of teaching approaches, Alexander (2017: 29) argues that it reduces the profession to simplistic 'polar opposites' which misrepresents 'the range of possibilities which are available to each teacher'. Instead, drawing upon extensive international research on talk in classrooms, Alexander (2017: 30) identifies three 'familiar and traditional' kinds of teacher talk - *rote*, *recitation* and *instruction/exposition*; and less frequently but no less international - *discussion* and *dialogue*. It is the latter two that meet the criteria of Alexander's view on 'dialogic teaching' and he claims that while the first three kinds of talk do contribute towards learning, if they were the only mode of discourse then students would unlikely encounter 'cognitive challenge' (p.31). Alexander's *principles of*

dialogic teaching, mentioned earlier and which was used with the teachers in this study is presented in figure 1.

Dialogic teaching is:

1. **collective:** teachers and children address learning tasks together, whether as a group or as class;
2. **reciprocal:** teachers and children listen to each other, share ideas and consider alternative viewpoints;
3. **supportive:** children articulate their ideas freely, without fear of embarrassment over 'wrong' answers; and they help each other to reach common understandings;
4. **cumulative:** teachers and children build on their own and each other's ideas and chain them into coherent lines of thinking and enquiry;
5. **purposeful:** teachers plan, and steer classroom talk with specific educational goals in view.

Figure 1: Alexander's *principles of dialogic teaching* adapted from Alexander (2017: 38) and used with the teachers in this study.

Following these principles, Alexander presents two groups of indicators; one which deals with 'the wider context within which dialogic teaching is placed and the conditions which encourage and support it' (listing 14 indicators), and the second group includes 'the main properties of the talk which provides the core of dialogic teaching' (listing 47 indicators) (ibid.: 40). These extensive lists reinforce the notion that the term 'interaction' in the context of classroom discourse is too general for describing 'the multifaceted ways in which talk can play in the classroom' (Myhill, 2006: 20). In this study, the indicators were used to code the 5 principles to analyse the teachers' lessons (see sections 4.2.1 and 4.3.3, pp.55-7 and pp.61-3 respectively) and are included in Appendix 1. However, as Alexander notes while these indicators are useful in describing the many characteristics of dialogic teaching the majority of the indicators 'simultaneously attend to two or more principles' (ibid.: 41). Having discussed some central ideas around classroom talk, the next section focuses on a key component of discourse - questioning.

2.1.3 Classroom questioning

Like Myhill's (2006) findings, Nystrand's (1997) large-scale study in American middle and high schools had found that the majority of teacher questioning was factual and closed requiring students to 'report what someone else thinks or has said' (p.38). Such interaction is described as taking the form of Sinclair and Coulthard's (1975) well known 'Initiation-Response-Feedback' (I-R-F) exchange structure (e.g. Alexander, 2017; Mercer et. al, 2009; Nunan, 1987). First the teacher asks a closed question (I) of a particular student who then provides an answer (R), then finally the teacher gives feedback for the answer (F) and is usually repeated several times in the lesson. The I-R-F pattern is considered to have the authoritative attributes discussed earlier, limiting the amount of talk with which students can meaningfully engage (Mercer et al., 2009; Thornbury, 1996; Nunan, 1987). The short 'wait-time', or as Alexander (2017) prefers 'thinking-time', students are given to process and convey their responses is also thought to discourage quality discourse (Baysen and Baysen, 2010; Black et al., 2002; Rowe, 1972) and impact negatively on achievement in science (Riley, 1986). Furthermore, some writers have suggested that relying on the I-R-F pattern in science classrooms, could dissuade the idea that science is tentative and non-absolute (Simon et al., 2006; Mortimer & Scott, 2003; Scott, 1998).

For some researchers, the *type* and *quality* of the feedback (F) move is the subject of consideration (Cullen, 2002; Lemke, 1982; Smith and Higgins, 2007). Smith and Higgins believe that emphasis ought not to be placed on the teachers' questions, but on the 'manner with teachers react to pupils' responses' (p.486). Their findings, supported by evidence gathered from a UK large-scale research project examining classroom interactions in primary schools, presents various forms of teacher feedback which appear to facilitate

students' subsequent use of talk. In this light, the I-R-F pattern is effective should feedback contribute towards development of new learning initiated by student talk and stimulate students to ask questions. However, in her influential work on student questioning Chin (2004) notes that in typical classroom settings student talk is more often made up of answering questions rather than asking them. And a study of secondary biology classrooms carried out in Portugal, revealed that teachers wrongly perceive students asking more questions than them and that these are of high quality (Almeida, 2010). However, it should be noted that this study was carried out with only 3 teachers and their students.

The importance of student-questioning, is conveyed by Chin (2004: 107) who reasons that questions:

> …are psychological tools for thinking as they help to explore and scaffold ideas, steer thinking in certain specific directions, and can advance student understanding of scientific concepts and phenomenon.

Chin conveys the importance of teachers' role to plan activities that encourage student-questioning in order to 'steer their students to ask questions' rather than to rely on them to 'occur naturally' (p.111). Hence here, authoritative interaction is essential as the teacher instructs students to carry out these planned activities. In contrast, using a metaphor of a medieval carnival in which 'the power classes of society were ignored', Nesari (2015: 646) draws a parallel to a model classroom where the teacher's authority is 'neutralised' as students 'exercise authority for themselves and make their voices heard'. However, for the teacher to 'steer the students in a particular direction' (Alexander, 2017: 32) as they engage in dialogic interaction and formulate 'wonderment questions' (Chin, 2004), teacher authority is necessary.

In summary, teachers find dialogic teaching difficult to facilitate and, even in some cases, wrongly perceive that their students ask more questions than them and that these are of high quality. Challenges that teachers encounter with dialogic teaching are likely to stem from lack of confidence in teaching and in subject knowledge. Therefore, support is needed to encourage and guide teachers with dialogic teaching.

2.2 How can learning and development be supported?

This sub-section begins by considering beginning teachers' beliefs which the literature shows will have an impact on their professional growth. Therefore, this is followed by a critique of key literature about theories of teacher development for beginning teachers. Having considered particular issues about teachers' beliefs and their professional growth, the review then focuses specifically on the means by which their practice will be developed in this study through the CoRe framework and mentoring.

2.2.1 Beginning teachers' beliefs

Beliefs about teaching, learning and science

Many educators agree that teachers' beliefs about the Nature of Science (NOS), teaching and learning, and science in the school curriculum may shape classroom practice (Nespor, 1987; Pajares, 1992; Tsai, 2002). These beliefs may stem from teachers' experiences at school such as how they were taught themselves (Furlong and Maynard, 1995; Tsai, 2002).

Moreover, influential studies claim that beginning teachers consider good classroom management and student engagement to equate to effective student learning (Joram and Gabriele, 1998), and that they hold inadequate views about NOS (Abd-El-Khalik and Boujaoude, 1997; Lederman, 2007). This will determine their ability to teach effectively (Bartholomew, 2004). It has been found that more traditional naïve understandings about teaching and learning and NOS tend to lead to more teacher-led classrooms (Tsai, 2002). In her study of 37 secondary school science teachers in Taiwan (ranging from 2 to 20 years of experience), Tsai (2002) found, as other researchers before her had (e.g. Donnelly, 1999; Gallagher, 1991; Lederman, 1992), that most teachers held a traditional - empiricist or logical positivist view of science. She developed a framework of teachers' beliefs categorised as 'traditional', 'process' and 'constructivist' (Appendix 2), which have also been used to analyse the teachers' beliefs and practice in this study (see sections 4.1.1 and 4.1.2, pp.41-7 and pp.49-51 respectively). A 'traditional' approach views scientific knowledge as 'correct answers or established truths' that the teacher transfers to students. The 'process' category includes the view that the application of the 'scientific method and problem-solving procedures' is necessary in teaching and learning science. While a 'constructivist' approach 'views teaching students as helping students construct knowledge, learning science as constructing personal understanding and science as a way of knowing' (ibid.: 773). These beliefs, she calls 'nested epistemologies', were closely aligned to the teachers' classroom practice which had been found to be mostly traditionally-oriented (ibid.: 777). Consequently, there is a need to support constructivist practice, such as dialogic teaching. It should be noted here, that the claim that beginning teachers hold naïve views about NOS that leads to undesirable teaching practice, is in contrast to a finding in my case study of Martin a pre-service teacher whose views about NOS were revealed in a structured

interview using Lederman et al.'s (2002) View of NOS (VNOS-C) questionnaire (Author, 2017a). While Martin held a naïve understanding of teaching and learning which was reflected in his teacher-led approach, he had more informed beliefs about NOS. This finding is supported by Sorenson et al.'s (2012: 43) study of 169 pre-service teachers in England, who revealed that they held less naïve views of NOS than indicated by the aforementioned influential studies. Questions from the VNOS-C were adapted to be used in pre-intervention interviews (Appendix 5.a) and Lederman et al.'s (2002) categorisation of *naive* and *more informed* beliefs was used to analyse the teachers' responses (presented in tables 2.a and 2.b in section 4).

Beliefs about the curriculum

In England, a key challenge has been delivering a curriculum to meet the needs of the 10% or so who pursue science beyond school and the majority who need to be 'scientifically literate' to understand and engage with scientific issues such as those presented in the media (Millar and Osborne, 1998). Others see scientific literacy as not only being limited to understanding newspaper and magazine articles about science but also being 'essential to a career as a professional scientist, engineer or technician' (Hodson, 2003: 646). As such, the debate since the late 19th century has been whether school science should be more content, or process based. Currently, the move is towards a content-led science curriculum that delivers theoretical ideas. Speaking at the recent Education World Forum, the minister of education Nick Gibb boldly advocated 'teacher-led instruction' asserting that 'children need to be taught the body of knowledge that we all take for granted' (Gibb, 2017). This content-biased approach provokes the continuing legacy to 'humanise science' which has culminated into curriculum components such as 'how science works'. These have aimed to

make the curriculum more relevant to students by using scientific, moral and ethical issues in society to teach science (Millar and Osborne, 1998). Such historical justifications of the purpose and approach taken by the curriculum has had implications for the way in which teachers perceive and deliver it (Jenkins, 2007). Hence, beginning teachers' beliefs about teaching and learning may be influenced by the curriculum setting they encounter at the start of their profession.

2.2.2 Teacher professional growth

The literature on theories of teacher development have emerged from the work of Frances Fuller (1969) who identified a stage-related and concerns-based developmental model (Berliner, 1988; Furlong and Maynard, 1995; Hollingsworth, 1989; Kagan, 1992; Ryan, 1992). Fuller's model sequences the concerns of beginning teachers as related to 'self' (survival, self-adequacy, and acceptance), 'tasks' (teacher duties), and 'impact' (on student performance, and on the education system). These stage theories, tend to show that in the initial stages of teachers' career the focus is on self and on control (or behaviour management), and not on student learning. Actions such as being reactive rather than proactive, using teaching strategies which are designed primarily to gain and maintain classroom control, and an unwillingness to deviate from a lesson plan (Furlong and Maynard, 1995), can lead to more teacher-led- and less dialogic-teaching. However, such models of an individual's professional development progressing through predictable and discrete 'stages' has been questioned. Examining such models Grossman (1992: 171) acknowledges that they are borne from how researchers 'frame teaching' - namely from the 'context of subject matter', or from an 'explicitly moral and ethical stance'. For example,

criticising Kagan's (1992) review of 40 learning-to-teach studies to construct a stage-theory model of professional growth, Grossman points out the omission of influential studies (e.g. Grossman and Richert, 1988; Shulman, 1987) that consider novice teachers' understanding of subject matter or PCK. Indeed, there is evidence that in fact novice teachers have a high level of concern and awareness for students' learning, but it is compromised due to their lack of PCK (Burn et al., 2003). As such, their shifting concerns are not restricted to the traditionally defined domains such as 'self', 'tasks' and 'impact' (He and Cooper, 2011). Furthermore, while there are numerous studies based on teachers' concerns there is much less focus on the emergence of such concerns and the strategies used to tackle them. Acknowledging this, He and Cooper (2011), professors at a teacher education college in America, carried out a study on 5 secondary pre-service teachers for 2 years during their teacher education programme and their first year at school. Their findings support their message to teacher educators about professional growth:

> By providing strategies for thinking about teaching experiences beyond subject matter content and ethical and moral issues, teacher educators offer additional, more meaningful, and lasting preparation for professional life beyond the security of teacher education programs. (ibid.: 98)

This is in light of Grossman's criticism on the notion of stage-based theories who asserts 'they imply that earlier stages lead naturally to later stages' (p.174) when in reality growth depends on unique challenges due to contextual factors such as school setting (He and Cooper, 2011: 106).

In summary, beginning teachers' beliefs about teaching and learning can be influenced by their own experiences as learners. Traditional-naïve understandings about teaching and learning and NOS can lead to teacher-led teaching. However, contrary to highly regarded

studies that reveal beliefs about NOS impacting classroom practice, there is some evidence of beginning teachers possessing desirable views about NOS which is not reflected in their classroom practice. The suggestion that beginning teachers are not really able to focus on what students are learning, is too simplistic (Burn et al., 2003). Hence, a sequential view about teacher growth which stem from assumptions about teachers' developmental stage should be questioned. Contextual factors, will play an important role in the professional growth of novice teachers as they face a variety of challenges to develop classroom practice. A key component of this practice is the methods in which talk is conducted in classrooms.

2.2.3 The CoRe framework

Having discussed the issues related to beginning teachers' development in the classroom, this sub-section will look at how learning and development can be supported in this project by using the CoRe framework with the beginning teachers within a mentoring relationship.

Loughran et al.'s (2012) content representation (CoRe) framework was developed to be completed by experienced teachers of a particular subject in order to map out their conceptualisation about the content of a topic. By considering the 'big ideas' related to a topic for a specific group of students, and through a series of prompts (or 'aspects'):

> .. the CoRe becomes a generalisable form of the participant teachers' pedagogical content knowledge as it links the how, why and what of the content to be taught with what they agree to be important in shaping students' learning and teachers' teaching. (ibid.: 17)

In this way, expert teachers' pedagogical reasoning would be made explicit for novice teachers, and particularly helpful for non-specialist teachers. Hagger and McIntyre (2006: 78) discuss how challenging it can be for experienced teachers to articulate their expertise and pedagogical reasoning when they say:

> Novice teachers do not know what there is to be learned, nor how they can learn it; experienced teachers take their tacit, intuitive expertise for granted and are therefore not motivated to reveal and explain it.

Therefore, completing CoRes is an opportunity for experienced teachers to share their 'implicit or tacit knowledge' with beginning teachers (Berliner, 2004: 206). When planning lessons, use of these CoRes could assist beginning teachers as it supports them in acknowledging and considering a variety of pedagogical approaches to constructivist teaching, such as dialogic interaction.

In this study, two completed CoRes have been used with the teachers (CoRe1 and CoRe2 - Appendix 3). CoRe1 was completed by a senior physics practitioner (and ex-teacher) at the IOP, and CoRe2 by another expert physics teacher and myself. As discussed later in section 3, CoRe2 was modified to allow for more ideas about dialogic teaching to be captured. The beginning teachers in this study had the opportunity to complete these new sections.

It should be noted that while CoRes can support beginning teachers plan effective lessons, it cannot be a one-size-fits-all solution even if it is completed with specific groups of students in mind. For example, a mixed-tiered year 9 group may have different educational needs to the same banded group in another school. However, my guidance as mentor is intended to further support the teachers in this study.

2.2.4 Mentoring

In this sub-section, relevant literature about mentoring is explored in light of my own role as mentor. There is a vast body of literature about the role of university- and school-based mentoring in the context of teacher training preparation (e.g. Calderhead, 1989; Hayward, 1997; Richter et al, 2013), some of which are applicable to my mentoring role. Since the teachers in this study have received university- and school-based mentoring, key literature on these types of mentoring will be explored to set the context in which I am providing additional support.

First, it is important to define what is meant by mentoring in this study as there are many descriptions (e.g. Clutterbuck, 1991; Gardiner, 1998; Landsberg, 1996; Wright. 2010). An appropriate definition is described by Hobson et al. (2008: 207), who carried out research on an extensive range of international literature on effective mentoring. They state mentoring as:

> …the one-to-one support of a novice or less experienced practitioner (mentee) by a more experienced practitioner (mentor), designed primarily to assist the development of the mentee's expertise and to facilitate their induction in the culture of the profession (in this case, teaching) and into the local specific context (here, the school or college).

This resonates with the IOP's view of mentoring support. Their mentoring programme (which ceased in December 2017 due to lack of funding), called Stimulating Physics Support (SPS), supported physics-specialist teachers in their first three years of teaching. The focus was on mentoring specialist teachers, particularly those with a good honours degree, to encourage these graduates to remain in the profession. Their belief, supported by evidence from CUREE (accessed, 2012), is that:

> …personalised support from an expert physics practitioner can facilitate the systematic improvement of a new teacher's teaching, encourage a reflective approach towards their professional development, and contribute to improved retention of new teachers in the profession (Institute of Physics, 2012: 1)

The SPS-mentor can be said to be a 'remote expert practitioner' whose interactions with beginning teachers (called 'mentees') remain focused on physics and rooted in or leading to subject-based professional development (ibid.: 2). As such, mentees have received support in the form of one-to-one mentoring (during which for example, targets are set), lesson observations and feedback, and professional development sessions (e.g. workshops to develop physics PCK). Importantly, unlike university- and school-based mentors, my role as mentor is independent from formal structures of assessment or performance management. While the evidence is inconclusive, a number of studies (e.g. Abell et al., 1995; Heilbronn et al., 2002; Williams and Prestage, 2002) have suggested that where assessment and support functions are carried out by the same mentor, it is more difficult to establish the kind of relationship, based on mutual trust, in which 'risk-free learning' can occur (Hobson et al., 2009: 213), and where mentees will try to meet different personnel's criteria (Hayword, 1997). SPS-mentees are made aware of this informal mentoring support, one of whom is a teacher in this study.

While the SPS-programme has done well to support specialist physics teachers, I was mindful that subject-specific personalised support was also particularly important for teachers teaching outside their specialism. Recent figures have revealed that 25% of physics teaching is carried out by teachers who do not have a post-A-level qualification in physics (House of Commons Education Committee, 2017). In this light, physics-specific mentoring is necessary not only for developing teachers' practice but also for enriching their physics

knowledge to build on their confidence in teaching the subject (Harlen and Holroyd, 1997). Alongside the SPS-mentoring role, as one of the IOP's Physics Network Coordinator (PNC), I organise and run physics workshops for teachers from local schools. My SPS-mentees are encouraged to attend these sessions where they have the opportunity to meet and work with teachers of varying experience and academic backgrounds (such as biology and chemistry specialists). It was at such a workshop that the aforementioned SPS-mentee (physics-specialist and in her first year of teaching) and another regular attender (non-specialist and in her third year of teaching) had expressed a need for subject-specific mentoring to develop their classroom practice. In particular, they wanted to focus on classroom talk and strategies to engage students in talking about physics. Hence, a programme of support to develop dialogic teaching was designed and carried out with them (see section 3).

Mentoring acquisition

As mentioned earlier, trainee teachers in the British system are assigned to a university- and school-based mentor in their teacher training year. In their second year as Newly Qualified Teachers (NQTs) university-based mentoring ceases but they continue to receive support from a school-based mentor which also ceases beyond the NQT year. The literature on teacher training highlights the mismatch between school- and university-based mentoring (Hayward, 1997), the incompatibility that can exist between *epistemic knowledge* (rooted in theory) and *phronesis knowledge* (linked to teachers' experience) (Korthagan and Kessels, 1999), and differences between trainees' view of teaching and learning and what they are actually taught (Calderhead, 1989; Hayward,1997). However, the availability of mentoring that offers instructional and psychological support (Gold, 1996) is perceived to be of value

to beginning teachers and is linked to retention rates (Burke et al., 2007). In their extensive research on early career teacher (ECT) support in Australia, Burke et al. (2007) point out the positive impact that mentoring support can have, and that 'inadequate support' is a 'key factor in attrition' amongst teachers (ibid.: 242). Their findings also reveal that 63% of the ECTs who had planned to leave the profession reported that they had no opportunities to carry out collaborative work with experienced teachers (ibid.: 250). Thus, formal and informal programmes of support from expert practitioners, can minimise negative experiences, such as isolation (Abdallah, 2009). An important question to ask here is: are certain forms of support more effective in achieving mentoring goals than others? Richter et al. (2013: 168) state that 'the primary goal of mentoring is to foster professional knowledge and skills'. In their study of 700 beginning teachers in Germany over the course of one year, they distinguish the quality of mentoring as either *transmission*- or *constructivist-oriented*. Mentoring that is *transmissive-oriented* is more conventional and relies on learning that is 'unidirectional in which learners are passive recipients of information' (ibid.: 168). On the other hand, *constructivist-oriented mentoring* reflects a knowledge transformation model in which 'learning is an active process' in which learners 'construct their own knowledge by connecting new information to their prior knowledge' (ibid.: 168). In their study, evidence revealed that the teachers who received constructivist-mentoring showed:

> …higher levels of efficacy, teaching enthusiasm, and job satisfaction and lower levels of emotional exhaustion after one year of training compared to those without constructivist mentoring. (ibid.: 174)

Moreover, it was found that the *quality* of mentoring rather than its *frequency* had a positive impact on teachers' early career (ibid.: 171). An unexpected finding in the study was that most of the school-based mentors demonstrated constructivist-oriented mentoring

involving ‘opportunities for reflection, experimentation with different teaching methods, and autonomous decision making’ (ibid.: 174). This is surprising because these tutors had not received any formal training. Hobson et al. (2009: 212) point out that mentors are more likely to employ effective mentoring strategies where they have undertaken an appropriate level of mentor preparation. And writing in the context of US mentoring preparation, Zeichner (2005: 118) reasons that ‘expertise as a teacher does not necessarily translate as expertise as a mentor of teachers’. Furthermore, Richter et al. do not make clear how the mentees’ emotional and psychological needs were supported in their study. There have been reports on how such needs have not been supported effectively due to mentors’ ‘unavailability’ (Hardy, 1999; Smith and Maclay, 2007). This calls to question Richter et al.’s claim that the *frequency* of mentoring is somewhat less necessary.

In summary, there are similarities and differences between my mentoring role as a ‘remote external practitioner’ and those of university- and school-based mentors. Similarities include pedagogical- and subject-knowledge development, lesson observations and feedback, and opportunities for reflective practice. A constructivist-oriented mentoring approach, (as opposed to one which is transmission-oriented), can lead to positive outcomes. It is also important to incorporate one-to-one time for psychological and emotional support to resist low teacher confidence and attrition. Relying on expertise as a teacher alone to mentor novice teachers, may risk effective support.

A significant difference is my informal role in comparison to university- and school-based mentors mainly due to no formal assessments being involved. Another important difference, is the specificity of mentoring I am offering to develop dialogic teaching in the physics classroom.

3. Methodology

This section begins with a description of the context in which this study has taken place, including a brief description of the teachers' academic backgrounds and relevant information about their school setting (3.1). The structure of the research is then presented (3.2) before applying Elliott's (1991) model of action research to the processes that have taken place within the project (3.3). Finally, ethical considerations that have been applied throughout the research are discussed (3.4).

3.1 The context

As discussed in section 2.2.4. (p.22), through my SPS-mentoring role I had met one of the teachers in this study and had applied this mentoring support to develop another teacher's practice who was a regular attender of my PNC workshops. At a recent workshop, these teachers were keen to have physics mentoring support to develop classroom interaction. Therefore, this study was developed to support these beginning teachers develop dialogic teaching in physics lessons within a mentoring relationship. Drawing upon *pedagogical* and *contextual knowledge* (Goodwin and Kosnik, 2013), a bespoke programme of support was designed to provide one-to-one mentoring which would guide the teachers to develop their classroom practice in this specific area. It is intended that the findings of this study will be shared with PNC colleagues at the IOP. As pointed out in 2.2.4., the ceasing of the SPS-mentoring project has meant that beginning teachers are no longer being provided with informal one-to-one 'no-risk' support. Instead, there is scope for such support to be

provided via the PNC teacher network. Currently the PNC network run workshops for local teachers with a wide range of experience. PNCs could identify the needs of beginning teachers' and develop similar programmes to support constructivist teaching approaches in physics classrooms. Indeed, as supporters of physics education we ought to invest such attention towards teachers' early careers if we wish to discourage negative feelings amongst them, helping the retention of physics teachers (IOP, 2012).

The following is a brief biography of the teachers in this study. They are given pseudonyms in order to protect their identities.

Leanne

Graduating with a second-class BSc Chemistry degree from Swansea University, Leanne then completed a PGCE in Science (specialising in chemistry) at King's College, London. Since then, she has taught for three years at a large mixed inner-city state-school in London. At the start of this study, Leanne had said that she believed in 'student-centred teaching' and wanted to be a 'facilitator' in the classroom. However, she felt that this was compromised due to her inexperience in teaching, especially physics (see table 2.a, p.45). Leanne has been a regular attender of my PNC-led workshops and we had known each other for two years prior to this study.

Angela

Angela graduated with a first-class MSci in Geophysics at Bristol University followed by an MSc in Petroleum Geoscience with distinction. After working in this industry for 5 years she decided to get into teaching as she enjoyed working with school students in her industrial

role. She completed her PGCE in Science (specialising in physics) at the Institute of Education and in the following year (this academic year) she is teaching at a large inner-city girls' state-school in London. Angela has had issues with support at this school, which will be discussed later. Like Leanne, at the start of the programme Angela had expressed a constructivist view to teaching and learning stating that teaching science should be about 'teaching students how to think' rather than 'as fact' (see table 2.a, p.45). Before the study, I had supported Angela throughout her teacher training year.

Prior to the study, Leanne and Angela had attended a workshop session after which we had a short informal meeting about their participation and how they could benefit from it. As discussed earlier, both had expressed a wish to have physics mentoring and wanted their lessons to be more 'student-centred'. After describing how I planned to develop their practice, I suggested they kept a reflective diary which they could use and refer to during our one-to-one meetings. In this way, reflection-in- and -on-action would encourage them to become researchers in their own contexts by allowing them to construct new theories of their own unique cases (Schon, 1983).

3.2 Structure of the research and intervention

The research was carried out in three phases (one per term), and in each phase the intervention and data-collection were intertwined.

Table 1 presents an outline summary of the structure of the study. The key questions were generated at the start of each phase, and in phase-2 and -3 these were informed by the

findings of the previous phase. The model of action research, which will be discussed in 3.3, was applied to the processes involved in this study. These are detailed in 3.3.1.

Phases and dates	*Phase-1: 4/9 - 20/9/17*	*Phase-2: 2/1 - 23/3/18*	*Phase-3: 9/4 - 20/7/18*
Research questions	What are the beliefs of the teachers? What is their practice?	To what extent is the CoRe framework effective in supporting dialogic interaction? To what extent is my mentoring effective?	To what extent is the modified CoRe effective in supporting the teachers plan for dialogic interaction? How may the support be developed?
Intervention	**To collect baseline data:** Initial face-to-face interviews using Luft & Roehrig's (2007) TBI and Lederman et. al's (2002) VNOS-C questionnaire; Pre-support lesson observations. Lesson observation feedback using the KQ.	Provision of - Chapter 3 of Loughran at al. (2012), Alexander's (2017) *principles of dialogic teaching* (APDT), and The CoRe on Energy (CoRe1); Lesson observation feedback using the KQ; Post-lesson interviews to discuss the usefulness of the CoRe; Modification of the CoRe to better support dialogic discourse.	Provision of the modified CoRe (CoRe2) on Electromagnetic Waves partly completed by the teachers in preparation for the lessons being observed in phase-3; Lesson observation feedback using the KQ; Joint interview with both teachers to discuss the effectiveness of CoRe2 and further support.
Data collection	Video recorded lessons; Field notes; Audio recorded interviews		
Analysis	KQ to analyse lessons; Tsai's (2002: 774-775) *framework of beliefs* and Lederman et al.'s (2012: 515-516) *examples of responses to VNOS items* to analyse responses from initial interviews.	KQ and APDT (and its indicators) to analyse lessons and to identify whether or not dialogic teaching had developed since phase-1; Analysis of my support by reflecting on notes in my journal, audio-recordings, and email communications.	KQ and APDT (and its indicators) to analyse lessons and to identify whether or not CoRe2 had supported dialogic teaching better; Analysis of the joint interview and field notes to consider ways to develop support.

Table 1: Outline of the key questions and processes taking place during each phase of this action research project.

In summary, in this project each teacher had a series of audio-recorded interviews, lesson observations, and feedback. However, the intervention and data collection were not just limited to these activities. Throughout the study, further interaction with the teachers took place depending on the support needed in each of their cases. For example, by email (see

Appendix 4). The most appropriate approach taken to carry out the data-collection and intervention is discussed below.

3.3 An action research approach

A purposive sampling technique was used to select the participants in this study. This is a non-probabilistic sampling method characterised by a deliberate effort to obtain representative samples through the inclusion of groups or typical areas in the sample (Kerlinger, 1986). As such, I had actively selected the most productive sample in my capacity to answer the research questions. This was based on my own practical knowledge of the research area, relevant literature, and evidence from the study itself. The results of purposive sampling are usually expected to be more representative of the population than those achieved with an alternative form of sampling (Patton, 2002). However, the selection criteria the researcher uses to answer the questions is likely to be subjective. In this study, selecting two participants to represent beginning teachers will not accurately inform issues about dialogic teaching for the population of beginning teachers at large. Having said that, this small-scale study is qualitative and in-depth, and it is intended that it provides ideas for supporting teachers with constructivist teaching approaches, rather than claim that the methods employed in doing so are fixed. Close interaction with the respondents resulted in 'collaborative inquiry' (Tobert, 1981) which enhanced the usefulness and validity of the findings (Borg and Gall, 1989). It is intended that these findings will be used as data by PNC-colleagues working with beginning teachers in the future.

Based on the sampling technique and close interactions with participants, an action research methodology was considered to be most suited. Action research is understood to be:

> …a collaborative approach to research that provides people with the means to take systematic action in an effort to resolve specific problems. This approach endorses consensual, democratic, and participatory strategies to encourage people to examine reflectively their problems or particular issues affecting them or their community. Furthermore, it encourages people to formulate accounts and explanations of their situation and to develop plans that may resolve these problems. (Berg, 2002: 196)

In action research, as with this study, theories are not validated independently and *applied to* practice, but validated *through* practice (Elliott, 1992: 69). Throughout the project, Leanne and Angela's input (including 'accounts and explanations of their situation') was key in developing the research questions that form the basis of this study. They were encouraged to be researchers in their own development by recording their experiences in a journal and engaging in relevant educational literature. Opportunities for collaboration within the study had allowed us to 'examine reflectively' the issues affecting their classroom practice and the methods used to develop dialogic teaching. Beyond this study, it is intended that collaboration between fellow (PNC) colleagues and myself will develop further effective support for beginning teachers.

3.3.1. A model of action research

The renowned social psychologist Kurt Lewin is often referred to as the originator of 'action research' who coined the term in the late 1930s (Adelman, 1993). Lewin's model involves a spiral of cycles which enables the researcher to acknowledge what action research involves.

However, as Elliott (1991) argues the model is only a good starting point and does not encapsulate the multifaceted process that take place at each stage of action research. Elaborating from Lewin's model, Elliott developed the model presented in figure 2 which will be applied to the approaches and processes that took place in conducting this study.



Figure 2: Elliott's (1991: 71) revised version of Lewin's model of action research.

Thus, a spiralling progression at each stage which is composed of some type of planning, action, and evaluation is presented (Berg, 2004). This was done in collaboration with the teachers. Importantly this method 'empowers individuals to share their stories, hear their voices, and minimise the power relationships that often exist between a researcher and their participants' (Cresswell, 2013: 48).

3.3.2 Application of Elliott's model

The following is an account of the processes that took place during data-collection and intervention within each phase. Elliott's model presented in figure 2 is applied.

Phase-1:

Identifying (initial) general idea

Eliott points out:

> The important criteria for selecting a 'general idea' are whether the situation it refers to (a) impinges on one's field of action, and (b) is something one would like to change or improve on. The extent to which one is able to change or improve on it is a question which action research should address, rather than assume an answer to (p.72).

As discussed earlier, both teachers had expressed interest in receiving mentoring in order to develop their classroom practice, and in particular to make their lessons more interactive. From this 'the general idea' - which Elliott refers to as '...a state of affairs or situation one wishes to change or improve on' (p.72) - was set.

This was that:

- Beginning teachers wish to have physics specific mentoring to develop classroom practice. How can we (as physics expert practitioners) provide effective mentoring support?

- Beginning teachers are aware that their physics lessons are not interactive enough. How can we support them in making lessons more interactive, that is promote dialogic teaching?

Reconnaissance - fact finding and analysis

Having identified the 'general idea' of the study, the 'facts' surrounding it were revealed in the literature. These are that:

- beginning teachers' knowledge and beliefs about NOS, teaching and learning could impact on their classroom practice (Nespor, 1987; Pajares, 1992; Tsai, 2002). These should be explored if we are to support them effectively.
- teachers find dialogic teaching difficult to facilitate (Alexander, 2017; Mercer et al., 2006). Therefore, it is likely that for beginning teachers support is needed to develop dialogic teaching.
- experienced teachers tend to find it difficult to share their knowledge (Berliner, 2004; Hagger and McIntyre, 2006). The CoRe framework is designed to capture this knowledge (Loughran et al., 2012).

In light of baseline data, these 'facts' were reconsidered before applying it to the study.

General plan and implementing the initial action step

The decision to carry out the data collection and intervention over three phases throughout the academic year, would allow for gradual progress to be captured during the whole of part 2 of this MTEd course. I had used the CoRe framework in previous studies (Assignment 2 and Assignment 3, Author 2017b and Author 2018a) which had shown to be a useful way

of capturing experienced teachers' PCK - something they would otherwise find difficult to do (Berliner, 2004; Hagger and McInyre, 2006). So, use of the CoRe could also provide useful information about expert teachers' thinking about physics teaching. As mentioned previously, CoRe1 (Appendix 3.a) had been completed by an expert physics practitioner at the IOP for a middle-ability KS3 group of students. I had reasoned that this could be a useful tool for aiding the planning of dialogic teaching with the beginning teachers in this study.

First, to answer the key questions 'What are the beliefs of the teachers?' and 'What is their practice?' baseline data was collected during phase-1 through individual face-to-face interviews and pre-intervention lesson observations. Semi-structured interviews would enable me to 'hear' more than what the participants had to say through their body language and tone, as well as allow me to ask follow-up questions (Birmingham and Wilkinson, 2003: 63). The interviews involved questions from Luft and Roehrig's (2007) TBI and Lederman et al.'s (2002) VNOS-C questionnaires (Appendix 5.a) as these have proved to be effective ways to measure teachers' beliefs about teaching and learning, and NOS. These were later analysed using Tsai's (2002) framework of beliefs (Appendix 2) and Lederman et al.'s (2012: 515-516) examples of responses to the VNOS-C, respectively. Video-recorded lesson observations which were then carried out, were later partially transcribed and analysed using the KQ (Appendix 6). Analysis of the findings, using Tsai's (2002) framework of categorising beliefs, revealed to what extent teachers' beliefs about science, and teaching and learning correlated with their classroom practice. In the post-lesson interviews, feedback was provided and evidence on the KQ shared with the teachers. During these interviews, a shared experience of the teachers' lessons had encouraged them to make sense of what they do (Brown and McIntyre, 1993).

Monitoring implementation and effects → Reconnaissance (failure to implement, and effects) → Revise general idea

The action step just described served well to reveal the teachers' beliefs and practice which set the context with regard to the level of support needed. However, while the post-lesson meetings allowed teachers to reflect on their practice, more was needed for them to acknowledge the lack of dialogic teaching and consider ways to develop it. As such, by the end of phase-1, the teachers did not have any significant opportunities to link their practice to dialogic teaching. It was apparent that only providing them with CoRe1 (Appendix 3.a) to assist with planning for dialogic teaching in phase-2, was insufficient. Provision of further material and guidance was needed. Hence, *Alexander's principles of dialogic teaching* (APDT) (figure 1, p.12) was provided and an explanation of how it could be used discussed with each teacher. As such, in light of baseline data my method was reconsidered and reformulated (Bullough and Gitlin, 1995) to allow me to 'change and improve' (Eliott, 1991) classroom interaction, namely dialogic teaching.

By the end of phase-1, the extent to which my role as mentor provided bespoke support for Leanne and Angela was another important consideration. Feedback during face-to-face meetings and other communication exchanges, like email correspondence (Appendix 4), had supported both teachers in acknowledging and reconciling their beliefs in order to develop classroom practice. In particular, the revelation (near the end of phase-1) of the issue concerning Angela's negative experience at school would have implications on how as an external mentor I could support her most appropriately. She had expressed that she wanted to continue participating in the study and that '…in fact it was the best thing that was happening in her career' (post-lesson interview, audiotaped on 15/11/17). What transpired

from this sensitive discussion was that as a result of receiving frequent criticism about her practice (mainly to do with classroom management) from her school-based mentor, Angela's confidence was being compromised. In contrast, she felt that the mentoring she was receiving as part of this study was enabling her to focus on developing constructivist approaches to physics teaching. So, on the one hand as mentor I had to support her development of classroom practice, and on the other I had to support her on an emotional and psychological level. Without the latter it would be difficult to accomplish and cultivate desirable classroom practice, such as dialogic teaching. As such, my role as mentor would need to incorporate psychological and emotional, as well as pedagogical support. This support also continued throughout phase-2 and -3 and will be discussed in section 4.

Phase-2:

Amended plan → Implement next action steps

Following the findings and considerations made in phase-1, the research questions 'To what extent is the CoRe framework effective in supporting dialogic interaction?' and 'To what extent is my mentoring effective?' were set. Prior to data collection, at the beginning of phase-2 the teachers were provided with a:

- copy of Loughran et al.'s (2012) chapter 3 - giving them the background about the CoRe framework and its objectives.
- CoRe on energy, CoRe1 (Appendix 3.a) - to be used in planning a lesson on energy with a year 9 mixed-tiered group.

- copy of Alexander's principles of dialogic teaching (APDT) (figure 1, p.12) - to be used to consider activities that would support classroom discourse.

Again, lessons were filmed during which field notes were taken. While analysing the lessons, the coded indicators (Appendix 1) for APDT were applied to the findings presented on the KQ to highlight areas were aspects of dialogic teaching had taken place (presented on tables 4.a-b, pp.55-7 and 5.a-b, pp.61-3). Findings were discussed in the post-lesson interviews. As such, data relating to events I had observed and analysed could be combined with explanations and accounts provided by the teachers (Birmingham and Wilkinson, 2003; 121).

Monitoring implementation and effects → Reconnaissance → Revise general idea

Both teachers had conveyed that the use of APDT was useful in designing activities for dialogic teaching (see section 4.2.2, pp.58-9). References made to APDT during post-observation lesson feedback also generated fruitful discussion about developing dialogic teaching further in future lessons.

While both teachers had found CoRe1 useful in planning their lesson on energy, their reflections revealed that the framework could be further modified to capture expert teachers' ideas on dialogic teaching (see 4.2.2). Consequently, with their input the CoRe template was modified to include additional aspects that would potentially capture knowledge about dialogic teaching for each of the 'big ideas' on the template. The next action was to complete this modified template for the 'big ideas' about 'Electromagnetic Waves' (the topic both teachers were going to be teaching in phase-3). I had considered that perhaps the teachers could attempt to complete CoRe2 for the 'Big Ideas' on

electromagnetic waves they would teach in phase-3. When approached with this idea, both teachers expressed discomfort at the prospect of doing so. This reinforced the fact that the CoRe is specifically designed to capture expert teachers' knowledge (Loughran et al., 2012) and beginning teachers' awareness that their PCK is insufficient (Burn et al., 2003).

Phase-3:

Amended plan → Implement next action steps

Following modification of the CoRe template the research question 'To what extent is the modified CoRe effective in supporting the teachers plan for dialogic interaction?' was set. In this final phase, it was also essential to consider any potential future impact of this study, and so the question 'How may the support be developed?' was also set. Firstly, CoRe2 was completed by myself and a fellow expert physics teacher at the school I teach part-time at (Appendix 3.b). However, I still felt that the teachers would benefit from making a contribution to completion of CoRe2 as it could encourage them to exercise their PCK, even if underdeveloped. As such, they were approached with a compromise to complete only the latter (additional) aspects of CoRe2. So, my colleague and I completed all parts of CoRe2 except for the last two aspects. Leanne and Angela were given the task to complete the blank 'aspects' only for the 'big ideas' they were planning to teach (figure 3, p.60). Once completed, they discussed their contributions with me before planning their lessons using CoRe2 and APDT.

Monitoring implementation and effects → Reconnaissance

Again, as table 1 (p.30) shows, data-collection was carried out to inform the key questions set at the beginning of phase-3. These findings are presented and discussed in detail in section 4. They reveal that to a large extent, the modified CoRe and the teachers' input had effectively supported planning for dialogic teaching. At the end of phase-3, a follow-up group audio-recorded interview took place with both teachers during which pre-planned questions were asked (Appendix 5.e). This was in order to provide the opportunity for them to share their experiences of participating in the project. As a result, I would be able to capture essential information about how effective they found the project to be in developing their classroom practice, and in particular how well the CoRe supported them with dialogic teaching. This led to considerations about the limitations of the project and how this support could be developed for Leanne, Angela and other beginning teachers (see sections 4.33 and 5, pp.65-6 and pp.70-74 respectively).

3.4. Ethical considerations

Central University Research Ethics Committee (CUREC) guidelines and recommendations by BERA (2011) were applied and adhered to throughout this study.

Prior to the study

Both teachers were provided with an information sheet outlining what to expect if they agreed to participate, a consent letter, and a consent form they were required to complete.

The information sheet outlined the background, aims, and benefits of the study, and made clear:

- what would happen in the study, stating the use of audio- and video-recording during lessons and meetings.
- that a potential risk would be time taken away from their other work priorities.
- that they were under no obligation to participate and could withdraw at any point. For Angela, in particular, this was an important message as being one of my SPS-mentees, she may have felt that she had to consent in case it would disadvantage our working relationship.
- that research and personal data would be stored confidentially using a password protected memory stick to which only I would have access to. This data would be destroyed soon after the write-up of the study.
- that their identities would be protected by referring to them by pseudonyms, and assurance of confidentiality given.
- who to contact if they had concerns or complaints about the study.

Also, assurance was given that there would be no sharing of information or interaction between me and any individuals at their schools, such as Angela's school-based mentor. Therefore, 'risk-free learning' would be sustained throughout their participation (Hobson et al., 2009).

After consent was given by Leanne and Angela, the head teachers at their schools gave permission to carry out video-recorded lessons. Consent letters were signed by parents to agree with their children participating in these lessons. One parent from Leanne's school

had objected, so the science department had made provisions for their child to be supervised in another classroom with work set by Leanne.

During the study

It can be argued that the very presence of power in the relation between researcher and participants is what constitutes the ethical issues (Brinkmann and Kvale, 2005). While the power the researcher has is inevitable, the participants should feel they can express their perspectives without manipulation nor judgement (Cresswell, 2013). Leanne and Angela could only feel free to disclose honest views, as well as sensitive issues, if I was approachable, non-judgemental, and trustworthy. During interviews, where much of this exchange took place, it was important for them to be assured about this. Indeed, 'with the close personal interaction of qualitative interviews, and the potentially powerful knowledge produced, ethics becomes as important as methodology in interview research' (Kvale, 2006: 497). The use of semi-structured interviews allowed both teachers to have a fair degree of freedom on what to say, how much to talk about, and how to express it (Drever, 1995). Also, the fact that both teachers knew me before the research on informal and no-risk capacity terms, leant itself to openness and ease of communication from their side.

Finally, ethical considerations were applied in the case of Angela's sensitive issue regarding the working relationship with her school-based mentor. The problems she encountered had started in phase-1 and continued throughout the course of the study. By the end of phase-2, Angela's teaching union was involved to ensure that she was given fair treatment at her school, and importantly for her to achieve her NQT qualification should she be entitled to it. Acknowledging the strain she was under, I had reminded her that she could withdraw from this study at any time. However, as discussed in 3.3.2 (p.37) Angela wished to continue as

she felt that the project had had a positive impact on her development. She had included the analyses of her lessons presented on the KQs (Appendix 6) as part of her NQT portfolio, which she recently told me had contributed to her qualifying as NQT. Angela will be teaching at another school in the forthcoming year.

4. Findings and discussion

This section presents findings of lesson observations and interviews throughout the 3 phases of the project. Key findings from lesson observations are presented in the *transformation* and *contingency sections* of the KQ as these domains are closely linked to dialogic teaching. During post-lesson interviews, other relevant observations were fed back to the teachers which had been transcribed from films. All findings are used to answer the research questions set at the beginning of each phase.

4.1 Phase-1: *What are the beliefs of the teachers? What is their practice?*

4.1.1 Pre-intervention interviews

The following tables present responses from Leanne and Angela during one-to-one audiotaped interviews. Table 2.a presents key responses to the TBI questions which have been analysed using Tsai's framework of categorising beliefs (Appendix 2). Table 2.b presents responses to the VNOS-C questionnaire analysed using Lederman et al.'s (2002) classification.

Table 2.a. Teachers' responses to the questions adapted from TBI (devised by Luft and Roehrig, 2007: 43; Appendix 5.a) and analysed using Tsai's (2002: Table1, 774; Appendix 2) framework of categorising beliefs (italicised in bold).

	Leanne	Angela
How do you maximise student learning in your classroom? (learning)	A more constructivist, student-centered view of learning was given: 'I believe student-centred learning, flip learning and peer work are powerful methods and would like to be a facilitator in the classroom. Ideally, all lessons should be interactive where students learn from exploring.' However, in practice, because as she said she 'doesn't have the tools to create this classroom' she perceived she taught in a more process-oriented mode when she said: 'But I rely on question and answer methods and getting students to complete worksheets.' ***Constructivist** view but practice is **process.***	A more constructivist, student-centred view of learning was given: 'The more we can make science lessons interactive and investigative the more we can inspire students and deepen their understanding of how science works.' However, in practice while she 'wanted for this to happen' she realised that this was not taking place in her classroom as she was 'only in her first year of teaching and new to it all'. Instead, she perceived she taught in a traditional-oriented mode when she said: 'I end up doing most of the talking at the front of the classroom working through my presentation.' ***Constructivist** view but practice is **traditional.***
How do you describe your role as a teacher? (teaching)	She described her role as 'a facilitator rather than just a deliverer of the subject' indicating a more constructivist view. However, she also said, in practice ', I tend to do more of the talking and questioning and I want the students to do more of this…' This seems to indicate her practice is more traditional. ***Constructivist** view but practice is **traditional.***	She acknowledged that 'it's very much teacher-centred' and conveyed a process-oriented mode of practice when she said: '…to ensure students carry out set work and practicals well'. However, her beliefs where more constructivist when she said: 'I think teaching of science should be about teaching students how to think, how to explore the world around them and use their observations to make sense of it.' And: '…models are of immense value in science, often being our only way of visualising something that we cannot see. Much scientific research is based around building models. So, if we can teach students to be able to analyse the benefits and potential pitfalls of models then we can set them with valuable skills, which will be useful beyond the pure sciences. ***Constructivist** view but practice is **process***
How do you know when your students understand? (learning)	A process-oriented view was reflected in her practice when she responded: 'Class-worksheets, verbal questioning, homework, and tests.'	Her practice was process-oriented when she said: 'Marking homework and tests mainly.'

	Process	However, she reflected on constructivist-oriented methods when she said: 'During lessons when they are carrying out activities like practicals and they are talking to one another, I can probe their understanding'. ***Process*** *with elements of* ***constructivist***
In the school setting, how do you decide what to teach and what not to teach? (teaching)	A traditional-oriented view was apparent when she conveyed that 'the schemes of work and exam specifications' were the 'main sources' to teach from. ***Traditional***	A traditional-oriented view was given when she stated her 'school's database' having 'lesson plans and schemes of work' and that her '…mentor [school-based] instructs on what [she] should cover.' ***Traditional***
How do you decide when to move on to a new topic in your classroom? (teaching)	A traditional-oriented view was given when she expressed a reliance on school resources such as: '…end of topic questions either in the text book or department's worksheets…' ***Traditional***	A process-oriented view was given when she expressed the belief of verification using: '…end of topic questions' before they '…move on from there.' ***Process***
How do your students learn science best? (learning)	A constructivist-oriented view was expressed as she had made a link between: '…new learning' and '…everyday examples and careers'. ***Constructivist***	A constructivist-oriented view was expressed when she conveyed positive learning outcomes: '…when they have opportunities to discuss the topic and ask questions.' ***Constructivist***
How do you know when learning is occurring in your classroom? (learning)	A traditional-oriented view was revealed when she said: 'When students are listening and engaged. They can answer questions during classroom discussion.' And she felt that 'thumbs-up, thumbs-down' was an adequate way to gauge learning by all students. ***Traditional***	She expressed a traditional-oriented mode of practice saying that she knew she had '…to work on this' as she acknowledged doing '…a lot of question and answer drills' that did not tell her if '…learning was happening for everyone'. Her constructivist-oriented view was revealed when she said: 'I need to come up with ways to get students talking to have a better idea of what they understand.' ***Constructivist*** *view, practice is* ***traditional***

The findings give insight into the teachers' beliefs about teaching and learning. Table 2.a indicates that both teachers have a constructivist view about how learning should be maximised, what a teacher's role should be, and how students learn science best. As was

found in Tsai's study, table 2.a reveals inconsistent beliefs about teaching and learning. For example, both had placed a higher goal with regards to their 'role as a teacher' by giving a constructivist-oriented view, and a lower goal for how they knew that their 'students understand' responding with a process-oriented view. This is consistent with Tsai's suggestion that when teachers' beliefs about teaching and learning are incongruent, 'often a higher position or goal is set about their teaching than it is for learning' (ibid.: 778). However, both believed that successful learning involved student-teacher interaction which ought to be less teacher-led and more student-centred. Both had expressed that this was not taking place as much as they had wished to. Leanne believed that this was as a consequence of her inadequate physics knowledge, while for Angela she was aware that it was due to her lack of PCK - a finding that resonates with Burn et al.'s (2003) analysis of novice teachers' thinking. Another difference between the teachers' views was to do with how they knew learning *by all* was taking place. While Angela had expressed that it should be revealed through student talk, Leanne believed that questioning students and using the technique 'thumbs up, thumbs down' would be sufficient.

Table 2.b. Responses to NOS aspects from Lederman et al, (2002: 509; Appendix 5.a) classified as *more informed* and *naïve.*

NOS Aspect	**Leanne**	**Angela**
Empirical NOS	'Science is about collecting and analysing data which informs hypotheses. This is to reach conclusions.' ***Naïve***	'Evidence is needed which is based on observations. But the evidence is never always fixed and can change.' ***More informed***
General structure and aim of experiments **and** validity of observationally based theories and disciplines	'Experiments are a good way for students to test theory.' 'Sometimes it takes them too long so it's not always beneficial for them to do practicals during class time.' ***Naïve***	'Science is always subject to change and experiments allow for our knowledge to be developed. For example, Penzias and Wilson's detection of background radiation gave credence to the Big Bang theory... but theories can be repeatedly tested using different experiments based on new ways of collecting data… As much as is possible, students should carry out experiments.' ***More informed***
Creative and imaginative NOS	'Students can be creative in science because they have opportunities to make predictions and think of ways to present their work.' ***More informed***	'Einstein is a good example of an imaginative scientist as he was able to think of something that is not present to create his theories.' ***More informed***
Social and cultural embeddedness of science	'Science in one society should be the same as in another…in some countries religion has a big impact on scientific views. An example is creationism taught in parts of the US…. Real science is what makes technological advancements, and this depends on the science before it, not on culture.' ***Naïve***	'Society and culture have a big part to play in science. For example, if our societies wish is to obtain specific types of medical or technological applications, then this can affect the types of scientific research that takes place.' ***More informed***
Tentative science	'Some things like Newton's laws are more certain, because it has been supported by lots of evidence.' ***Naïve***	'Models can never be proven with absolute certainty. It can always be contested with opposing evidence.' ***More informed***
Theory versus law	'Good theories turn into laws.' ***Naive***	'Laws can be disproved but not so much as theories.' ***Naïve***

Key responses to questions from the VNOS-C questionnaire, summarised in table 2.b, suggest that Angela had *more informed* views about NOS when using Lederman et al.'s (2002) categorisation to analyse responses. A finding supported by Sorenson et al.'s (2012) comprehensive study of student teachers' conception of NOS which revealed that they had less naïve views than most studies suggest. However, like Leanne, Angela had expressed the common misconception that laws are more hierarchical than theories (Lederman et al., 2002). Leanne's view about creativity and imagination in science were revealed to be *more informed* but she conveyed *naïve* views on all other aspects of NOS. For example, her response about 'empirical NOS' (in table 2.b) revealed belief in the scientific method which entails a 'recipelike stepwise procedure that all scientists follow when they do science' (ibid.: 501).

4.1.2 Baseline-lesson observations

Lesson observations allowed me to obtain knowledge about the teachers' practice and make links with their views and beliefs. The following presents the teachers' KQs analysed using Tsai's framework of categorising beliefs (Appendix 2). Both lessons were to mixed-tier year 8 groups.

Table 3.a Leanne's baseline-lesson

Lesson title: Investigating Hooke's law.
Duration: 1 hour and 10 minutes.

Transformation	**Contingency**
Each student was provided with a worksheet to complete throughout the lesson. 25 minutes was spent going through the theory of Hooke's law. Leanne would ask questions to which students would volunteer and she selected individuals to answer ***(traditional)***. Links were made to careers in engineering. ***(constructivist)*** Students then worked in groups of four to set-up and carry out Hooke's law experiment. While it took them a while to follow instructions to set-up the practical ***(traditional)***, once they started to collect data it allowed Leanne to circulate the lab and help students with collecting data. She asked questions that would encourage the students to consider what their data showed. ***(process)*** A pair of students were discussing the results: Student A: Look at how the force is increasing with the extension Student B: …It doubles every time. Leanne praised them and asked what they should plot to investigate the relationship. They then carried this out on the worksheet. ***(process)***	The only significant episode of contingency took place at the start of the lesson when Leanne gave an example of '…engineers making sure that they build bridges that don't break'. A student responded: 'Can bridges actually break?' To which Leanne gave the example of the Tacoma Bridge collapsing and played them a short film she found on-line. ***(constructivist)***

Table 3.b Angela's baseline-lesson

Lesson title: The effect of forces.
Duration: 1 hour and 30 minutes

Transformation	**Contingency**
Angela had prepared a circus of experiments for students to add force arrows (cut out of coloured card) to. Students worked in groups of two and three. She presented the instructions on the board which was useful for students as they applied their learning to add the forces making references to 'pulls' and 'pushes'. ***(process).*** At one-point Angela asked everyone to gather around to see one of the groups who had been working well on the activity. This clarified for students what they needed to do. At the end of the activity each group presented theirs to the others. ***(constructivist)*** Students were asked to draw a free body force diagram for their object. As they did so, Angela circulated the room answering students' questions. For example: "Miss, am I drawing this wrong?" Another: What is this force called? This was a good opportunity for her to elicit her students' understanding. ***(constructivist)***	As mentioned in *Transformation*, Angela had realised that some students were not clear about what they had to with the cut-out force arrows, so she drew their attention to the work of a group who were working on task. ***(constructivist)***

4.1.3 Post-lesson interviews

Semi-structured interviews were conducted during which the KQs (without Tsai's categorisations) were shared to aid discussion about the lessons and encourage teachers to reflect on their practice (Appendix 5.b). While the KQs highlight instances of constructivist teaching, the lesson observations revealed that for both teachers, particularly Leanne, the lessons were largely teacher-led. This was discussed with each teacher.

Leanne

Leanne felt that her lesson did not go as well as she had wanted because she had ended up 'doing most of the talking'. This was particularly the case in the first half of the lesson as she went through her presentation on Hooke's law only using the I-R-F method of questioning with short 'thinking-time' (Alexander, 2017) to interact with students. This resulted in a predominantly teacher-led approach whereby her instructions were dominant with little opportunity for student contributions (Mortimer and Scott, 2003). She was also dissatisfied with how long it had taken for students to set up the equipment which resulted in many of them not completing the worksheet she had prepared. Leanne expressed that while she would like to plan more student-centred lessons, her concern was 'if students talk more, they wouldn't write much down'. A possible reason for Leanne's focus on writing could be that she said that her head of science did half-termly checks on students' workbooks and so this was an issue. On the KQ (table 3.a), Leanne was drawn to the reference made about the contingent moment when she accessed the film of the Tacoma Bridge in response to her student's unawareness of bridges collapsing. She reflected that this occurred because she had stimulated students' thinking by using real-life applications of Hooke's law. Hence, the 'availability of tools and resources', the short film in this case, had triggered her to act contingently to resolve her student's uncertainty (Rowland, et al. 2011).

Angela

Angela's main concern was that she had not covered everything on her lesson plan which is a key concern of beginning teachers (Furlong and Maynard, 1995). She felt that the best part of her lesson was when 'students worked in groups' allowing her to 'listen to their thoughts'. But she was concerned about the students who would take advantage of the

situation and 'just chat'. This is consistent with the notion that behaviour management is a major concern for beginning teachers (Fuller, 1969). At the end of the lesson there was an opportunity for students to talk about their observations and ask questions, however Angela relied on the I-R-F method of questioning with short 'thinking-times' (Alexander, 2017) to summarise the lesson. Like Leanne, Angela was drawn to the 'contingency' domain of the KQ (table 3.b) commenting that '…it had just come naturally to me as I hadn't planned it'.

Both teachers acknowledged insufficient dialogic teaching and reliance on the I-R-F method and factual questioning, agreeing that there were opportunities during which student talk could have been more prominent. Therefore, as the literature points out like most teachers they were aware of the benefits of dialogic teaching but found it difficult to facilitate (Mercer et. al, 2009; Mitchell, 2010; Taylor and Lelliot, 2015). For example, Leanne reflected that there would be more student dialogue if they had collected data at the start rather than her going through the theory. I suggested that if students had then applied their findings to an inquiry (such as using their graphs to find the mass of a mystery object) discussion would further have been encouraged. Angela reflected on episodes during which students were talking about forces and suggested that she could have placed some questions at each station to stimulate their thinking. Therefore, the findings about the teachers' beliefs, shown in tables 2.a and 2.b, do correlate to an extent with their classroom practice. For Leanne, the findings for her views on science (table 2.a) are found to be 'nested' in her practice (table 3.a). While for Angela as mentioned earlier, her *more informed* views about science (table 2.a) did not fully translate in to her classroom practice because of her priority to adhere to the lesson plan and control the class.

Thus, in light of the findings the CoRe framework and further mentor support could support each teacher develop as constructivist-oriented practitioners.

4.2 Phase-2: *To what extent is the CoRe framework effective in supporting dialogic interaction? To what extent is my mentoring effective?*

Both teachers used CoRe1 (Appendix 3.a) to prepare lessons that have been analysed in the following KQs (tables 4.a and 4.b). APDT (figure 1, p.12), also used by the teachers to plan lessons, together with the associated indicators (Appendix 1) were applied to identify the extent that dialogic teaching had occurred (shown in bold in tables 4.a and 4.b). Teacher feedback during post-lesson interviews and my reflections on their progress have been used to consider the extent to which my mentoring has been effective.

Lessons were carried out with middle-tier year 9 groups.

4.2.1 Lesson observations

Table 4.a Leanne's phase-2 lesson.

Big idea (from CoRe1): Energy and food
What students are intended to learn: Use of the terms 'stores' and 'pathways to describe energy transfers.
Brief lesson structure: In small groups students circulated a station of experiments to consider the energy transfers taking place.
Duration: 1 hour and 10 minutes

Transformation	**Contingency**
After been given a description of what they were expected to do, students worked in groups discussing energy transfers taking place at each station. **Reciprocal** Students applied the new terms 'energy stores' and 'pathways' to describe the energy transfers taking place. Leanne interacted with groups to aid their thinking. For example, one group considered the energy transfer of a toy car rolling down a ramp: Student A: The car has gravitational energy at the top… Student B: Shouldn't that be a gravitational potential energy store? Student C: Oh yeah because it is the starting energy Student A: So, at the end where does it go? Student C: Isn't it heat? Student B: And kinetic energy Leanne: It depends where you're taking the end to be… remember the snapshots we discussed earlier?... and there is a better word to use for heat (directed to student C) Student C: Oh... thermal? Leanne: Yes, a thermal store. **Collective/Reciprocal/Supportive** At the end of the lesson, Leanne selects students from each of the five groups to share their findings with the class. As they do so, other students make contributions. **Reciprocal/Supportive**	At the start of the lesson, Leanne used an analogy that she had learnt at a previous workshop. This was using coloured water to represent energy which she filled in beakers representing energy stores. As she did so, she added (off lesson-plan): '…it's like having money *stored* in the bank which you spend on things. As you spend it, the *store* of money decreases but it goes to other *stores* like money towards toys and sweets.' This reinforced the model she was demonstrating. During the practical activity while students worked in groups, Leanne answered unexpected questions and intervened with their work where necessary. **Purposeful** During class discussion, one student queried about the sound being emitted from a ball hitting the ground and why this was not a 'type of energy'. Leanne was not able to give an answer straight away but asked the rest of the class to consider how sound could be accounted for. As they discussed this in pairs she heard a pair of students referring to sound being caused by particles vibrating. She stopped the class and asked the pair to share it with everyone. A student said: 'then maybe it goes into the kinetic energy store of air'. Leanne praised this response and then asked: '…and where might that end up?'. A student answered: 'heat?' Leanne praised this correcting their terminology to 'thermal'. **Reciprocal/Purposeful**

The analysis in table 4.a indicates development of dialogic teaching since phase 1. Using Alexander's characteristics of dialogic teaching indicators (Appendix 1) to analyse the

lesson, revealed the strength to be during student-student interaction. As such, students 'listen[ed] carefully to each other', 'encourag[ed] each other to participate and share ideas', and 'buil[t] on their own and each other's contributions' (Alexander: 43; Appendix 1). However, Leanne could not answer some of the students' questions on energy due to her lack of SMK. An example is given in the 'contingency' domain in table 4.a and is placed there because she reacted by posing the question back to the rest of the class giving the students the task of considering it. This allowed her to listen in on their thinking and then share what she felt was good physics with the rest of the class.

Table 4.b Angela's phase-2 lesson.

Big idea - Heating to raise temperature.
What students are intended to learn - The different heat transfers.
Brief lesson structure - Students observe demonstrations of different heat transfers and then carry out an experiment of radiation.
Duration - 1 hour and 30 minutes.

Transformation	**Contingency**
Students were presented a concept cartoon of a snowman in a jacket and asked to discuss whether the statement about the jacket 'keeping the snowman warm' was true or false. This allowed Angela to listen in on students' conceptions about heat transfer. **(Reciprocal/Purposeful).** Then students were selected to tell the class what they thought. This generated constructive discourse between the students and Angela. A student who referred to word the 'insulation', was praised and enabled Angela to reinforce what this meant and how it would be later used in the practical they were doing. **(Supportive/Cumulative)** Angela demonstrated conduction and convection using various equipment. As she carried these out students observed, and she asked them questions. This initiated discussion. Some students asked her questions, and again this led to useful discourse. For example, a student linked the convection demonstration to a lava lamp and another to convection in the Earth's mantle. **(Collective/Reciprocal/Supportive)**	There were several occasions during which Angela demonstrated thinking on her feet to support learning. For example, at the start of the lesson when students were completing an exercise that involved recalling key words, she wrote out the words on the board for them (in random order) when she realised that some students were struggling. Also, her responses to unexpected questions from students throughout required her to draw upon her subject knowledge. **(Supportive)** When demonstrating convection to the class, a student commented that it was 'like the convection in the mantle in the Earth' that she had studied in geography. Angela encouraged this contribution and discussed it further with the students (drawing on her own specialism knowledge in geophysics). **(Reciprocal)** When carrying out the experiment, realising that not all of the students had result tables, Angela drew one on the board and with their contributions added headings to the columns. **(Collective)**

During the practical activity, students were prompted to discuss the variables (independent, dependent and control) in their groups. Angela adds to the board 'what am I investigating?' and 'what is the start temperature' to further support discussion in the groups. Angela circulated the room listening to students' discussions. She intervened by asking prompt questions to guide their planning. During the practical activity, most students were engaged and interacting with each other to complete the practical. **(Supportive/Purposeful)** Angela selected groups to discuss their findings from their experiments. One student gave a model answer stating: 'We were looking at how fast the radiation was given out. The bigger the temperature drop the more radiation given out', which Angela wrote out on the board for others to make a note of. Then Angela gave a further example of a marathon runner wrapped in a shiny blanket and then on the board presented a black and a shiny surface and asked students to comment on which one would keep a person warm. Students contributed and gave some interesting examples such as how 'the houses in Greece are painted white to keep cool' and 'cricket players wear white to keep cool'. **(Reciprocal/Supportive)**	During the practical activity, one student asked if radiation was dangerous (as she was linking it to nuclear radiation). Angela was able to clarify for the student that that was a different kind of radiation and she drew upon relevant examples to reinforce this. **(Reciprocal)**

The analysis in table 4.b indicates development of dialogic teaching. Using Alexander's characteristics of dialogic teaching indicators (Appendix 1) to analyse the lesson, highlights strengths in questioning such as 'mov[ing] beyond yes/no or simple recall to extended answers involving reasoning, hypothesizing and thinking aloud' (Alexander: 43; Appendix 1). This was particularly evident during the snowman activity at the start of the lesson.

Therefore, the lesson analyses suggest that the CoRe framework had supported dialogic teaching for both teachers. Semi-structured post-lesson interviews were prepared to gauge to what extent this was so, and whether or not the mentoring support had contributed to their development.

4.2.2 Post-lesson interviews

Leanne

Leanne was pleased with the student talk and discussions that had taken place. By careful planning of the circus activity she had 'steered' students to ask questions unlike her phase-1 lesson where her intention was for student-questioning to 'occur naturally' (Chin, 2004). She was satisfied with using the analogy she had learnt in one of our previous workshops saying that she thought 'it allowed students to picture energy transfer'. However, there were limitations with this analogy representing energy transfer which was pointed out to her. Within our mentor-mentee relationship such subject support was particularly appreciated by Leanne. She expressed that learning ideas, like the analogy she used in her lesson, was 'extremely effective' in her physics teaching. She also felt that using CoRe1 was helpful for lesson planning. In particular, she found that as a non-specialist it provided her with 'valuable ideas' about teaching about energy. However, she suggested that an additional aspect on the CoRe that 'specifically linked to' student talk would be more helpful for planning dialogic teaching. The use of APDT to consider dialogic teaching was also useful for Leanne, stating that it made her 'mindful of the sort of thing [she] had to do'.

Angela

Angela acknowledged that student talk had developed since her phase-1 lesson. Since then, she had applied the advice given during feedback to develop proceeding lessons. She had also taken on the advice to keep a journal which she had used to reflect on her practice. As indicated on the KQ in table 4.b, the discussion amongst students about the insulated snowman had set the theme for the rest of the lesson as well as allowed Angela to elicit

students' understanding about thermal transfers. In the practical activity, students felt at ease to ask her questions and to share ideas amongst themselves. As such, a 'supportive' and 'reciprocal' learning environment contributed towards dialogic teaching (Alexander, 2017). However, there still remained some low-level disruption due to a number of students talking off topic.

Angela felt that CoRe1 had assisted her in planning for dialogic teaching. She thought that the 9th aspect on the CoRe, 'Specific ways of ascertaining students' understanding or confusion around this idea', was the most closely linked to capturing teachers' pedagogical knowledge about dialogic teaching yet it did not 'explicitly do so'. In response to what aspects of the mentoring was most useful, Angela addressed the issues she had been having with her school-based mentor which had 'lowered her confidence and self-esteem' as a teacher. In contrast the mentoring she received in this project had allowed her to focus on developing her teaching. In particular, she had found the KQs providing feedback helpful as they highlighted 'positive features' of her teaching, which contributed towards reclaiming her confidence in the classroom. As such, within our mentee-mentoring relationship 'emotional and psychological support' had resisted low confidence and attrition (Burke et al., 2007).

Following feedback from the teachers, two further aspects were added to the CoRe template, to explicitly capture thinking about dialogic teaching. As discussed in 3.3.2 (p.40), both teachers completed these only for the lessons that would be observed in phase-3. Their contributions are shown below in Figure 3 (adapted from CoRe2 in Appendix 3.b).

Specific ways that dialogic interaction can be used to ascertain students' understanding or confusion around this area	Demo the reflection of microwaves without talking to the students. In small groups, students discuss their observations. This will lead them to acknowledge that invisible waves also reflect. (Angela) Demo refraction of light between air and glass, again without talking. Students discuss their observations. (Angela) In groups, students discuss and draw conclusions from data provided about the risks and consequences of exposure to radiation. (My example)	At each station leave prompt questions to encourage students to discuss the types of EM waves. (Leanne)
Other ways to ascertain students' understanding or confusion around this area	Provide real-life examples of reflection and refraction. E.g. in a microwave cooker, light leaving lamps on the floor of a swimming pool through water. Students discuss how each happens. (Angela)	Prepare questions to ask students as they are carrying out the activities. (Leanne)

Figure 3: The additional aspects of CoRe2 with contributions by both teachers in preparation for phase-3 lessons.

4.3 Phase-3 - *To what extent is the modified CoRe effective in supporting the teachers plan for dialogic interaction? How may the support be developed?*

The teachers used CoRe2 and APDT to prepare lessons in phase-3. Again, key findings from the lesson observations are presented in the KQs below and annotated using APDT to highlight features of dialogic teaching revealed. Post-lesson interviews and the final group interview with both teachers would shed light on how effective the modified CoRe was in developing dialogic teaching and how support may be further developed.

4.3.1 Lesson observations

Table 5.a Leanne's phase-3 lesson.

Big Idea - Applications of EM waves
What students are intended to learn - EM waves have many practical applications and know some examples.
Brief lesson structure - In small groups, students circulated a circus of 7 stations at which they would find resources representing each type of wave.
Lesson duration - 1 hour and 10 minutes

Transformation	**Contingency**
Students were asked to look at an animated picture of an airport lobby presented on the board. In pairs, students made a list of the different waves. Leanne asked students to share their ideas with the class and as they did, she wrote them on the board as a mind map. One pair said that sound waves were present which made Leanne pause and from her reaction a student called out that sound was not an EM wave. **(Supportive/Reciprocal)** During the circus activity, Leanne circulated the room listening in on students' discussions. This allowed students to ask her questions. For example, a group working at the microwaves station discussed one of the questions Leanne had set: Student A: I think it is the same as the waves coming out of my phone. Student B: But that would just cook your brain if it was the same as in an oven! Student A: …maybe it's not coming out of the phone for as long? Leanne: Would you say that all microwaves carry the same energy? Student B: Oh yeah… isn't it something to do with the frequency or power? **(Collective/Reciprocal/Supportive)** During the plenary, students were asked to pair with another person to again study the picture of the airport lobby. Again, Leanne added their comments to the mind map as they were shared. **(Collective/Reciprocal/Supportive)**	The mind map that Leanne had produced on the board had evolved as she added more information to it as the lesson proceeded. This was made up of students' contributions. **(Collective)** For the majority of the lesson time students interacted with each other in their groups. This allowed Leanne to engage in answering their questions generated from the pre-planned questions she had provided at each station. **(Reciprocal/Supportive/Purposeful)**

Table 5.a reveals that Leanne had used CoRe2 and her contributions to it (figure 3) which had made her lesson more dialogic. She had prepared worksheets for students to complete which they pasted into their books at the end of the lesson.

Table 5.b Angela's phase-3 lesson.

Big idea - Properties of EM waves
What students are intended to learn - EM waves can reflect and refract; Drawing ray diagrams for reflection and refraction.
Brief lesson structure - After being shown demonstrations of reflection and refraction, students worked in groups of 3 on activities prepared by Angela.
Lesson duration - 1 hour and 30 minutes

Transformation	**Contingency**
Students discussed a True/False activity about the characteristics of EM waves displayed on the board. This allowed students to reflect on and recall the previous lesson's learning. This initiated a short discussion with the class. **(Reciprocal/Purposeful)** Angela demonstrated reflection of microwaves from a metal plate using a transmitter and receiver. She did this in silence and had asked students to observe what they saw and discuss the result with each other. As they did, Angela circulated the room to listen to their comments. She then demonstrated the refraction of light using a camera to project it on the screen. Again, this was done without her talking and students then discussed what they observed. At the end of both activities, students contributed their ideas with the whole class as Angela selected groups. For example, pointing out a group: Angela: Would you like to share your ideas about each demo? Student A: In the first one the waves... Student B: ...microwaves... Student A: ...microwaves…must be bouncing off the metal. Student C: So, we think it is showing reflection. Angela (to the rest of the class): Hands up if you agree. This discussion continued for about 10 minutes during which students contributed their ideas about both observations which lead to the conclusion that EM waves can reflect and refract. **(Collective/Reciprocal/Supportive/ Cumulative/Purposeful)** After demonstrating the methods used to draw ray diagrams students worked in groups to construct ray diagrams for light reflecting off a plane mirror and refracting through a rectangular glass block. Angela circulated the room providing additional support where needed. Students felt at ease asking each other and Angela for help. **(Collective/Supportive)** Students applied their learning to applications of	The majority of this lesson was spent with students in dialogue with one another and with Angela. This resulted in a number of contingent moments during which Angela answered unexpected questions and intervened with student discussions to guide them through the activities. For example, Angela approached a group of students who were discussing the best way to draw a reflection ray diagram: Student A (to the other two): We need to put the pins on the rays then… what did miss say again? Student B: Don't we mark it with a pencil afterwards and join the dots? Student C: Yes, let's do it and see. Angela: Before you do this, is there anything else you need to mark on the paper? Student B: …oh yeah, the mirror and that line… what's it called again? Student C: The normal? Angela: That's right. **(Collective/Supportive)**

reflection and refraction as Angela displayed images of examples such as a bent pencil in water, a satellite orbiting the Earth, and a microwave oven. In their groups, students considered how reflection and refraction applied to each. Students then shared their ideas at the end of the activity. **(Collective/Reciprocal/Supportive/Purposeful)**	

Table 5.b reveals that Angela had used her contributions to CoRe2 (figure 3) to plan her lesson. As such, dialogic teaching had developed. As the table shows, 'cumulative' interaction had taken place during the main activity. Alexander points out that 'cumulation is possibly the toughest of the five principles of dialogic teaching' as it:

> …tests the teacher's ability to receive and review what has been said and to judge what to offer by way of an individually tailored response which will take learners' thinking forward. (p.50)

Angela demonstrated confidence with her subject knowledge as she responded to student questions about reflection and refraction, before they applied it to the practical activity.

Therefore, the analyses suggest that the modified CoRe and the teachers' contributions to it had a positive impact on developing dialogic teaching for both teachers. Semi-structured post-lesson interviews were prepared to explore their views on the effectiveness of CoRe2 (Appendix 3.b).

4.3.2 Post-lesson interview

Leanne

The questions that Leanne had placed at each station had prompted students to engage in discussion. She acknowledged that completing the additional aspects on CoRe2 had allowed her to consider such a strategy that would encourage student talk. Figure 3 indicates her focus on preparing questions to ask students which had resulted in less 'factual and closed questions', a practice found to be common in many classrooms (Nystrand, 1997). Instead, as shown in table 5.a (p.61), questions set initiated student questioning during group work allowing Leanne to participate appropriately. Leanne was pleased to see the mind map she had produced included in the *contingency* domain of the KQ. On reflection, she acknowledged that it was because of students' contributions through discussion that this had evolved which had allowed her to develop their ideas and present it on the mind map. Therefore, for Leanne the modified CoRe and her contribution to it, had been effective in developing dialogic teaching.

Angela

Similarly, Angela felt that her lesson had benefited from using CoRe2 to develop dialogic teaching. The lesson observation data revealed that she had implemented her CoRe2 additions (figure 3) to the lesson. As shown in the KQ in table 5.b (pp.62-3), for the majority of the lesson students were in discussion during the activities prepared by Angela. Good quality feedback to student responses stimulated student questioning further which is acknowledged to be an effective way in using the I-R-F method (Smith and Higgins, 2007; Cullen, 2002; Lemke, 1982). However, Angela expressed concern that some students were

not participating in the activities in group work. This led to a discussion about strategies to prevent certain individuals from dominating groupwork, such as assigning roles. Since phase-2 Angela had continued to record her experiences and reflections in her journal. She believed that this had helped in her professional development.

4.3.3 Joint interview with Leanne and Angela

Both teachers reflected on use of CoRes to develop their classroom practice. They felt that it did have a positive impact on developing dialogic teaching and that the modified CoRe had supported this further. It was apparent that both valued a look into expert teachers' thinking about topics, which the CoRe framework had captured. They both also found use of APDT helpful, but Angela felt that there was some overlap between the principles, so they were not clearly differentiated. Therefore, it would have been useful for them if I had provided further reading from Alexander's (2017) work on dialogic teaching, especially the *indicators of dialogic teaching* presented in the same publication (Appendix 1).

In response to the question about how support could be developed (Appendix 5.e), Leanne expressed the positive impact the lesson observations and feedback had been for her and for there to be more of it. She felt that she 'didn't have to worry about getting things wrong' as I was not assessing her. So, 'risk-free learning' had occurred (Hobson et al., 2009: 213) which was certainly an intended feature of how I planned to work with them as a mentor. Angela agreed stating that this was particularly important in her case and also wanted the support to continue beyond the project. She suggested that they could contribute towards supporting other beginning teachers during a workshop session by sharing their experience

of using the CoRe to develop dialogic teaching. This could certainly be included in a workshop for beginning teachers.

Angela reflected on the KQ helping her focus on transformational and contingent episodes in the classroom and wanted to know how she could become more contingent in lessons. We discussed how for both teachers the key trigger for contingency was 'responding to student ideas' (Rowland et al., 2011) which had developed as result of dialogic teaching.

It is important to note a challenge facing future support to develop constructivist classroom practices like dialogic teaching. During this interview Leanne pointed out that her head of science was critical of dialogic teaching saying that it was more important for teachers to lead lessons with students completing work in their books, than to have student-centred classrooms. This notion reflects the current politico-educational climate (discussed in 2.2.1, p.18) in which a content-led curriculum has meant that strategies such as dialogic teaching are not supported. In other words, the purpose of the curriculum, set by policy makers, has implications for the way teachers view and deliver it (Jenkins, 2007*)* which in turn has implications for the support given by teacher educators*.*

5. Conclusion and implications

This report concludes with a discussion of key findings and their implications in light of the research questions.

5.1 Research questions revisited

The exploratory questions set at the start of phase-1 had revealed challenges facing beginning teachers towards developing classroom practice, and in particular dialogic teaching. Findings from previous phases then informed the research questions generated in phase-2 and phase-3 and were based on using the CoRe framework, with mentoring, as a tool for support. Together, the findings give insight into how beginning teachers may be supported to develop constructivist-oriented approaches, like dialogic teaching.

5.1.1 *What are the beliefs of the teachers? What is their practice?*

The findings seem to suggest that having more informed views about science does not necessarily translate to constructivist-oriented classroom practice. This was the case for Angela, who had more informed beliefs about NOS, but her practice was mainly traditional. As a novice in her first year of teaching, Angela's concern with classroom management and control (Furlong and Maynard, 1995) had resulted in a predominantly teacher-led classroom. This was reinforced by her school-based mentor's expectations of good classroom management. Furthermore, Angela was aware of her 'teacher-led' approach and in the post-lesson interview had commented '…it is similar to how I was taught at school, and I hated it'. This suggests that teachers' experiences of their teachers, good or bad, plays a role in shaping their beliefs. These beliefs are likely to be deeply rooted and pose a challenge for teacher educators (Kagan, 1992). However, as the KQ in table 4.b (pp.56-7) shows there were instances of constructivist-oriented practice which is consistent with the

majority of Angela's views about teaching presented in table 2.a (pp.45-6). One-to-one support she received on this programme had primarily aimed to develop this 'expertise' and 'to facilitate' her 'induction in the culture of the profession' (Hobson et al., 2008; 207).

Leanne's baseline lesson was mostly traditional- and process-oriented which seemed to reflect her more naïve beliefs about science (presented in table 2.b, p.48), a finding consistent with the literature (e.g. Bartholomew, 2004; Lederman et al., 2002; Tsai, 2002). In particular, her belief about the scientific method was demonstrated by the activity she had prepared for students to follow instructions to collect data for the Hooke's law experiment. To ensure that students' work was captured at each stage of the lesson, she continuously reminded students to add it to the worksheet. This was partly so that she had evidence for work being carried out by her students since her head of science would do half-termly checks on exercise books. So, as in Angela's case, 'contextual factors' related to expectations from line managers, was impacting on her 'professional growth' (He and Cooper, 2011). Furthermore, being a non-specialist Leanne's less informed physics SMK was a concern for her, contributing to reliance on resources such as student worksheets and textbook activities, and instruction-laden practical work. Indeed, it has been found when teaching outside one's own specialism teachers perceive that their lessons are tightly controlled during which textbooks are frequently used and practical work is 'closely related to students being less autonomous' (Childs and McNicholl, 2007: 11). Leanne's dedication to develop her physics SMK and PCK had resulted in attending numerous IOP workshops and participating in this project. She had also expressed the desire to plan for more student-centred lessons (see table 2.a, p.45), and like Angela was aware that this needed

development. This had made our professional relationship conducive to working together to develop their practice.

5.1.2 *To what extent is the CoRe framework effective in supporting dialogic interaction? To what extent is my mentoring effective?*

Phase-2 lesson analyses and teachers' responses during post lesson interviews seemed to suggest that CoRe1 was helpful for both teachers when planning for dialogic teaching. For these novices, having access to a resource that maps out an expert's thinking had enabled them to consider appropriate activities involving developing student talk. And, provision of relevant literature (chapter 3 of Loughran et al.'s (2012) book and APDT) had supported their *phronesis knowledge* which is 'related to the context in which they meet a problem' to bring 'their already existing, subjective perception of personally relevant classroom situations one step further' (Korthagan and Kessels, 1999: 7). Taking on the advice to keep a journal had further enabled Angela to develop this knowledge.

Through collaboration with the teachers we decided that the CoRe framework required modification in order to specifically capture ideas for dialogic teaching, such as opportunities for student questioning. Indeed, such opportunities to work collaboratively, if sustained, with more experienced practitioners has been found to resist attrition amongst novices (Burke et al., 2007).

While it is difficult to claim with certainty that the mentoring received by the teachers was effective, there were indications that one-to-one support had had a positive impact on their

professional development. As well as bespoke support to develop dialogic teaching, Angela had received psychological support and for Leanne it was more subject-specific. In both cases, 'risk-free learning' had allowed them to be practitioners in their own right (Hobson et al., 2009). Furthermore, the constructivist-oriented mentoring they had received, based on 'collaborative inquiry and critical reflection' had contributed to their enthusiasm for teaching (Richter et al., 2013) as shown by their continued efforts throughout the study to develop their practice.

5.1.3 *To what extent is the modified CoRe effective in supporting the teachers plan for dialogic interaction? How may the support be developed?*

Phase-3 Lesson analyses and teachers' responses during post lesson interviews seem to suggest that CoRe2 had further supported planning for dialogic teaching. Again, an opportunity for collaboration had occurred when the teachers agreed to make contributions to the additional aspects of CoRe2 (figure 3, p.60). As such, the 'modified CoRe' was not only the changed framework but a way to encourage beginning teachers make contributions that required them to tap into their own PCK. It was good practice that both had fully incorporated these contributions to their phase-3 lessons as well as the other ideas contributed by the expert teachers. In this way, they had played a part in planning for dialogic teaching using the CoRe framework. Therefore, working together to complete a CoRe could be a useful way for experts to support novices' PCK development. Supported by the findings in Assignment 3 (discussed in 3.3.2, p.35), it could also provide an opportunity

for collaborative team work during which experienced teachers vocalise their 'tacit knowledge', something they normally find challenging (Berliner, 2004).

Both teachers had asked for further support to develop dialogic teaching beyond this study. This and possible support for other beginning teachers is considered in the following section.

5.2 To what extent can the findings support development?

Reflecting on the study and the findings, three main limitations present themselves. Firstly, as the research method is qualitative and uses semi-structured interviews to explore the teachers' views, no statistical claims or generalisations can be made from it (Cohen and Manion, 1997). However, the in-depth exploration of these teachers' views, practice, and development by a remote-mentor, is the strength of this study. Within this mentoring relationship use of a tool like CoRes to develop constructivist-oriented classroom practice like dialogic teaching exemplifies what this support may look like. The second limitation is to do with time constraints. While the findings reveal development of the teachers' practice throughout the academic year, the research questions would have been better informed if there were more than one lesson observation per phase. This would have contributed to the conclusions drawn about the efficacy of the CoRe framework in developing dialogic teaching. Time constraints also meant that a deep analysis of teachers' practice could only be carried out with a small number of participants (in this case two). Nevertheless, application of Elliott's (1991) model of action research (figure 2, p.33) has enabled an in-depth analysis of the teachers' practice and development. As such, it has been

demonstrated how a tool like the CoRe framework can bridge the gap between novices work with experts, so that in collaboration constructivist-oriented practice is developed. Thirdly, contextual factors linked to the teachers' school environment posed another limitation. In both cases, expectations by line managers to prioritise other aspects of classroom practice, as reported above, resulted in tension and conflict when Leanne and Angela had focused on developing dialogic teaching. Therefore, rather than developing their practice to 'facilitate their induction into the local specific context' (i.e. their school) (Hobson et al., 2008: 207), their development was only on a personal level. This also presented ethical dilemmas for me as an outsider to support the teachers' practice but to allow them to operate within the constraints offered by their contexts. As such, whenever these constraints were referred to by the teachers, a diplomatic and non-judgemental reaction was given to discourage negativity within working relationships with their school colleagues.

5.2.1 Future support for Leanne and Angela

Beyond this study, it is intended that the one-to-one support will continue with both teachers in order to develop dialogic teaching. During the joint interview, both had agreed to using CoRe1 and CoRe2 again in the forthcoming academic year when teaching another 'Big idea' on energy (Core1) and electromagnetic waves (CoRe2). This would be a good opportunity for them to again consider the modified aspects on the CoRe involving dialogic teaching and for me to observe these lessons. I had advised both to access *Towards dialogic teaching: rethinking classroom talk* (Alexander, 2017) for further insight. In particular, the

indicators for dialogic teaching that I had used to analyse their lessons (Appendix 1) is hoped to elaborate on the APDT (figure 1, p.12) that they were provided in phase-2. Thus, I am continuing to work with them and introduce more theoretical ideas (episteme) resonant with the realistic teacher education approach advocated by Korthagan and Kessels (1999) but in this case with in-service rather than pre-service teachers.

5.2.2 Supporting other beginning teachers

While time constraints will not allow such an intensive mentoring programme for the other beginning teachers in my network, there are ways that the findings and outcomes of this study can help support them develop constructivist-oriented practice. Angela's suggestion, in the joint interview (4.3.3, p.65) about sharing her experience with other beginning teachers could be a good starting point. This could be done in a workshop only for beginning teachers. Angela and Leanne could work with the teachers on activities based on the CoRe framework and APDT. Following this, teachers could enact their learning in the classroom and then share their experience with others on a group forum (such as on the IOP's social network website - www.TalkPhysics.org). This could be monitored by me during which feedback and comments would be added. Further workshops throughout the year for these beginning teachers could allow gradual development.

5.3 Implications of the findings - a message for PNC colleagues

It is intended that the findings of this study, as well as my own experience of working closely with the two beginning teachers, are shared with PNC colleagues. As discussed in 2.2.4, the ceasing of the SPS-mentoring programme has meant that the IOP no longer offers bespoke support for beginning teachers. This is a concern because often the support that this cohort of teachers need cannot be fully provided through the workshops catering for all teachers (and technicians) regardless of experience. As we have seen, issues relating to contextual factors have a significant impact on novices adding to the practical challenges they already face in the classroom. For non-specialist physics teachers, lack of subject knowledge is another difficulty encountered. Therefore, designing workshops for beginning teachers could help them develop their practice because we could support their pedagogical difficulties. A suggestion is that if amongst the PNC community (there are 42 of us) we shared our knowledge by completing the modified version of the CoRe for different physics topics, then these could be utilised by beginning teachers. As was done in this study, to encourage participation the teachers could contribute their own PCK by adding to certain aspects of the CoRe. This could also be done during a workshop session which included expert teachers who would have the opportunity to share their knowledge. Furthermore, support through one-to-one mentoring of individuals could further help those who are faced with numerous challenges in their early career. Like the teachers in this study, being encouraged to be researchers in their own development, could contribute towards beginning teachers' professional growth.

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Appendix 1: The indicators used to code *Alexander's principles of dialogic discourse*, Alexander, 2017: 42-44). Annotated with c-collective, s-supportive, cu-cumulative, and p-purposeful.

Characteristics

Dialogic teaching is indicated by:

- *Teacher–pupil interaction (for example in whole class teaching and teacher-led group work) in which:*
  - questions are structured so as to provoke thoughtful answers, and - no less important -
  - answers provoke further questions and are seen as the building blocks of dialogue rather than its terminal point;
  - individual teacher-pupil and pupil-pupil exchanges are chained into coherent lines of enquiry rather than left stranded and disconnected;
  - there is an appropriate balance between the social and the cognitive purposes of talk, or between encouraging participation and extending understanding;
  - pupils - not just teachers - ask questions and provide explanations, and they are encouraged to do so;
  - turns are managed by shared routines rather than through high-stakes competitive (or reluctant) bidding;
  - those who are not speaking at a given time participate no less actively by listening, looking, reflecting and evaluating, and the classroom is arranged so as to encourage this;
  - all parties speak clearly, audibly and expressively;
  - children understand that different school subjects and social circumstances demand different registers, and they learn how to use them;
  - children have the confidence to make mistakes, and understand that mistakes are viewed as something to learn from rather than be ashamed of;

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- *Pupil-pupil interaction (for example, in collaborative group settings) in which:*
  - children listen carefully to each other;
  - they encourage each other to participate and share ideas;
  - they build on their own and each other's contributions;
  - they strive to reach common understanding and agreed conclusions, yet
  - they respect minority viewpoints.
- *Teacher-pupil one-to-one monitoring which:*
  - lasts for long enough to make a difference;
  - is instructional rather than merely supervisory;
  - provides diagnostic feedback on which children can build.
- *Questioning (whether in whole class, group or individual interactions) which:*
  - is anchored in the context and content of the lesson;
  - builds on previous knowledge;
  - elicits evidence of children's understanding;
  - appropriately combines invitations for closed / narrow and open / discursive / speculative responses (what is?' and 'what might be?' questions);
  - combines the routine and the probing;
  - uses cued elicitations and leading questions sparingly rather than habitually;
  - prompts and challenges thinking and reasoning;
  - balances open-endedness with guidance and structure in order to reduce the possibility for error;
  - achieves consistency between form and intent (e.g. where questions are questions rather than instructions, and open questions are genuinely open, rather than invitations to guess the one 'right' answer);
  - gives children time to think.
- *Responses to questioning which:*
  - address the question in the depth it invites rather than worry about spotting the 'correct' answer;
  - move beyond yes/no or simple recall to extended answers involving reasoning, hypothesising and 'thinking aloud';
  - are, where appropriate, considered and discursive rather than brief and prematurely curtailed.

Appendix 1 (continued):

- *Feedback on responses which:*
  - replaces the simple positive, negative or non-committal judgement, or mere repetition of the respondent's answer, by informative diagnostic feedback on which pupils can build;
  - uses reformulation in a way which avoids ambiguity about whether the reformulation signals approval or disapproval;
  - uses praise discriminatingly and appropriately, and filters out the habitual or phatic 'good boy', 'good girl', 'very good', 'excellent', 'fantastic', 'brilliant' etc;
  - keeps lines of enquiry open rather than closes them down;
  - encourages children to articulate their ideas openly and confidently, without fear of embarrassment or retribution if they are wrong.

- *Pupil talk through which children:*
  - narrate
  - explain
  - instruct
  - ask different kinds of question
  - receive, act and build upon answers
  - analyse and solve problems
  - speculate and imagine
  - explore and evaluate ideas
  - discuss
  - argue, reason and justify
  - negotiate.

Appendix 2: The framework of categorising teachers' beliefs of teaching science (Table 1), and learning science (Table 2), from Tsai (2002: 774-5).

Table 1:

Category	*Perspective and descriptors*
Traditional	Science is best taught by transferring knowledge from teacher to students.
	Descriptors: transferring of knowledge; giving firm answers; providing clear definition; giving accurate explanations; practicing tutorial problems; presenting the scientific truths or facts.
	Sample interview transcript: Teaching science is transferring concepts from my brain to students. Teaching science should also emphasize the certainty and accuracy of these concepts.
Process	Science is best taught by focusing the processes of science or problem-solving procedures.
	Descriptors: teaching the scientific method; following problem-solving procedures; experiencing the processes of (self) discovery; working on the processes of verification.
	Sample interview transcript: Teaching science focuses on the processes of discovering the scientific knowledge. Hence, students need to know the scientific method.
Constructivist	Science is best taught by helping students construct knowledge.
	Descriptors: helping students make interpretations; providing authentic experiences; interacting with students; encouraging discussion and cooperative learning; paying attentions to students' prior knowledge or misconceptions.
	Sample interview transcript: Teaching science needs to help students think about their ideas, and then help them construct scientific ideas. Therefore, as a science teacher, I need to explore students' prior knowledge when implementing science instruction.

Table 2:

Category	*Perspective and descriptors*
Traditional	Learning science is acquiring or 'reproducing' knowledge from credible sources.
	Descriptors: transferring of knowledge; memorizing formula, definition, keywords and scientific facts; copying what teachers do; hard work on practicing tutorial problems; passive listening; finding the right answer; accurate calculation.
	Sample interview transcript: For successful learning science, students, first, need to memorize relevant formulae and definitions. Moreover, they need to practice tutorial problems extensively.
Process	Learning science is focusing the processes of science or problem-solving procedures.
	Descriptors: understanding the scientific method; following problem-solving procedures; learning through the processes of (self) discovery; working on the processes of verification.
	Sample interview transcript: Science is best learned through practicing the scientific method. If students carefully followed the processes of verification, they can gain scientific concepts.
Constructivist	Learning science is constructing personal understanding.
	Descriptors: making interpretations; exploring or coping with authentic experiences; discussing with peers and teacher; relating to prior knowledge or (personal or daily) experiences.
	Sample interview transcript: Learning science will become successful if students can effectively relate the scientific concepts to their personal experiences. They should use scientific concepts to interpret personal experiences.

Appendix 3.a.: The CoRe on the topic of energy at key stage 3. Used by the teachers to plan their lessons in phase-2 of the teacher education programme. Activities involving the teacher directing the talk are highlighted green and those led by students in yellow.

Big Idea (or Key Skill)	A. Energy and food	B. Machines and energy conservation	C. Some examples of doing work in mechanical situations	D. Doing work to raise the temperature	E. Heating to raise temperature	F. Bringing it together
What you intend students to learn about this idea.	1. Working with energy is about quantifying energy shifted: joules everywhere. Energy is, essentially, a quantitative tool. 2. The physical/biological description can be informative and powerful without referring to energy; often the processes tell us more about what is actually going on than an energy discussion 3. A simple model of the body/metabolism as a system that does work and keeps warm by using up an energy source (food + oxygen)	1. In a basic mechanical situation, you don't get something for nothing. In fact, you get out the same as you put in. And the quantity that is the same before and after is energy. 2. Reinforce the idea that working with energy is about quantifying energy shifted. In this case by working. 3. We can get a value for how much total effort we use in lifting an object using the Quantity of work. 4. Work = force x distance 5. The mathematical idea of compensation.	1. Develop their idea that energy is conserved. 2.Comparing the starting with the final conditions of a system and describing increases and decreases in the amount of energy. 3. Describing changes in the way that energy is stored in a system when work is done.	1. Introduce the idea of working to raise the temperature. 2. Dissipation: that working can lead to an unwanted rise in temperature. And, in such cases, the energy gets stored in a way that makes it hard to recover.	1. That temperature rises are related to changes in particle motion and configuration. 2. That an object at a higher temperature will raise the temperature of an object at a lower temperature by heating. 3.Two objects at the same temperature are in thermal equilibrium 4. Heating can be by contact or by radiation 5. We can reduce heating by conduction using insulation 6. That the change in energy stored thermally by an object is connected to its mass and to the temperature change. Another example of	1.Looking at changes that involve working and heating 2. Summarising the use of start and end point analysis. 3. Be able to distinguish between an explanation of a process and an analysis that involves energy.

	4. The body is able to function by reacting (in a controlled way) chemicals derived from foods with oxygen 5. Idea of a numerical way of balancing food intake with how quickly we use it up. 6. Introduce the idea of a chemical store. In this case it is associated with the oxygen and the chemicals derived from foods. 7. Gently introduce the idea that the amount of energy stored (say chemically) puts a limit on what can be achieved.	For a conserved quantity that is the product of two other quantities, if one increases, the other decreases by the same amount.			compensation. 7. Fuels and energy resources (and chemical stores)	
Why is it important for students to know this?	1. To show that energy calculations are powerful and helpful for health and as a tool for analysing, in a scientific way, important attitudes and decisions. 2. Begin to establish the idea of energy as an accounting tool 3. Begin to dispel the idea that energy is a	1. Machines and leavers are a nice simple situation where there is very little dissipation. They will have some sense (from the every day) that you don't get something for nothing. This is, in effect, a conservation law. Something has the same value before a change than after it.	1. Purely mechanical situations are a good place to start when thinking about the conservation of energy and analysing start and end points. 2. We can do work and that energy is stored (in a different way) as a result of doing work	1. So that they know that there are two ways of raising the temperature of an object: working and heating. They will know about heating but working may be new.	1. That they know that you can raise the temperature of an object by heating. 2. So that they know that raising the temperature by heating is a different process (and pathway) from raising the temperature by working. 3. They begin to get an understanding that, in the conservation of	1. Students should now have the tools that enable them to analyse a number of situations in which an energy analysis tells us something useful. 2. These will usually be

	substance that 'makes things happen'. 4. To encourage a healthy diet (in terms of amount): i.e. the importance of not over- or under-eating.	2. But they won't know what that 'something' is. By introducing the quantity of 'work', we can show them that it is possible to measure and account for the quantity – energy - that is conserved.			energy, one way in which the total energy value stays constant is that the temperature of bodies increases.	situations in which a calculation could be performed.
What else you might know about this idea (that you don't intend students to know yet)?	1. Energy is dissipated – this may come up but not in detail 2. Lots of details about the way in which the metabolism works.	1. Dissipation. As with any real machine, levers and pulleys will have some friction or resistance. As such, doing work on the machine will raise its temperature a little and it will then heat the surroundings. It might be best to defer discussions of dissipation for now. 2. Historically, heat (or caloric) and energy (or its predecessor) were considered as different quantities for many decades. And bringing them together remains quite a challenge for experts and learners. Hence, at this stage, it is helpful to reserve discussions about heating and energy stored thermally.	1. There will be some dissipation in the real examples. The idea of dissipation could be deferred for now.	1. We are getting close to stating a version of the first law of thermodynamics. That there are two ways of changing the internal energy of a system: by doing work and/or by heating it. $dU = dQ + dW$ (the equation is better thought of as a definition of heating, but it is also a way of thinking of energy being conserved). All of which is way beyond what you would mention. But is worth knowing. And it relates to the point below about quantifying the amount of heating.	1. The historic difficulties of bringing together ideas relating to heating and working. 2. That a process with pure working will always be reversible (there is no change in entropy). As soon as there is dissipation, the process will not be reversible.	1. All the formulae for the changes in the amount of energy stored in different ways. Whilst all the examples that the students analyse should be susceptible to an energy calculation (and would reveal some useful information from an energy calculation), they are not going to do calculations at this stage.

		2. Work = force x distance assumes that the two are parallel vectors. This is for much later.				
Difficulties & limitations connected with teaching this idea.	1. It is ingrained in most people's thinking (including our own) that energy is a substance that takes on different forms. Beware of reinforcing such ideas. 2. Beware of referring to food releasing energy. Or referring to energy being used up. It is the food that is used up.	1. It is quite mathematical. It is important to show students how the amount of working increases with both the force and distance. And is therefore the product of the two quantities.	1. One of the barriers to arriving at the idea of energy being conserved is that purely mechanical energy is rarely conserved. Usually there is an unwanted temperature rise so the mechanical stores do not all add to the same amount before and after. This is because, usually, some energy is stored thermally at the end (dissipation). So, at first sight, it may seem that the accounting tool (energy) does not work. It only starts to work when we include thermal stores in the accounting process.	1. It is very easy to say that 'rubbing your hands produces heat'. Beware of doing so. This is, again, a caloric view of thermal physics. That heat is a substance that is created by doing work. 2. It is also easy to say, 'rubbing your hands heats them up'. Again, try not to. Rubbing your hands raises the temperature of the surface. It is important to make the point that the energy stored thermally in the surface of your hands increases by working (not heating). The processes are different but can produce the same outcome. [It is, however, the case, that the hot surface will heat the interior] 3. These ideas relate to the Joule experiment and	1. Our language relating to heating makes discussing thermal situations tricky. Traditionally, we have use the word 'heat' as noun to mean both the energy that is stored thermally and the energy that is transferred by thermal processes. By linking the store with the transfer, we are essentially using 'heat' to mean caloric in an old-fashioned sense (a substance that is both stored and transferred). 2. Also, we use 'heat' or 'heating' as a verb/process in two ways: to transfer energy due to a temperature difference (the correct usage) and also to raise the temperature (not correct). 3. Therefore, it is better	1. See column A. 2. It is often felt that there must be a set of rules for the language that you and students use. Beware of being too forceful about exact wording (for yourself and students) and try to listen for the pictures that the language is painting and the models that are being built up by the language.

				what many would call the 'mechanical equivalence of heat'. This phrase should be handled with care. A poor interpretation of it is that work and heat are equivalent. They are not. But they can produce the same change to the temperature of an object. So, a better interpretation is that working and heating an object can both raise its temperature. And we can quantify the amount of heating by thinking how much work we would do to achieve the same temperature change.	to a) avoid using the word 'heat' as a noun – instead referring to 'energy stored thermally' or a 'thermal store' for the way energy is stored; and referring to 'heating' or 'energy transferred by heating' for the process. b) Refer to 'heating' as the process of transferring energy and 'raising the temperature' as a separate consequence. The reason being that you can raise the temperature by working (as well as by heating); also, you can transfer energy by heating and not raise the temperature (when there is a change of state).	
Knowledge about students' thinking that influences your teaching of this idea.	1. Students may think that 'energy makes things happen'; or 'energy allows your body to work'. This is not the case: it is the fuel + oxygen that allows the body to work – plus the fact that our metabolism is an amazing machine.			1. They will know that friction can raise the temperature of a surface. However, they are likely to express it differently. "Friction causes heat"; or "friction heats the surrounding"; or "friction creates energy". 2. It is worth trying to work towards a more physics-based description	1. Students will have existing and possibly engrained views of what 'heat' is. The suggestions above will avoid this problem because we don't need to refer to 'heat' as a type of energy in the laboratory. Instead we can refer to energy being stored thermally. Or a thermal store.	1. It is likely that students will want to talk about energy flowing or changing. Or what happens to the energy during the process.

				of processes: “the friction between the surfaces makes the particles in the surfaces vibrate more vigorously – and this is measured a s a temperature rise”. 3. And a more physics-based version of the energy analysis: “By working against friction (doing work) we have raised the temperature of the surface and increase the energy stored thermally in the surface”.		
Other factors that influence your teaching of this idea.	1. Many. The two main ones are the way in which energy is used in everyday language. And the way in which energy has traditionally been taught and discussed in schools. There is much written about both. And not enough space here.	1. In all cases (throughout), avoid using the terms ‘sound energy’, ‘light energy’, ‘heat energy’ (or ‘heat’) and ‘electrical energy’.	1. Choose examples carefully. Many of the traditional examples used to discuss changes that involve energy are not helpful and will lead to chains of ‘energy transformations’. 2. Use physical processes and mechanisms, rather than energy, to explain the intermediate steps that bring about these changes.		1. A determination to move science teaching (and the vernacular) away from the caloric view of thermal physics.	1. In all cases, continue to avoid using the terms ‘sound energy’, ‘light energy’, ‘heat energy’ (or ‘heat’) and ‘electrical energy’. 2. Avoid getting drawn into chains of energy; especially if they are purely labelling exercises.

Teaching procedures (and particular reasons for using these to engage with this idea)	1. Comparing energy values of different foods. To show that we can quantify (using calorimeters) how much energy is stored in the chemicals. 2. Possibly burning a peanut to raise the temperature of water. Comparing the temperature rise from a peanut and the same mass of another food. To show they have different calorific values. 3. Make the point that the energy stored chemically (by the peanut + oxygen) puts a limit on how much it will raise the temperature of the water. 4. Calculations of energy requirements in a healthy daily diet. 5. Using energy as an accounting tool to balance the calorific value of all the food eaten in a day with the typical requirements of a teenager.	1. Introduce working. Discuss situation in which there is no work – these can be identified because they do not require a fuel (book on a shelf or a meteor flying through space). Discuss how working requires both a force and movement. 2. Use the example of lifting an apple (2 apples, 3 apples etc.) onto a shelf (at 1m, 2m, 3m etc.) to talk about work being proportional to both force and distance. Lead up to work = force x distance 3. Introduce levers as force reducers. Discuss 'Are we getting something for nothing if the force out is bigger than the force in?' 4. Introduce compensation. If the force is bigger, the distance it moves is less. The thing that is constant is the product of the two: i.e. work.	1. Return to the idea that you can do work to lift something up. The system stores energy gravitationally. 2. Discuss start and end points and changes in the way that energy is stored in this system. A chemical store empties (associated with food + oxygen) and a gravitational store fills. By the same amount. 3. You can also do work to make something move. E.g. throwing ball. Start and end points. A chemical store empties, a kinetic store fills. 4. Discuss changes in the way that energy is stored when you drop something. 5. Discuss choosing start and end points. 6. Emphasise that in all cases, (the changes in) the amount of energy in each of the stores can be calculated.	1. Use examples of doing work to raise the temperature of an object. Rubbing your hands. Rubbing sticks to start a fire. Squashing and releasing a squash ball. 2. Consider these in terms of start and end points and changes to the way that the energy is stored. 3. Mention pathways. At this point restrict the start and end point so that the only pathway is 'working'. E.g. rubbing hands: a chemical store empties, a thermal store fill. And the pathway is working. 4. This could be run as a circus of activities. All of which lead to a rise in temperature due to working. 5. It might be worth doing an experiment such as the lead waterfall to begin to quantify by how much the temperature will rise. However, this could be reserved for Year 10.	1. Discuss raising the temperature of some milk for hot chocolate. In a microwave (or pan), how long will it take to raise the temperature of a big cup of milk as compared with one of half the size. Relate this to the energy that is stored thermally. Use start and end point analysis. The pathway is heating. 2. Discuss examples of heating water for a bath. And discuss what happens to the temperature in the water tank over time. Again, use start and end analysis. And discuss heating by conduction and radiation. Refer to lagging. Run an activity on heating a beaker of water and lagging it to compare the rate of cooling. 3. Similar activity on keeping ice cool (or frozen) in a cooler bag. 4. Discuss when the temperature stops changing (when it is same as surroundings). Discuss	1. Provide examples of a variety situation in which the way in which energy is stored changes. 2. Discuss the start and end points that would be helpful for analysis. 3. Separately discuss the physical processes that bring about the changes. 4. Carry out start to end analysis. 5. Include examples where there is dissipation.

			7. Introduce the idea that you can do work to store energy elastically. Using springy bouncy toys. 8. Introduce the idea that doing work can raise the temperature of a body and the surroundings. And sometimes this is wasteful.		idea of equilibrium (at a particle level). 5. Spend some time on the Sun as a nuclear store. It heats the earth by radiation. Discuss why cars get hotter than their surroundings in the sunlight. And dog safety!	
Specific ways of ascertaining students' understanding or confusion around this area	1. Many students will think food contains energy. And that energy is 'released'. Discuss the role of oxygen. Would the food be useful if we couldn't breathe? 2. They may also think that 'energy is used up'. Probe what they think is used up. And lead towards it being food. We have to grow more to replace what is eaten. I.e. it is the source that is used up.	1. Set some examples of situations in which work is done or not done. 2. Set some example that require the calculation of work. Include some that use the idea of proportionality and/or compensation to determine amounts of work. I.e. not solely plugging numbers into a formula.	1. Get students to talk through their start and end point analysis. Encourage them to use the term 'working' as the pathway that links the start and point.	1. Talk though (and get students to talk about) situations that involve temperature changes. Listen for the use of terms like 'heat', 'heating', 'temperature rise' and 'energy' being used appropriately.	1. Talk through (and get students to talk about) situations that involve temperature changes. Listen for the use of terms like 'heat', 'heating', 'temperature rise' and 'energy' being used appropriately.	1. Get students to talk through the start and end point analysis. And also, the physical processes in between. 2. They can do this in groups with each other. And with you. Gently address any infelicities in language that they use.

Appendix 3.b.: The CoRe on electromagnetic waves for middle level year 9 students used by the teachers to prepare phase-3 lessons. The last two aspects (highlighted) are modifications to the framework and completed by Leanne and Angela.

Big Idea (or Key Skill)	A. Types of electromagnetic waves	B. Properties of electromagnetic waves	C. Applications of electromagnetic waves
What you intend students to learn about this idea.	1. EM waves are transverse and transfer energy; 2. EM waves form a continuous spectrum; 3. All EM waves travel at the same speed and can travel through a vacuum; 4. EM waves are grouped in terms of their wavelength and frequency and their names; 5. The eye can only detect a very small fraction of the EM spectrum, called visible light.	1. EM waves can reflect and refract; 2. How to draw ray diagrams to show reflection and refraction; 3. Gamma rays originate from the changes in the nucleus of an atom; 4. UV, X-rays and gamma rays can have hazardous effects on human body tissue which depends on the type of radiation and size of dose; 5. UV can cause skin to age prematurely and increase the risk of skin cancer. X-rays and gamma rays are ionising radiation that can case the mutation of genes and cancer.	1. EM waves have many practical applications. 2. To know example of uses for each type of EM wave. For example: a) radio waves: including broadcasting, communications and satellite transmissions b) microwaves: including cooking, communications and satellite transmissions c) infrared: including cooking, thermal imaging, short range communications, optical fibres, television remote controls and security systems d) visible light: including vision, photography and illumination e) ultraviolet: including security marking, fluorescent lamps, detecting forged bank notes and disinfecting water f) x-rays: including observing the internal structure of objects, airport security scanners and medical x-rays g) gamma rays: including sterilising food and medical equipment, and the detection of cancer and its treatment.

Why is it important for students to know this?	1. Links with characteristics of waves. That is, whether they are transverse or longitudinal; 2. Each type of wave has a range of frequencies and therefore are not discrete; 3. To acknowledge that EM waves can travel through space which is why, for example, we can observe the Sun, planets and galaxies. 4. Learning the order of waves using their nomenclature links with increasing wavelength (or decreasing frequency). This can later be linked to the wave equation. Since the speed is constant for all EM waves then wavelength is inversely proportional to frequency. 5. To appreciate that there are many more EM waves that we are only able to detect using technology e.g. radio-telescopes and IR-cameras; Links to line spectra in the study of the Big Bang theory, and the eye which students study in Biology,	1. Links with all waves being able to reflect and refract, not just light and sound (which student experience visually and audibly). 2. So that they can apply the fact that rays travel in straight lines and will change speed when they enter another medium. This will cause the ray to change direction. Later on, for some students this can be applied to lenses. 3. Links with the radioactivity topic. 4 & 5. Essential knowledge for students' own health. Links with genetics in Biology.	1&2. Links with everyday applications that students are familiar with.
What else you might know about this idea (that you don't intend students to know yet)?	1.That EM waves are propagated by disturbances in electric and magnetic fields; Polarisation of EM waves. 3 & 5. Use of spectroscopy to analyse line spectra to determine the composition of distant gas giants.	1 &2. Ray diagrams for convex and concave mirrors, and lenses; 3. Changes in atoms and in nuclei of atoms can result in EM waves being generated or absorbed over a wide frequency range; 4&5. Detail about UV-A, UV-B and UV-C form the Sun.	1&2. Applications based on frequency of waves and diffraction properties.
Difficulties & limitations connected with teaching this idea.	1. That EM waves, like mechanical waves are propagated due to vibrations; Teaching waves as energy pathways. 2&5. All, but light is invisible. The concept that the visible band occupies a very small fraction of the EM spectrum. 3&4. Teaching the names of the waves and the order they have to go in, can end up becoming rote learning for students.	1. Demonstrating that all EM waves can reflect and refract. 2. Modelling how to draw ray diagrams for every student to see (difficult in a typical class of 30). 3. Unless radioactivity has been taught, this will be challenging to teach; 4 &5. This can be quite dry to teach and requires engaging data built into activities.	1&2. Selecting appropriate resources to demonstrate each type of wave; Hazards linked to X-rays and gamma demonstrations,

Knowledge about students' thinking that influences your teaching of this idea.	1. If they understand what a transverse wave is, they may struggle to accept that 'something' oscillates perpendicularly to the propagation of the wave. 2 &5. Difficultly in visualising that the waves are on a continuous spectrum with each band having varying widths. 3. Some find it difficult to accept that travelling through a vacuum is unique to EM waves. For example, that sound does not travel through space. 4. That wavelength and frequency are inversely proportional and recalling the names in the correct order.	1. Some will find it difficult to accept that waves that are invisible have similar properties as light waves; 2. Drawing clear ray diagrams may be difficult for students; 3. How much they know about radioactivity; 4. They can apply this quite readily to everyday experiences. 5. Students can struggle with the term 'ionisation' and how it may lead to cancer.	1&2. Students can make better associations when presented with demonstrations for each of the waves.
Other factors that influence your teaching of this idea.	The use of language. It is important for students to use key words like transverse, energy, wavelength and frequency in appropriate ways to effectively communicate their understanding.	Same as in column A.	Same as in column A. Also, good background knowledge about each of the applications which are integrated into interesting examples and demonstrations.

Teaching procedures (and particular reasons for using these to engage with this idea)	1. Demo transverse waves using a Slinky spring. This may have been used before in teaching waves, but it is important that students make a link with EM waves and how they travel. Alternatively, waves propagated on in a ripple tank can be used. 2&4. Provide students with a blank spectrum that they complete during or after a presentation/discussion of the spectrum. 3. After discussing the speed of light, demo measuring the speed of microwaves using chocolate and a microwave oven. While the physics of this is beyond the scope of this group of students, it is a memorable way for them to have learnt that all EM waves travel at the speed of light. Here is a link to the experiment. 5. Ask students to imagine that they could see all EM waves. Provide them with a diagram of an area, such as the security area of an airport, and ask them to add all the waves they could see. This is an effective way for them to appreciate that the space around use is 'a soup' of many more forms of EM waves than it is visible light.	1&2. Students can carry out reflection and refraction of light activities using plane mirrors and rectangular glass blocks. Reflection of other forms EM waves, such as IR or microwaves. 3. Remind students about the structure of an atom before focusing their attention towards the nucleus. Discuss the radiation of energy form a radioactive nucleus in the form of high frequency gamma waves. As an extension, discuss that the energy of a wave is directly proportional to its frequency - so gamma waves are very high energy waves. 4&5. Provide students with data about the hazards of UV, X-rays and gamma rays that they can use to apply to activities.	1&2. Talk students through a circus of demos for each of the types of waves before they circulate the stations.
Specific ways that dialogic interaction can be used to ascertain students' understanding or confusion around this area		Demo the reflection of microwaves without talking to the students. In small groups, students discuss their observations. This will lead them to acknowledge that invisible waves also reflect. (Angela) Demo refraction of light between air and glass, again without talking. Students discus their observations. (Angela) In groups, students discuss and draw	At each station leave prompt questions to encourage students to discuss the types of EM waves. (Leanne)

		conclusions from data provided about the risks and consequences of exposure to radiation. (My example)	
Other ways to ascertain students' understanding or confusion around this area		Provide real-life examples of reflection and refraction. E.g. in a microwave cooker, light leaving lamps on the floor of a swimming pool through water. Students discuss how each happens. (Angela)	Prepare questions to ask students as they are carrying out the activities. (Leanne)

Appendix 4: Email to Leanne following her phase-1 post lesson interview.

Thank you for letting me observe your lesson on Monday and for the post-lesson interview we just had.

Here is some feedback and suggestions:

Overall the lesson was good as students were engaged and it was made clear to them what the learning objectives were and what they had to do in the practical activity. I thought getting them to come up with uses of Hooke's law was an effective way to get them engaged and it put the topic into the context of the real world.

As discussed on the phone, the lesson could have also been carried out the other way around so that after minimal input at the start, students would carry out the experiment, collected data and drawn a graph which could then be used to apply to the theory and make links to what they found out. This would mean that there would be more opportunities to hear students talk and opportunities for them to ask you questions as they carried out the investigation. This would allow you to conduct AFL and act contingently. We also discussed opportunities to assess each student's learning by using a tool like mini whiteboards or Plickers.

Attached is the CoRe template on energy that we discussed. Please use this to plan for the next lesson I'll be observing. You only need to focus on one 'Big idea'. When planning for this lesson, you will use the CoRe template to consider ways to make the lesson more interactive so that classroom discourse is more dialogical. That is, there will be activities where students are talking about the topic and asking you questions. We can discuss this further when you are planning the lesson. Can you let me know some possible dates?

Also - here is the link to the cardboard (forces) arrows I mentioned: http://supportingphysicsteaching.net/Fo01TA.html#TA2

Looking forward to continuing our work together!

Appendix 5.a) - e): Semi-structured questions used during interviews.

a) Phase-1: Pre-lesson observation interview.

Part 1 - Questions adapted from TBI questionnaire (devised by Luft and Roehrig, 2007 p.43) and used to explore teachers' beliefs about teaching and learning.

How do you maximise student learning in your classroom?
How do you describe your role as a teacher?
How do you know when your students understand?
In the school setting, how do you decide what to teach and what not to teach?
How do you decide when to move on to a new topic in your classroom?
How do your students learn science best?
How do you know when learning is occurring in your classroom?

Part 2 - Questions adapted from the VNOS-C questionnaire (devised by Lederman et al., 2002, p509) and used to explore teachers' beliefs about NOS.

1. What in your view is science?

What makes science (or a scientific discipline such as physics, biology etc.) different from other disciplines of inquiry (e.g. religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge require experiments?

-If yes, explain why. Give an example to defend your position.
-If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does it ever change?
-If you believe that scientific theories do not change, explain why. Defend your answers with examples.
-If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories. Defend your answer with examples.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Some claim science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political and philosophical values, and intellectual norms of the culture in which it is practiced.

-If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
-If you believe science is universal, explain why. Defend your answer with examples.

7. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use creativity and imagination during their investigations?

-If yes, then at what stage of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Explain why scientists use imagination and creativity. Provide examples if appropriate.
-If you do not believe scientists use imagination and creativity, please explain why. Provide examples if appropriate.

b) Phase-1 post-lesson interview questions.

1. How do you think the lesson went? Describe what you think went well and what did not.
2. How much learning do you think took place?
3. On reflection, is there anything you would change in the way you delivered that lesson?
4. Based on the learning outcomes of this lesson, how will you approach the next lesson?
5. What in your opinion makes a good teacher?

c) Phase-2 post-lesson interview questions.

1. How do you think the lesson went? Describe what you think went well and what did not.
2. a) Do you think the CoRe on energy has helped with planning for dialogic teaching? If so, how and if not, why not? b) Do you think the CoRe template should be modified to capture strategies for dialogic teaching? If so, how?
3. Do you think that *Alexander's principles of dialogic teaching* have helped with planning for dialogic teaching? If so, how and if not, why not?
4. How, if at all, has my mentoring helped you develop dialogic teaching? Also, add any other ways you feel the mentoring support has helped you.

d) Phase-3 post-lesson interview questions.

1. How do you think the lesson went? Describe what you think went well and what did not.
2. a) Do you think the modified CoRe has helped further with planning for dialogic teaching? If so, how and if not, why not? b) How did you find completing the additional aspects of the CoRe? Did it help with planning for dialogic teaching or would it have been better for the expert teacher to have completed it?
3. Comment on anything else you think has helped you develop dialogic teaching

e) Group interview questions.

1. Summarise how you have found the use of CoRe1 and CoRe2 in developing dialogic teaching in your classrooms?
2. Summarise how you have found the mentoring support to contributing to developing dialogic teaching in your classrooms?
3. How might support for yourselves be continued?
4. How might this project be developed to support other beginning teachers?
5. Any other comments?

Appendix 6: Example of a completed KQ with additional comments that was shared with Angela during her phase-1 post-lesson interview.

Lesson: Introduction to forces

Foundation After graduating with first-class honours in MSci Geology and a distinction in MSc Petroleum Geoscience, Angela had worked in this industry for 5 years. Throughout this time, she was heavily involved with Schools Link and participating in University recruitments and field trips which she enjoyed. This led her to consider working in education. So, she decided to pursue a PGCE in Physics which she completed successfully and is currently in her NQT year. Angela believes that teaching of science should be about teaching students 'how to think', how to explore the world around them and use their observations of it to make sense of it. She dislikes the idea of teaching science 'as fact' but realises that she ends up doing it at times. She believes that understanding in science is constantly changing. Angela believes that science lessons should be interactive and investigative as this would inspire students and deepen their understanding of how science works. She believes that models are of immense value in science, often being the only way of visualising something that we cannot see and realises that much scientific research is based around building models. So, she says, if students are able to analyse the benefits and potential pitfalls of models then teachers can set them with valuable skills, which will be useful beyond the pure sciences. During the lesson Angela demonstrated good subject knowledge and teaching at this level. For example, she would correct words such as weight to mass. This was also evident by the confidence she held and the way in which she was able to answer questions at ease. The questions she asked to elicit and develop students' understanding in this topic revealed good knowledge about how her students learn. The pace of the lesson was appropriate for the mixed ability students and her lesson reflected her lesson plan well.	**Transformation** Angela had prepared a circus of experiments for students to add force arrows (cut out of coloured card) to. Students worked in groups of two and three. She presented the instructions on the board which was useful for students as they applied their learning to add the forces making references to 'pulls' and 'pushes' At one-point Angela asked everyone to gather around to see one of the groups who had been working well on the activity. This clarified for students what they needed to do. At the end of the activity each group presented theirs to the others. Finally, students were asked to draw a free body force diagram for their object. As they did so, Angela circulated the room answering students' questions. For example: "Miss, am I drawing this wrong?" Another: "What is this force called?" This was a good opportunity for her to elicit her students' understanding of the lesson.
Connection Angela reminds students of the previous lesson's learning which is relevant to this lesson. Connections were also made within the lesson as Angela reminded students about the learning at the start of the lesson as they carried out the following activities.	**Contingency** There were several occasions in which Angela acted contingently during the lesson. As mentioned above (in *Transformation*) Angela had realised that some students were not clear about what they had to with the cut-out force arrows, so she drew their attention to the work of a group who

	were working on task. There were moments throughout the lesson that students asked Angela questions and she was able to draw upon examples and secondary information to support her responses to them. Finally, at the end of the lesson a student stayed back to ask questions about planets. Again, Angela responded encouragingly and contributed to the students' ideas about the Solar System.

Additional comments:

Angela's lesson was well organised. For example, she had arranged students into groups prior to the lesson and this was presented on the board. In our post-lesson discussion, she had said that this was done to ensure a good working dynamic within the groups. She acknowledged that it needed to be updated as some of the groups were quite chatty. Students were clear about collecting and putting away the equipment in an orderly manner which was as a result of Angela's organised and clear instructions.
On the whole students worked well in the groups and were engaged with the activity. As mentioned above, some were distracted by each other's company. As well as changing the groups, I had suggested that Angela could set up some key questions that they would be asked at the end of the activity. This could have encouraged engagement especially if they were aware that they would be selected to respond to the questions.
The part in which students listened to each groups presentation was limited by the arrangement of benches in the lab. I had suggested to Angela that each group could take their equipment to the front of the class to present it to the others. This would avoid students being huddled around each station to observe the group's presentation.
Finally, I enjoyed observing this lesson. On the whole, students were engaged and seemed to enjoy the lesson as well. Angela had made an effort to make the lesson interactive as we have been working towards making it so.