LITERATURE REVIEW OF SUBJECT-SPECIALIST PEDAGOGY

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INTRODUCTION

The review has been divided into two main sections. Section One addresses the challenges of conducting a literature review in this field and the thinking underpinning our approach, before considering some of the key ideas that have been identified. Section Two is a more detailed exploration of the studies located during the review process. This introductory section will summarise the aims and scope of the review.

The literature review was designed to:

- Provide a framework for understanding and critiquing the notion of subject-specialist pedagogy in the Further Education (FE) and Skills sector
- Inform the development of interventions within FE initial teacher education programmes with the intention of improving the development of trainees' subject-specialist pedagogy
- Inform the development of a research methodology for investigating the subject-specialist pedagogies of trainee teachers and evaluating the impact of the interventions
- Inform the development of a Theory of Change approach to articulate the assumptions underlying the interventions and their evaluation

It aims to answer the following key research questions:

1. What constitutes subject-specialist pedagogy (in the context of science, engineering and technology teaching in further education) and how can it be conceptualised?
2. How do teachers acquire a knowledge of subject-specialist pedagogy?
3. How do teachers articulate and use their knowledge of subject-specialist pedagogy?
4. How is subject-specialist pedagogy developed in courses of initial teacher education and in CPD?
5. What concerns and issues exist relating to subject-specialist pedagogy (in the context of SET teaching in further education)?
6. What good practice has been disseminated relating to the development of subject-specialist pedagogy?

The bulk of the literature review took place between October 2015 and June 2016 so that it could inform the final intervention design. There was subsequent regular maintenance until March 2018.

The scope of the literature review is expressed by a Boolean search specification which combines relevant terms, and which can be expressed roughly by the diagram in Figure 1.

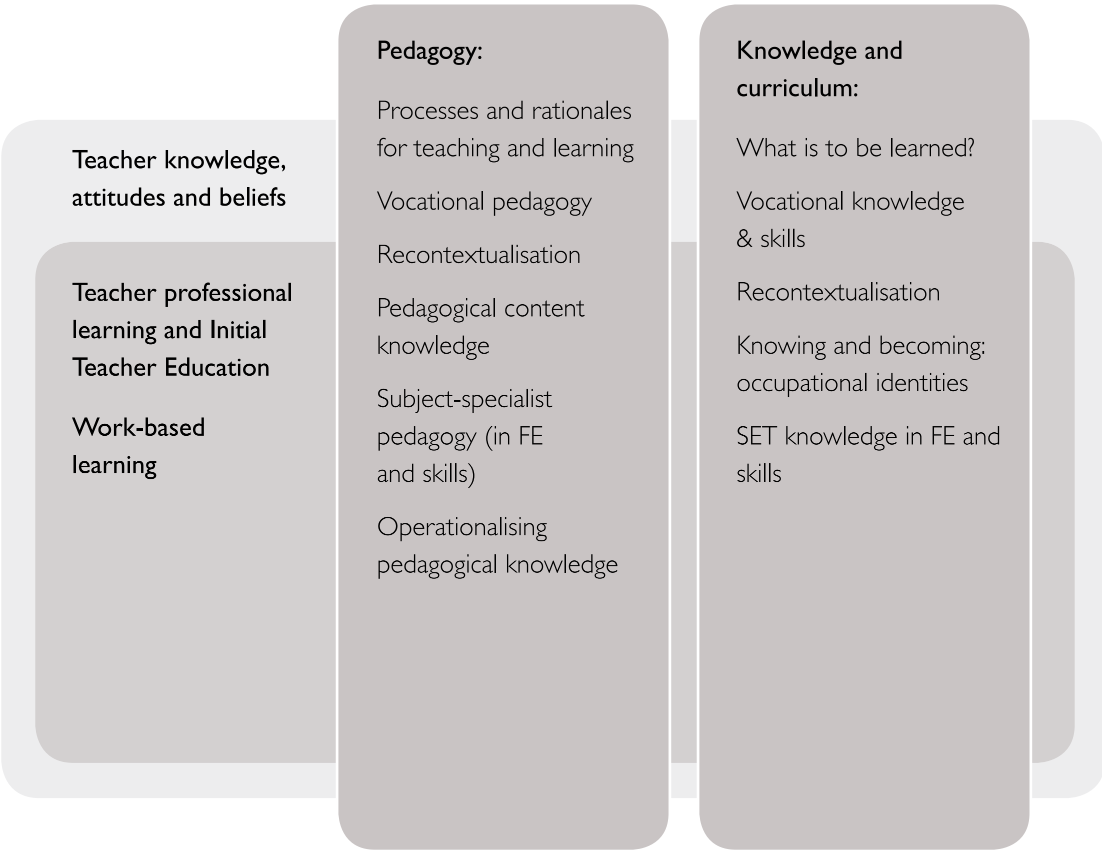

Figure 1: Scope of the literature review

The search terms were refined as the literature review progressed; for example, pedagogical content knowledge and recontextualisation were not initially included as search terms, but were revealed as important by broader search terms such as subject-specialist pedagogy. Some literature items associated with the search terms were regarded as being normally out of scope; for example, primary and elementary education, and subject-specialist pedagogies not associated with STEM subjects. However, such items were reviewed before being excluded and where appropriate were retained. Synonyms were used where appropriate to ensure that important items are not inadvertently missed; for example, teacher training and teacher education were both included in the search. Purposive searches were also conducted of journals likely to contain items of relevance, and of the work of authors known to be active in relevant fields.

Our inclusion criteria for selecting literature were:

1. Studies could use any methods (qualitative, quantitative or mixed)
2. Studies could have taken place in any country, but the findings had to be accessible in English
3. The date of publication had to be 2000 or later. Older studies that offered important insights or that were the basis of significant future work could be included.

The full bibliography contains 252 items from which a smaller subset of the most relevant articles was selected for detailed examination; these latter articles are listed at the end of this report.

SECTION ONE: CONCEPTS OF SUBJECT-SPECIALIST PEDAGOGY

1. BACKGROUND

Debates concerning the nature and status of teacher knowledge can be traced back at least to the 19th century. From an early stage, these debates have included what teachers might know that is distinctive to the occupation of teaching, and how this knowledge might relate to the knowledge of specific academic disciplines. Bullough (2001) notes that struggles between universities and schools over the location of teacher education gave rise to an examination of what might constitute a special province of knowledge for teachers. According to Parr (1888, p. 469 cited in Bullough, 2001), "there is a special knowledge in each subject that belongs to instruction. This is quite distinct from academic knowledge … the ideas of an academic subject are arranged in an order which is determined by their own relations. The order of the same ideas, when they are arranged for teaching, is determined by their relation to the learning mind". Almost a century later, Parr's idea of a 'special knowledge' held by teachers was to be echoed by Lee Shulman in his advocacy of pedagogical content knowledge (Shulman, 1986; 1987), which has become one of the central frameworks for research in subject-specific pedagogy, particularly in secondary school science education.

Debates about teacher knowledge are, of course, situated in wider controversies over the availability and purposes of education, including questions concerning who should learn what, and how. Moreover, socio-cultural theories of learning suggest that teacher knowledge and practices cannot be adequately conceptualised apart from the contexts in which they are embedded. For this reason, it is necessary to supplement Parr's distinction between the order imposed by the structure of the academic discipline and the order imposed by the needs of learners. Whilst these are important factors in the construction of pedagogy, there will also be an *institutional order* imposed by the culture, history and social relations of individual educational establishments and their place in specific national educational systems, as well as a *social order* which derives from the relationship between education and the production/reproduction of broader social structures, including the distribution of educational attainment according to class, gender and ethnicity. The operation and relationships of these distinct, but interacting, orders has been profoundly analysed by Basil Bernstein (see, for example, Bernstein, 2000).

For this literature review, the importance of the institutional and social orders is perhaps most evident in the need to locate considerations of subject-specific pedagogy within the international context of vocational education and training (VET) and, more specifically, the English FE and Skills sector. As is well known, the FE sector has a distinctive character which has been produced by the interaction of historical, cultural, political and social factors shaping education in England over more than a century. These factors have combined to produce a situation in which, although successive governments have highlighted the importance of the sector to national economic well-being, the social status of FE belies its potential contribution to society. For technical education in particular, issues such as the complexity and fragmentation of the qualifications system have posed considerable challenges to realising this potential, and although the reports of the Wolf Review (Wolf, 2011) and the Sainsbury Panel on technical education (DfE 2016) have led to government action to streamline this system and make it more robust, real progress will take time. These features of the FE sector pose a number of challenges to understanding and developing subject-specific pedagogy, not least the marginalisation of teacher education and professional development within the sector and the lack of research which specifically addresses subject pedagogy in FE. Conceptually, there is also the question of how the idea of a subject can be appropriate in the highly diverse context of further education, both because of the proliferation of occupational categories driven by competence-based approaches to vocational training and also arising from the erosion of traditional disciplinary boundaries and identities entailed by the complexities of modern industrial production as well as the questionings of postmodernism (Fisher & Webb, 2006).

The complexities introduced by our focus on vocational education and training are not confined to the nature of the FE sector. There is also the question of the nature of vocational knowledge and skill, and the practices involved in their development, and there is an ongoing debate about what kinds of knowledge are or should be made available to vocational learners (Wheelahan, 2012; Bathmaker, 2013). Some of these debates have been framed by the notion of recontextualisation, understood as the social and intellectual processes of transformation by which knowledge and practices originally located in real vocational contexts are selected, organised and re-interpreted within vocational curricula (see, for example, Hordern, 2013). Although recontextualisation as a concept has been developed by a number of authors in different ways it has perhaps been used most powerfully by Bernstein, who brings to it characteristic preoccupations with the social distribution of knowledge and the use of pedagogy for the implicit projection of certain forms of learner identity.

In conceptualising vocational teaching and learning, it is natural to think of commonalities between vocational areas such as science and engineering and their related academic disciplines – drawing conclusions about vocational pedagogies from corresponding pedagogies within subjects such as physics or biology. However, there has been increasing attention in recent years to the notion of vocational pedagogy *per se*. In this kind of approach, the focus is on what pedagogies are useful across a range of vocational contexts, supporting in a consistent way the development of knowledge, skill and identity among learners. Building on the work of David Guile, Bill Lucas and a number of co-workers (see, for example, Lucas et al., 2012), the report of the *Commission on Adult Vocational Teaching and Learning* summarises a number of distinctive features of vocational pedagogy, which synthesise key notions of recontextualisation, interdisciplinarity and identity formation (CAVTL, 2013, pp. 15-16).

This brief summary of the key issues framing research into subject-specific pedagogy indicates that a review of the relevant literature will be complex and wide-ranging. It needs to recognise the wider context of research into teacher knowledge and identity, curriculum and pedagogy, as well as examining more closely the claims that pedagogies characteristic of particular subjects exist distinctly from generic pedagogies. For the present purposes, this examination also needs to take into account the nature of the FE and Skills sector, and question particular features of pedagogies appropriate to vocational science, engineering and technology. Finally, there are questions concerning how teachers – particularly those new to teaching – acquire (or participate in) pedagogical knowledge and practices associated with their specialist areas, and how their developing knowledge, identities and practices can be investigated empirically.

2. THE CONTEXT OF ITE FOR FE

The professional status of teaching in the further education (FE) sector is recognised as precarious throughout the academic, professional and policy literature. Once described as a 'Cinderella sector' in which a history of 'benign neglect' by policymakers had left it without a clear sense of direction and purpose, FE became subject to successive waves of change from the early 1990s onwards. From the incorporation of colleges in 1993, through the reforms of New Labour around the turn of the millennium, to the moves away from regulation marked by the Lingfield reports, these changes have yet to create a secure sense of professional identity among FE teachers. Although there have been notable achievements in learning environments, curricula and professional training, questions relating to the nature of professionalism in the sector are still fiercely contested and, depending on their political complexion, future governments are likely to introduce further change.

In any sector of education, a central component of teacher professionalism is the professional development teachers undergo, both at the start of their teaching career and as they gain experience. In particular, the nature and status of initial teacher education (ITE) is of crucial importance to how professionalism is viewed both within and outside the sector. However, ITE is perhaps the area which illustrates most clearly how changing political circumstances have introduced considerable volatility into notions of FE professionalism. The aftermath of incorporation reduced the proportion of trained teachers as experienced and qualified staff retired or were made redundant, a situation which in 2000 led to the introduction of a compulsory requirement for FE teachers to acquire a recognised teaching qualification. Alongside other reforms, including the creation of a set of teaching standards and transferring responsibility for the inspection of ITE programmes to Ofsted, this signalled a decade of increasing government regulation of FE teacher training (for a comprehensive discussion of the recent history of ITE for the FE sector, see Thompson, 2014).

Although not always welcomed by university-based providers, who were used to a greater degree of autonomy, by 2010 it appeared that – in spite of recognised weaknesses within the new system – progress had been made and the proportion of qualified staff was increasing. So, at least, was the conclusion of an evaluation of the Labour government reforms carried out by the then Department for Business, Innovation and Skills. However, as the first Lingfield report pointed out, the methods used to achieve this progress were contrary to the new spirit of market liberalism, de-regulation and entrepreneurship desired by the Coalition government. They would also prove difficult to maintain in a period of significant reductions in funding for FE. Consequently, the requirement for teachers to obtain a recognised teaching qualification was removed, together with other regulations introduced in 2007 such as compulsory continuing professional development (CPD) and a requirement to achieve a recognised professional status administered by the Institute for Learning[1]. Nonetheless, the elaborate system of teaching qualifications developed in the period 2007-2011 has largely remained in place – albeit as an option for those teaching or wishing to teach in the sector.

1 These moves reflected more limited de-regulation in the school sector relating to requirements for teaching qualifications.

This brief survey helps us to understand some of the broader issues that may prove problematic for attempts to develop subject-specific pedagogy in the FE sector. These issues include:

- A lack of knowledge about the FE teaching workforce, including subject-specialist issues such as levels of qualification in relation to teaching responsibilities, industrial experience, teaching qualifications and engagement in CPD
- Mixed messages to FE teachers about the value of teaching qualifications and ITE
- Uncertainties around the professional status of FE teaching that may result in a 'craft' rather than 'professional' perception of teaching, potentially undervaluing pedagogical knowledge
- The limited potential of CPD for reaching significant numbers of FE teachers in sufficient depth to have a serious impact
- Pressures on staffing in FE colleges following significant reductions in funding since 2011. These pressures are likely to increase as a series of Area Reviews aimed at rationalising FE provision come to fruition.

Data concerning the FE teaching workforce has generally been patchy and inconsistent, although recent work on behalf of the Education and Training Foundation has reversed a downwards trend in the availability and quality of data (see, for example, ETF 2015a on the teaching workforce and ETF 2015b on ITE provision). The majority of the data is still not sufficiently granular to shed sufficient light on subject-specialist issues in specific subject areas. However, Hayward and Homer (2015) provide a valuable analysis of the SET teaching workforce in FE, indicating that:

- The current SET workforce is well-qualified, both in terms of subject and teaching qualifications, to deliver programmes up to and including Level 3. However, they are less well-qualified and less experienced in terms of meeting future demand for courses at Levels 4-5.
- The age profile of this workforce is such that significant replacement demand will occur in the future
- Although most SET staff receive some CPD, its duration tends to be limited and existing models of CPD are unlikely to deliver the training needed to equip SET staff for changing course demands, particularly in relation to science teachers

An understanding of the issues concerning subject-specific pedagogy also requires some discussion of the ITE curriculum for teaching qualifications in the FE sector. Although providers are increasingly aligning their offer with the 2014 Professional Standards[2] developed by the Education and Training Foundation (ETF), the curriculum is largely based on guidance produced by the Learning and Skills Advisory Service (LSIS) in 2011, which itself evolved from the curriculum introduced in 2007 to implement the LLUK standards. Within this curriculum, subject-specific pedagogy is given some prominence, but with the exception of the specialist qualifications in English and mathematics – aimed mainly at teachers of language, literacy and numeracy – there is no attempt to make explicit the areas of

2 This is the third set of FE professional standards in a period of 15 years, following the FENTO standards of 1999 and the LLUK standards of 2006. Each set has been markedly different to its predecessor.

pedagogical knowledge that must be covered. For this reason, there is considerable variation between providers in terms of the content of subject-specific pedagogical knowledge made available to trainees, and in the approaches used to develop this knowledge. The factors underlying this situation will now be discussed.

Subject-specific pedagogy in ITE for the FE sector has been a strongly contested issue for over a decade, although it must be said that the empirical basis for these debates has been extremely thin. Some of the factors within the debate are:

- External pressures from policymakers and from Ofsted, which have tended to start from the assumption that subject-specific pedagogy in FE is similar to that encountered in school subjects. Under these external pressures, ITE for FE has been seen as inadequate because it tends to lack a formal body of knowledge about subject-specialist pedagogy and is not organised along subject-specialist lines.
- Critiques of disciplinary knowledge in general, and subject-specific pedagogical knowledge in particular, which argue that such knowledge has decreasing relevance in postmodern times of fluidity, interdisciplinarity, and the erosion of authority (Fisher & Webb 2006)
- Critiques which contrast the meaning of 'subject' in FE with that in schools, drawing attention to the numerous specialist areas in the FE curriculum and the diverse interdisciplinary combinations of traditional subjects that they draw on. Whilst school subjects number only a dozen or so, it has been estimated that there are up to 200 specialist areas in FE (Crawley, 2005). Within technical education, national occupational maps may rationalise and standardise many of these areas (IfA, 2017), but the number of specialist areas is unlikely to reduce significantly.
- A recognition that the formal acquisition of codified pedagogical knowledge plays a relatively limited role in the professional development of FE teachers, and that social learning processes which develop a range of knowledge resources, including tacit as opposed to explicit knowledge, are important (Lucas, 2007; Nasta, 2007; Maxwell, 2010)
- A lack of empirical research on how FE trainees develop their subject-specific pedagogy, or on the effectiveness of specific interventions aimed at improvement in this area of ITE – the small-scale study by Maxwell (2010) is a notable exception to this
- Logistical issues related to the difficulty of maintaining viable groups of subject-specialist trainees given the diversity of FE 'subjects', and of staffing these groups with suitably qualified and experienced teacher educators – particularly in SET subjects

Although these factors had been present for some time beforehand, they became particularly prominent from 2003 onwards when, having recently taken over responsibility for the inspection of ITE programmes in FE, Ofsted published a survey report which was severely critical of existing ITE provision. One of the key areas identified by Ofsted as requiring improvement was the development of subject-specific pedagogy, which in their view compared poorly with corresponding provision for trainee school teachers. In this respect, the specific criticisms contained in the Ofsted (2003) report may be summarised by a single paragraph within it:

> None of the formal training includes provision to help trainees improve their subject knowledge or their vocational competence. There is also little

> opportunity for trainees to develop subject-specific pedagogy which would enable them to understand and practise the particular skills relevant to teaching their specialist area. In some cases, subject-specific mentors are available to give advice and guidance, and trainees greatly value the contributions made by these work-based staff. However, benefiting from this informal element of training is often a matter of chance … (pp. 20-21)

In other words, both subject knowledge *per se* and pedagogical content knowledge were neglected, with advice on pedagogy being largely generic. Ofsted (2003) found that the quality of the generic training led by teacher educators was generally good; nevertheless, 'The quality of the trainees' teaching is affected adversely by their limited knowledge of how to teach their subject' (p. 4).

The perceived weaknesses identified by Ofsted contrasted with the more optimistic – or perhaps complacent – assumptions embedded in the FENTO standards current at that time.

> The standards are based on the assumption that those who teach in the sector already possess specialised subject knowledge, skills and experience. The standards, therefore, address the professional development of teachers and teaching teams rather than the development of their subject expertise. (FENTO, 1999, p. 3)

Although leaving room for the development of subject-specific *pedagogy* as opposed to subject knowledge as a legitimate concern of ITE for the sector, this assumption nevertheless reflected the somewhat laissez-faire attitude which then existed and which has proved difficult to eradicate through successive waves of reform. Echoing a supposedly widespread belief in the FE sector that teaching skills flow naturally from subject expertise, it is expressed by Robson (2006, p. 14) in the following terms: "The assumption has been … that if I know my subject, I can, by definition, teach it to others."

Providers responded to the Ofsted criticisms in a variety of ways, largely through attempting to improve subject-specific mentoring arrangements but also through innovations in course content and delivery (see, for example, Fisher & Webb, 2006). However, although these improvements had some impact, a review based on the 2004-08 inspection cycle noted that the quality of subject-specialist support remained variable (Ofsted, 2009). There is also evidence that subject-specific pedagogy is not a strong element of CPD for SET teachers in FE, and science teachers in particular would welcome more CPD (Hayward & Homer, 2015).

3. PEDAGOGY AND THE SUBJECT-SPECIALIST TEACHER

The Ofsted report of 2003 and its aftermath have caused providers of initial teacher education for the FE sector to confront the notion of subject-specific pedagogy more seriously than ever before. Outside the FE sector, similar trends have existed for even longer, and Thornton (1998) sees increased government emphasis on subject-based curricular arrangements as part of the reaction against progressivism which gathered momentum throughout most of the 1980s and 1990s. However, as already mentioned, subject-specific pedagogy remains a contested notion both within and outside the FE sector, "one that sits in contradiction to strong intellectual and epistemological trends" (Fisher & Webb, 2006, p. 339). On the one hand, this is connected with pressures towards interdisciplinarity enforced by the complex nature of modern enterprises, but on the other hand with more fundamental questioning of the authority of disciplinary knowledge associated with postmodernism. Although the idea of a distinctive pedagogy associated with individual subjects or related groups of subjects might appear attractive or even intuitively obvious, these trends make it necessary to examine the assumptions underpinning notions of subject-specific pedagogy more closely, particularly in the context of FE.

Generic pedagogy

There are several important questions concerning subject-specific pedagogy in ITE that need to be answered before real progress can be made. These include:

- What should be encompassed by the term 'subject-specific pedagogy', and what relationships exist between subject-specific and what might be termed 'generic' pedagogy?
- What constitutes a 'subject' in the FE sector, and what kinds of knowledge are present in the subjects and curricula commonly encountered there?
- How will policy developments such as national occupational maps and associated standards modify the current 'subject' structure in FE, and what are the implications for pedagogy?
- How do trainees acquire and develop knowledge and skills relating to subject-specific pedagogy?
- How can the development of subject-specific pedagogy be supported more effectively in ITE courses?

At present, the evidence base on these questions is severely limited. Within the FE sector, the term 'pedagogy' itself can be controversial, partly perhaps because it suggests a concern with younger learners, but also because it evokes wider controversies over the status of education as a discipline and the value of 'theory' in the activity of teaching (Simon, 1981). Either way, a mistrust of 'pedagogy' has been reported:

> A robust vocational teaching and learning system must be underpinned by a serious focus on vocational pedagogy. And yet, as we have gone round the country visiting sites of vocational teaching and learning and in our seminars, of all the terms we have discussed the one that gets people most agitated is 'pedagogy'. (CAVTL, 2013, p. 13)

We therefore begin with a definition of pedagogy in general. Following Bernstein (2000), we first conceptualise pedagogy very broadly as a process, encompassing a wide range of possible settings and relationships which may frame the acquisition of knowledge, values and behaviour:

> Pedagogy is a sustained process whereby somebody(s) acquires new forms or develops existing forms of conduct, knowledge, practice and criteria from somebody(s) or something deemed to be an appropriate provider and evaluator … We can distinguish between: institutional pedagogy and segmented (informal) pedagogy.
>
> Institutional pedagogy is carried out in official sites … usually with accredited providers … Segmental pedagogy is carried out usually in the face to

> face relations of everyday experience and practice by informal providers. (Bernstein, 2000, p. 78)

Pedagogies may be explicit, implicit (in which the pedagogic process is less visible, but still intentional) or tacit (in which learning occurs without intention; for example, through unintended modelling), and are underpinned by socially constructed rules or principles governing how content is to be distributed, contextualised and evaluated. For Bernstein, pedagogy can therefore exist in various *modalities* or forms of arrangement of the relationships and practices involved in the process of acquisition[3]. From this point of view, subject-specific pedagogies could exist relatively superficially at the level of particular relationships and/or practices within modalities that recur across a range of subject areas, or more profoundly by exhibiting characteristic modalities in the arrangement of relationships and practices. Pedagogic *knowledge* could then be regarded as knowledge about the possible forms of these modalities, the conditions under which they may apply and the consequences they may have.

Whilst this abstract conception of pedagogy as process is helpful in thinking about and classifying different pedagogies, it leaves open the question of teacher agency and its role in mediating between the needs of industry and the state on the one hand, and the needs of learners on the other. FE teachers may have varying degrees of control over what is learned in their classrooms and how; nevertheless, their ability to come to informed and principled decisions about pedagogic practices is of crucial importance. Edwards (2001, p. 163) makes this a part of her definition of pedagogy: "For me a pedagogic act involves those who are teaching in informed interpretations of learners, knowledge and environments in order to manipulate environments in ways that help learners make sense of the knowledge available to them. It is an intense, complex and discursive act, which demands considerable expertise". The ability of teachers to justify their decisions is also an important facet of pedagogy:

> Pedagogy is the act of teaching together with its attendant discourse. It is what one needs to know, and the skills one needs to command, in order to make and justify the many different kinds of decisions of which teaching is constituted. (Alexander, 2004, p. 11)

On this account, pedagogical knowledge is knowledge that underpins such 'informed interpretations' and must therefore bring together a range of subject-specific and generic elements.

Our working definition of pedagogy in general therefore contains four related elements:

- Pedagogy as content: the knowledge, skills and attributes that students are given the opportunity to learn
- Pedagogy as process: what happens, or potentially can happen, in educational environments, whether formal or informal, to bring about or evaluate learning
- Pedagogy as knowledge: the knowledge that teachers have, or potentially could have, about pedagogical content, processes and their possible outcomes, including knowledge about their students and the context in which they are learning

3 Some authors distinguish between conceptualisations of pedagogy based on metaphors of learning as acquisition or as participation (Sfard 1998). Bernstein would not make the distinction in this way, but would consider participative approaches as one of the modalities through which pedagogy is enacted.

- Pedagogy as decision-making: the processes and actions through which teachers come to decisions about what will happen in their classrooms and to what purpose

Critically-informed teaching will involve teachers relating pedagogical decision-making to the first three of these elements. In relation to content, the autonomy of classroom teachers has always been limited by externally-set syllabuses and assessment criteria, and policy developments aimed at rationalising technical education provision may tend to reduce this further. However, teachers still need to make content decisions; for example, about sequencing, pacing, and contextualisation. They also need to interpret official statements about standards in ways that can be implemented in their own institutional settings, a notoriously problematic process (Nasta, 2007). Decision-making will be socially situated, because teachers work as part of national, institutional, professional and discipline-based contexts. By criticality, we mean teachers being aware of the four elements, their socially constructed nature, and the need to adopt a reflexive approach which acknowledges the importance of context and the impact of the teacher's own values on the decisions they make.

In this model of pedagogy, decision-making is central but *draws* on pedagogical knowledge and *is about* content and process (within the range of autonomy the teacher has). Figure 2 illustrates these relationships:

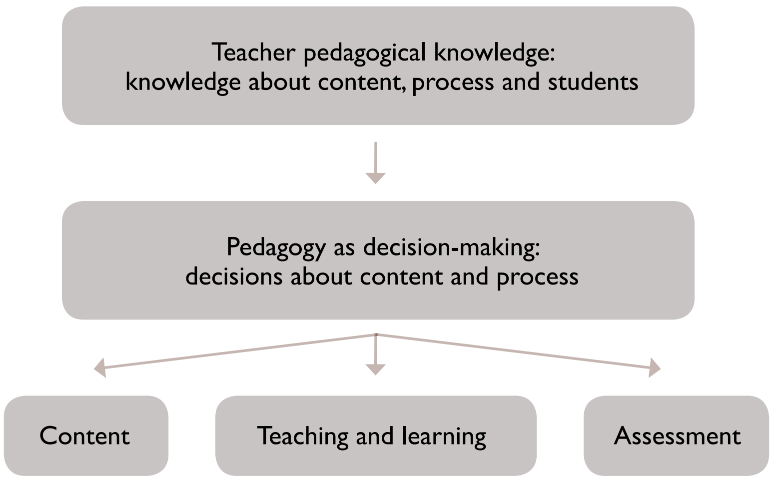

Figure 2: Generic pedagogy

Subject-specialist pedagogy

In delineating what is special in subject-specialist pedagogy, the work of Shulman (1986; 1987; 2004) is particularly helpful, although its influence has been mainly in the school sector. Shulman's model of what he calls *pedagogical content knowledge* (PCK) has been explicitly used in analyses of science education in England (for example, Lock et al., 2011), and international literature abounds with studies of the PCK in science and mathematics. Application to engineering is infrequent, but contributions include Viiri (2003), De Miranda (2008), and Jolly, Brody and Midgley (2012). Work using PCK is also beginning to appear in the broader context of vocational education; for example, Kuhn, Alonzo, & Zlatkin-Troitschanskaia (2016). Building on Shulman's work, the term technological pedagogical content knowledge (TPACK) has also been introduced to describe the essential qualities of teacher knowledge required for integrating educational technology within teaching and learning (Mishra & Koehler, 2006).

In its original form, PCK derived from an attempt to identify an overarching knowledge base for teaching, "a codified or codifiable aggregation of knowledge, skill, understanding and technology, of ethics and disposition, of collective responsibility – as well as a means for representing and communicating it" (Shulman, 1987, p. 4). Within this knowledge base, Shulman (1987, p. 8) identifies seven categories of teacher knowledge:

- Content knowledge – that is, subject knowledge *per se*
- General pedagogical knowledge – the broad principles and strategies of classroom management and organisation that appear to transcend subject matter
- Curriculum knowledge – knowledge of the ways in which subject content is made available through educational curricula, including syllabuses, learning resources and assessment strategies
- Knowledge of learners and their characteristics
- Knowledge of educational contexts, both at the micro (classroom) and meso/macro (communities and cultures) levels
- Knowledge of educational ends, purposes and values, and their philosophical and historical grounds
- Pedagogical content knowledge

This structure contains both generic pedagogical knowledge, which may be possessed by any teacher, and knowledge of content, which may be possessed by subject-specialists who are not teachers. However, Shulman (1986) argued that knowledge for teaching needed to include more than just these categories. In his view, what was distinctive about the knowledge base of subject teachers lay *at the intersection of content and pedagogy.* PCK was conceptualised as being uniquely associated with expert teachers of a particular subject-specialist area, to be understood as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding … It represents the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organised, represented and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8). More specifically, Shulman includes within PCK two broad areas: knowledge of how to teach a subject to particular learners, and knowledge of factors which might influence the effectiveness of learning:

> Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful form of representations of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others …
>
> Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners … (Shulman, 1986, pp. 9-10)

The development of PCK theory and its detailed application to the practice of teachers has been carried on by many authors, and has become something of a paradigm for those interested in the development of mathematics and science teachers. Kind (2009) provides an exhaustive review of perspectives on PCK and the potential for further work, and another useful review can be found in Park and Oliver (2008). Kind (2009, p. 173) draws attention to an understanding of PCK as the capacity of the teacher to transform knowledge for the benefit of learners which is shared by many, but not all, of the later reworkings of PCK. These understandings build on Shulman's original conception, which is "the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (Shulman, 1987, p. 15). In this respect, therefore, it may be useful to explore connections between the ideas contained in PCK and the process of recontextualisation as described by David Guile and others.

The idea of PCK is open to a number of criticisms – for example, that it promotes an outdated transmissive model of teaching, that it ignores the social context in which teachers and learners operate and which might affect different subjects in different ways, and that it privileges explicit and codifiable knowledge over knowledge tacitly held and acquired. It also lacks a theoretical background (Kind, 2009) and begs the questions of whether PCK actually exists as a distinct form of knowledge for teachers, and whether what appears to be PCK is actually the working out in a particular context of generic pedagogical principles. Shulman himself has attempted to answer some of these criticisms; for example, by tracing how teachers may learn and develop within communities of practice (Shulman & Shulman, 2004).

Shulman's work has also been criticised by researchers working specifically on the FE system for embodying objectivist assumptions about knowledge which are less appropriate for the vocational contexts in which many FE teachers work (Lucas, 2007; Nasta, 2007; Maxwell, 2010). The strongly context-dependent nature of teaching in the FE sector is emphasised by Hodkinson and James (2003, p. 401): "what works, or is deemed good practice in one learning site may not work or be good practice in another". This suggests a more open and fluid conception of pedagogical knowledge than proposed by Shulman, one in which there may be no agreed body of knowledge concerning the conceptual structure of a subject or vocational area, the best ways of representing its concepts, propositions and skills, or that learners behave and develop in similar and essentially predictable ways. In this conception of knowledge for subject teaching, the emphasis shifts from codifying and transmitting objective knowledge to the construction of knowledge within specific contexts, as socially-situated individuals grapple with the particular problems they face: "learning to teach is a 'situated process' that takes place in and between contexts … in taking this approach I highlight the importance of seeing learning as a social process and that the basis for analysing learning should be the 'community of practice'" (Lucas, 2007, p. 98).

Whatever the validity of these criticisms, PCK appears to be a valuable construct in understanding and developing the practice of teachers in certain subject areas. Coe et al. (2014) identify PCK as a key element of effective teaching, judging that there is strong evidence that it enhances outcomes for learners. Although this is partly because of the importance of subject knowledge *per se*, knowledge of content alone is not sufficient:

> The evidence to support the inclusion of content knowledge in a model of teaching effectiveness is strong, at least in curriculum areas such as mathematics, literacy and science. Different forms of content knowledge are required. As well as a strong, connected understanding of the material being taught, teachers must also understand the ways students think about the content, be able to evaluate the thinking behind non-standard methods, and identify typical misconceptions students have. (Coe et al., 2014, p. 44)

Although Shulman distinguishes pedagogical content knowledge (PCK) from other areas, such as knowledge of learners and of curricula, other authors have tended to bring the subject-specific aspects of these areas into the PCK construct. For example, Magnusson, Krajcik and Borko (1999) propose that PCK has five components:

- orientations towards teaching (knowledge of and about their subject and beliefs about it, and how to teach it)
- knowledge of curriculum (what and when to teach)
- knowledge of assessment (why, what and how to assess)
- knowledge of students' understanding of the subject
- knowledge of instructional strategies

This more inclusive approach is used in the model of subject-specific pedagogy outlined in Figure 3 below. Rather than attempt a dualistic separation of generic pedagogy and subject-specialist pedagogy, this model emphasises the situating role of the particular discipline, subject or vocational area in shaping the four elements of generic pedagogy discussed above. The model expands the diagram of generic pedagogy in Figure 2, placing at the centre *teachers' pedagogical content knowledge* and *teachers' decision-making*, those elements where greater autonomy is possible. Content/curriculum and externally-imposed processes of learning and assessment in the discipline are regarded as largely exogenous factors in the FE context.

According to this model, all pedagogy is 'subject specific' in that a teacher enacts it through decisions and action within a specialist area. However, the specialist area is not an unimportant backdrop to these decisions: its knowledge base, values and 'ways of knowing and being' permeate and interact with the various elements of pedagogy to produce pedagogical processes that are distinctive to a greater or lesser degree. Pedagogical content knowledge (the shaded area in the diagram) is not the reductive intersection of subject knowledge and generic pedagogy; it is the union of these elements, and potentially greater than the sum of its parts.

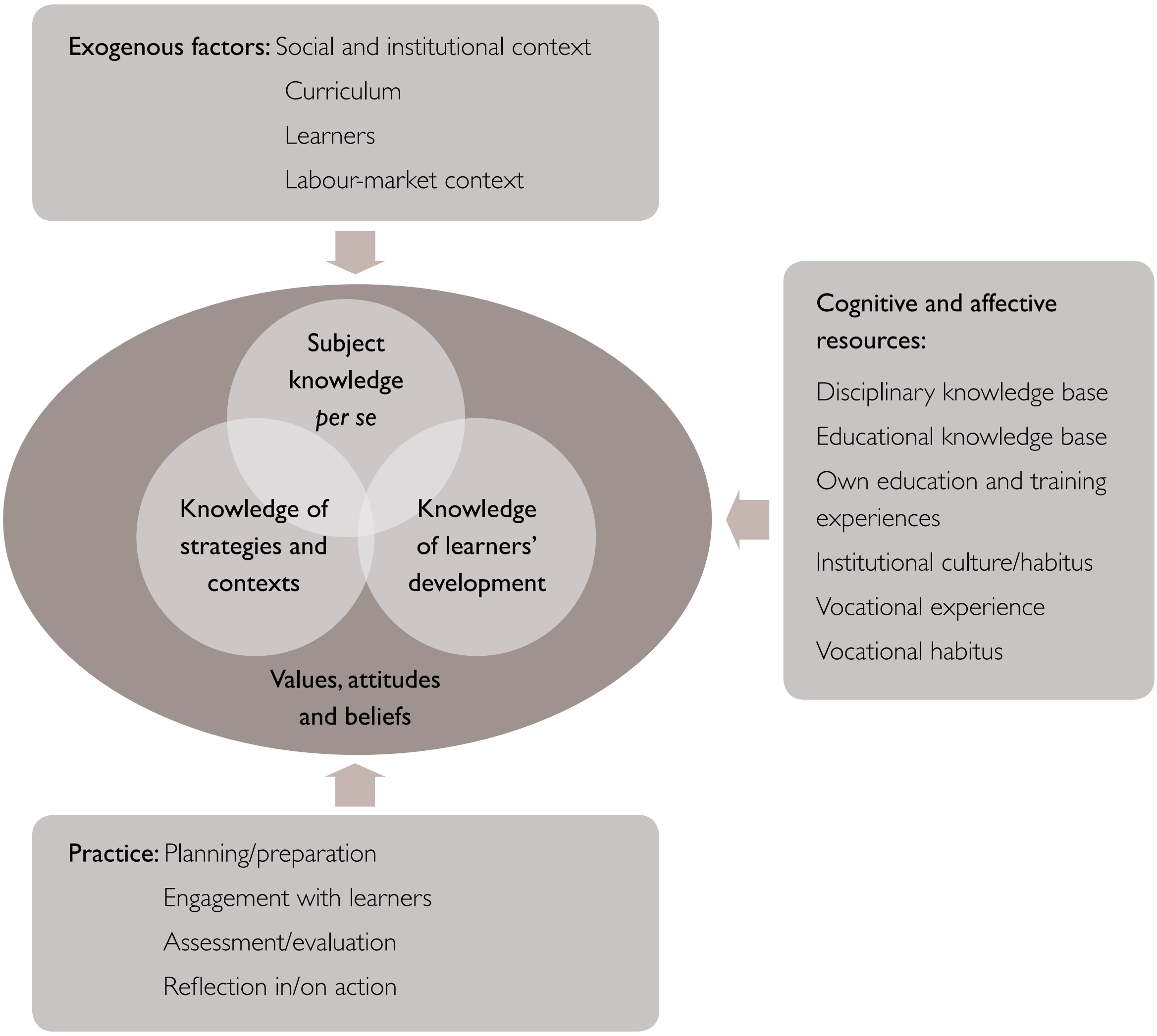

Figure 3: Subject-specialist pedagogy as situated reasoning about teaching decisions.

THE 'SUBJECT' IN FE

Although the range and diversity of subject areas in FE is one of the most obvious characteristics of the conceptions of 'subject' appropriate to the sector, other factors are more fundamental. Our understanding of this term is that subjects in FE are only rarely the recontextualisations of singular academic disciplines encountered in the school curriculum. Instead, they are characterised by some or all of the following features:

- A vocational orientation and/or a focus on the development of generic abilities associated with employment and everyday life
- A distinctive base of knowledge and abilities derived from its vocational or generic origins and including occupational as well as disciplinary knowledge
- Regional rather than singular (Bernstein, 2000) – that is, drawing on more than one academic discipline for its knowledge base

- Sometimes related to specific groups of learners and/or broad groupings of occupational areas
- Characteristic (but not necessarily distinctive) pedagogies and pedagogical knowledge bases, although these may not be explicitly articulated
- An identifiable 'curriculum' which may be formal (involving officially accredited courses and qualifications) or informal (such as recreational programmes for adults)

Bernstein (2000) draws a distinction between strongly and weakly classified subject areas. That is, certain subjects have a strong identity, a well-defined and distinctive body of knowledge, usually deriving from a small number of academic disciplines, and a clear status distinct from everyday life. Other subjects either do not satisfy these requirements, or do so only weakly and in ill-defined ways. Thus, in FE, a subject such as mechanical engineering could be regarded as strongly classified, whilst uniformed services programmes are likely to lie at the opposite end of the spectrum.

Although it may seem self-evident that certain subjects have well-developed bodies of pedagogical knowledge, and that these differ significantly between subjects, it is important not to conflate the epistemological nature of subject areas with the social organisation of these areas. For example, the existence of subject-pedagogic professional bodies, academic journals dealing with subject pedagogy, or distinctive concerns related to curricula, learning and assessment, may relate more to the social, economic and historical context of the subject than to its intrinsic character. In a similar way, whether or not subject-specific pedagogical knowledge is contained in a particular ITE curriculum is also a contingent matter. Furthermore, given the interdisciplinary nature of many vocational areas in FE, it is perhaps the crossing of boundaries between disciplines that should receive the greatest pedagogical attention – resulting in a focus on what Bernstein called regional rather than singular knowledge structures, and how trainee teachers may be supported to work more effectively in regional modes.

4. EVIDENCE FOR THE NATURE OF PEDAGOGICAL CONTENT KNOWLEDGE

Thompson (2014) argues that questions about the nature of subject-specific pedagogical knowledge – how distinctive it is from subject to subject and the extent to which it differs from generic pedagogical knowledge – as well as the ways in which it can be developed in trainees are at least partly *empirical* questions that need to be answered by research rather than conceptual analysis alone. The first question is addressed by a number of studies working within or close to the PCK tradition, which typically examine the behaviour, explanations and reflections of experienced subject teachers in order to arrive at conceptualisations of professional knowledge which can reasonably be called subject-specific (Barnett & Hodson, 2001; Viiri, 2003; Ball, Thames & Phelps, 2008; Hill, Ball, & Schilling, 2008; Lee & Luft, 2008). These studies indicate the importance of knowledge of subject content which is also possessed by non-teachers, but also that PCK must go beyond this to blend knowledge of content with knowledge of how learners respond to this content (Viiri, 2003; Ball et al., 2008). Moreover, PCK is more than static knowledge. For example, teachers do not merely 'know that' students make certain kinds of errors: they reason about student behaviour in order to uncover what they are thinking and doing, so that *knowledge about content and students* is a unitary component of PCK rather than two separate elements (Ball et al., 2008, p. 401; Hill et al., 2008, p. 396). There is also empirical support for the five categories proposed by Magnusson et al. (1999) and outlined earlier – see; for example, Lee and Luft (2008). Barnett and Hodson (2001) propose a broader model, *pedagogical context knowledge*, which includes similar understandings of PCK but also a varied blend of other forms of specialist and generic knowledge for teaching.

One of the major areas of current research in PCK is how to capture this knowledge empirically, both to assess the extent of a teacher's grasp of PCK and to trace its development over time and through different interventions. Perhaps the most influential of these approaches at present is the use of Content Representations (CoRes) and Pedagogical and Professional experience Repertoires (PaP-eRs) which have been developed over a number of years in Australia by John Loughran, Amanda Berry and Pam Mulhall (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Loughran, Mulhall, & Berry, 2004; Loughran, Mulhall, & Berry, 2008; Loughran, Berry, & Mulhall, 2012). A CoRe focuses on what a teacher (or group of colleagues) consider to be a 'big idea' in their subject, and probes their thinking on how best to teach this particular topic, using prompts such as "*What you intend the students to learn about this idea*", "*Why it is important for students to know this*" and "*Knowledge about students' thinking which influences your teaching of this idea*" (Loughran et al., 2012, p. 18). For example, Williams, Eames, Hume and Lockley (2012) describe using a CoRe approach with early-career teachers to develop their PCK. A PaP-eR is a narrative piece of reflection written by a teacher, showing in their own voice how they are thinking about teaching a particular topic to a particular group of students. In her review of PCK, Kind (2009, p. 195), states that using CoRes "offers, in my opinion, the most useful technique devised to date for eliciting and recording PCK directly from teachers". Moreover, there is evidence that the CoRe approach can be useful in developing as well as eliciting PCK, and may therefore be promising for our purposes.

Other approaches to eliciting PCK have been used, including multiple-choice items (Hill et al., 2008) and video-based interviews (Alonzo & Kim, 2015). However, many of these approaches are extremely time consuming and have been conducted with very small samples (for example, McCaughtry, 2005; Bertram & Loughran, 2012). Others are highly research-focused and of limited use for designing or evaluating interventions (Alonzo, Kobarg, & Seidel, 2012). Nevertheless, some of this work, although labour-intensive, contains useful ideas that may help in designing the intervention. Nilsson and Vikström (2015) describe the use of a *learning study* as a means of developing teachers' professional knowledge. By 'learning study', the article means a specific form of activity involving a small group of teachers (three in this case). Teacher 1 plans a lesson on an agreed (problematic) topic, which is then delivered and video-recorded. The students involved in the lesson are also given a pre- and post-test. All three teachers then discuss the students' learning and the impact of the lesson, leading to a revised lesson which is delivered by Teacher 2. The process is repeated, leading to a further revised lesson delivered by Teacher 3. The lessons taught by each teacher before and after participating in the learning study are not related to the topic taught in the learning study, but the teachers are intended to have developed their PCK through the activity and therefore to have changed - or improved - their practice as a result.

In a small-scale study of knowledge growth among in-service trainee teachers, Maxwell (2010) uses the concept of *knowledge* resources to explore how trainees construct, generate and share knowledge relevant to their teaching. This concept derives from a 'communities of practice' perspective in which learning is situated within social and organisational contexts, but also draws on ideas from the structuration theory of Anthony Giddens, which emphasises the role of 'rules' and 'resources' in the reproduction of social practices. The learner – in this case a trainee teacher – is seen as having access to a range of different knowledge resources associated with the community of practice, including both resources that are formal, explicit and technical and those that are informal, tacit and culturally embedded. As they engage within the practices of the community, learners produce and access existing knowledge resources as rules that frame their work behaviour, and enter into the production of new knowledge resources, thereby generating new rules of behaviour in a continually evolving cycle (Saunders, 2006, p. 16).

In Maxwell's study, trainees were found to draw on a range of knowledge resources which in some ways reflected Shulman's categories of teacher knowledge but showed little evidence of what could be thought of as pedagogical content knowledge. Not surprisingly, subject or vocational knowledge was a key resource, and some trainees kept up-to-date by reading academic, vocational and curriculum literature. Prior experiences as a learner were also important knowledge resources, a point also noted specifically for engineering teachers by McKenna & Yalvac (2007). As in Shulman's model, knowledge of learning groups and individuals was constructed and used by trainees, although Maxwell – perhaps unfairly – asserts that these resources were qualitatively different from Shulman's 'decontextualised and more generalised knowledge about learners' (Maxwell, 2010, p. 343). Generic pedagogical knowledge was another important resource, derived from participation in teacher education programmes, practical teaching experience, and – where trainees were not isolated – interactions with other teachers. Organisational 'ways of doing things' were also sources of rules governing teaching behaviours. Finally, Maxwell identifies the importance of trainees' beliefs, values and prior knowledge in constructing knowledge resources applicable to their teaching.

5. RECONTEXTUALISATION

As noted earlier, recontextualisation may be understood as the social and intellectual processes of transformation by which knowledge and practices originally located in real vocational contexts are selected, organised and re-interpreted within vocational and professional curricula. In this sense of the term, recontextualisation is thought of as an element of the social control and distribution of knowledge, with learners regarded as largely passive recipients of curricula, learning strategies and assessment practices designed elsewhere. However, although this aspect of recontextualisation is of great interest, it may also be thought of as a more dynamic set of processes in which learners and teachers themselves operate between and across contexts, adapting and re-formulating their knowledge and abilities to meet the requirements of the context in which they are currently operating. Pedagogic practices which support this multi-directional recontextualisation are likely to enrich and deepen vocational learning.

In the former sense of recontextualisation, Bernstein (2000) identifies two arenas contributing to the transformation of knowledge and practices: the official recontextualising field (educational agencies which are part of or closely associated with the state) and the pedagogic recontextualising field (individual teachers and their professional communities). Whilst the first of these fields may affect subject-specialist pedagogy more or less directly, the second is perhaps of more interest for our current purposes. At its simplest, recontextualisation in this sense has been used to capture the need for individual vocational teachers to bring appropriate features of workplace practices into the context of training; for example, by requiring them to "recontextualise theoretical and occupational knowledge to suit specific situations" or to "replicate in the learning environment the way people are assessed and given feedback on their performance in the workplace" (CAVTL, 2013, pp. 15-16). However, the recontextualisation concept is richer and more flexible than this, and derives from a range of authors working through different theoretical perspectives, as Hordern's (2013) article shows. As already mentioned, in addition to being closely linked to conceptualisations of different forms of knowledge, the work of Bernstein (2000) is particularly strong in showing how the process of recontextualisation is class-based and ideologically loaded, an arena of struggle rather than the rational application of functionalist principles. From a different perspective, based on Cultural-Historical Activity Theory, Guile (2010; 2014) considers recontextualisation as a key facet of the cultural mediation of experience. Regarding vocational learning as being as much about thinking as it is about practice, Guile (2014, p. 89) identifies four components of the recontextualisation process:

- Selection of content and construction of vocational curricula (content recontextualisation)
- Approach to learning and teaching (pedagogic recontextualisation)
- Organisation of and engagement with work experience (workplace recontextualisation)
- Development of theoretical and occupational reasoning (learner recontextualisation)

Associated with these components are four key practices of vocational learning (Griffiths & Guile, 2004; Guile, Kersh, & Tiris, 2016, p. 25):

- Theoretical thinking – the ability to use concepts and procedures drawn from relevant disciplines as a resource to engage with occupationally-specific practice and problems
- Dialogic inquiry – the ability to ask questions of more experienced others in the contexts of education and work, as a resource to engage with problems which are either discipline or occupation specific depending on the context
- Boundary crossing – the ability to operate effectively in both the education and work contexts
- Resituation – the ability to modify ways of thinking, ask questions and deploy technical skills according to the situation rather than in accordance with habituated practice.

In addition to supporting our conceptualisation of subject-specialist pedagogy, these components could be valuable in structuring the design and evaluation of possible interventions. In the context of vocational education, Guile's model of recontexualisation offers a way of conceptualising more rigorously ideas such as the integration of theory and practice, vocational pedagogy and the 'two-way street' between education and work.

6. SIGNATURE PEDAGOGIES, VOCATIONAL HABITUS AND LEARNING AS BECOMING

Whilst PCK focuses on the reproduction of disciplinary knowledge structures, subject-specialist pedagogy also fosters the development of disciplinary, professional or occupational identities. This may happen explicitly through studies of the history and epistemology of the specialist area, curriculum elements concerned with behaviours expected in the professional context, and codes of professional conduct. However, identities are also formed implicitly through learning processes which are strongly characteristic of the specialism. To describe these characteristic learning processes, Shulman (2005) introduced the term *signature pedagogies*, defined as "types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions. In these signature pedagogies, the novices are instructed in critical aspects of the three fundamental dimensions of professional work – to think, to perform and to act with integrity" (p. 52). Signature pedagogies are therefore about much more than reproducing technical knowledge and skill within a learner – they act to create a world view, which brings to mind the *vocational habitus* of a different theoretical tradition:

> Signature pedagogies are important precisely because they are pervasive. They implicitly define what counts as knowledge in a field and how things become known. They define how knowledge is analyzed, criticized, accepted, or discarded. They define the functions of expertise in a field, the locus of authority, and the privileges of rank and standing … these pedagogies even determine the architectural design of educational institutions, which in turn serves to perpetuate these approaches. (Shulman, 2005, p. 54)
>
> In each of the VET sites we have described, a central aspect of students' learning appears to be a process of orientation to a particular identity, a sense

> of what makes 'the right person for the job'. We term this 'vocational habitus'. Vocational habitus proposes that the learner aspires to a certain combination of dispositions demanded by the vocational culture. It operates in disciplinary ways to dictate how one should properly feel, look, and act, as well as the values, attitudes and beliefs that one should espouse. As such, it is affective and embodied, and calls upon the innermost aspects of learners' own habitus. (Colley, James, Diment, & Tedder, 2003, p. 484)

Of course, neither of these perspectives imply that the pedagogies they describe are the best available, or even necessarily appropriate – the perpetuation of class- and gender-based roles through the inculcation of vocational habitus is one of the themes of the paper by Colley et al. They are discussed here for their potential as a means of analysing pedagogies, and suggesting ways of working with trainee teachers that might interrupt as much as reproduce the dominant pedagogies within their fields. As a richer and more deeply theorised concept, vocational habitus probably has more to offer in this respect, whilst the idea of signature pedagogies appears so far to have been little used in discussions of non-professional vocational education. An exception is the recent conference paper by Lucas (2015), which links signature pedagogies to work on expansive learning, with the aim of supporting a more theorised rethinking of teaching and learning in an 'expansive' version of vocational education (see also Lucas et al., 2013).

Theorisations of teacher learning in FE and Skills have been dominated by the idea that learning – particularly professional learning – is best conceptualised as a social rather than individual activity (James & Biesta, 2007; Hodkinson, Biesta, & James, 2008; Hager & Hodkinson, 2009). A social theory of learning, according to Wenger (1998, p. 5), integrates four interconnected components:

(1) community ("learning as belonging");
(2) practice ("learning as doing");
(3) identity ("learning as becoming"); and
(4) meaning ("learning as experience")

Because learning transforms who we are and what we can do, it is an experience of identity (trans)formation (Billett & Somerville, 2004). It is therefore not just an accumulation of skills and information, but a process of becoming – to become a certain person or, in a vocational context, a practitioner whose knowledge, skills and values are shared with others in the same field. It is situated, institutionally, geographically, historically and culturally rather than being abstract and delocated.

> Viewed as an experience of identity, learning entails both a process and a place. It entails a process of transforming knowledge as well as a context in which to define an identity of participation. (Wenger 1998, p. 215)

However, the situatedness of learning as becoming means that certain practices and conceptions associated with a specific occupation may be open to critique, so that learning as becoming cannot be accepted uncritically (see, for example, Colley et al., 2003).

7. FROM LITERATURE REVIEW TO INTERVENTION DESIGN

Given the complexity of subject-specialist pedagogy and the limited time available for the intervention, we decided to focus on the central, shaded region in Figure 3. This region is crucial to teachers' pedagogical decision-making and reflects those areas where they can exercise greatest autonomy, and therefore provides the greatest potential for impact. We also decided to rule out developing teachers' subject knowledge *per se*, for reasons of time and the diversity of the expected participant group. The remaining region can therefore broadly be described as representing pedagogical content knowledge, and our assumption is that improving PCK will improve teachers' pedagogical decisions.

In relation to PCK, we aimed to first introduce participants to the concept, but more importantly to develop and improve PCK. As discussed earlier, empirical studies of PCK indicate that Content Representation activities, which encourage teachers to think about what, how and why students learn within specific topics in their specialist area, are effective tools for improving PCK. We therefore decided that PCK activities would be a key part of the intervention. The idea of PCK, and its development through Content Representations, constitutes Theme 1 of the intervention.

Within technical education programmes, learning must be securely related to the workplace, so that PCK in FE must involve teachers knowing how to recontextualise scientific and technical content, and also being able to develop recontextualising abilities in their students. This underpins the rationale for including the recontextualisation concept in the intervention, supported by purpose-designed video learning materials to illustrate the idea in practice. Whilst recontextualisation in Guile's model provides a framework for understanding how students and teachers might make sense of the relationship between work and vocational education, Bernstein's conception of recontextualisation provides an underpinning for attempts to challenge existing models of pedagogy, and existing distributions of power and participation within vocational education – particularly in terms of race, gender and class. Recontextualisation, drawing on both of these models, forms Theme 2 of the intervention and provides a way of theorising and critiquing more concrete and specific connectivities between educational and work settings, which constitutes Theme 3.

Finally, knowledge of learner development in the occupational area is a key part of PCK for FE. This includes cognitive development, which is addressed through Content Representation activities – including identifying potential misconceptions – but also personal development. For this reason, we also included the idea of learning as becoming, which captures the notion of learners developing an occupational identity as part of their learning at college and in the workplace.

SECTION TWO: EMPIRICAL STUDIES

8. BACKGROUND

This section of the review explores the empirical research relating to generic pedagogy and subject-specialist pedagogy (including PCK). The earlier discussion about definitions is set in the context of this work. The methodological details of the studies are then examined. The objectives are to establish:

- How pedagogical concepts have been defined by researchers in devising their studies
- How pedagogical practices have been identified as effective
- What methodologies and methods have been used to explore and evaluate different approaches
- What we can learn from the strengths and weaknesses of previous studies that will help steer our programme development, implementation and evaluation

There is a dearth of FE-based empirical studies concerning pedagogy and PCK. James and Biesta (2007) describe FE as "chronically under-researched" (p7). As a result, most of the research cited here has been carried out at the level of secondary rather than tertiary education. Even within the tertiary sector, it is much more common to study the university rather than the FE setting. Where relevant, work in primary or early years settings has also been included, since it is not unreasonable to assume that some generalisation is possible across educational contexts. This is confirmed by Faraday et al. (2011) in their report on vocational education, based on a literature review and observation of vocational sessions in eight English FE colleges judged "outstanding" by Ofsted. They conclude: "There was little evidence that vocational teaching and learning was fundamentally different from any other type of teaching and learning except in one respect – that of context" (p2).

Similarly, Entwistle and Walker (2000) maintain that HE teaching has many elements in common with teaching more generically. They believe that, although higher education literature focuses more on conceptions of learning and teaching and schools on teachers' knowledge and beliefs, the two have been separated unnecessarily. Kane, Sandretto and Heath (2002) also express concern at the under-use of examples from primary and secondary education to inform research into teacher beliefs in tertiary education. They call for research that compares the formal training for teachers entering pre-service primary and secondary programmes with learning to teach "on the job" in the university context. Within the profession, however, such comparisons may be resisted. For instance, Kember (1997) claims that "many university lecturers consider themselves a breed apart from school teachers. Indeed many university academics hardly consider themselves 'teachers' at all, instead visualising themselves more as a member of their discipline" (p. 255).

There are some limited examples of learning from schools being used in other forms of education. Nind (2015) applied the ten principles for effective pedagogy derived from the ESRC Teaching and Learning Research Programme (TLRP), mainly drawn from school-based research literature, to develop a programme for teaching advanced social science research methods aimed at researchers. Sandretto, Kane and Heath (2002) based their training programme for novice HE lecturers on research into the beliefs and practices of primary and secondary school teachers.

Nonetheless, the context of a study is important. In addition to educational level, considerations include the subject (much of the literature is based on academic rather than vocational courses, especially secondary science and mathematics) and degree of teacher experience (pre-service trainees tend to be over-represented because they are more easily accessed for studies).

9. REVIEWS OF EFFECTIVE PEDAGOGY

Before exploring approaches to improve pedagogical practice, it is essential to establish what represents effective pedagogy and how it can be identified. Elements that are considered important contributors to effective pedagogy need to be clearly identified, along with evidence that supports such claims.

There was little within the literature that grounded lessons about good pedagogy in research evidence until Goe, Bell and Little (2008) published a synthesis of studies that assessed teacher performance. Integral to this was clarifying what constitutes effective teaching. In 2011, James and Pollard produced a summary of a large research programme funded by the ESRC: "TLRP's [Teaching and Learning Research Programme] ten principles for effective pedagogy". Subsequently, two reviews of the research literature were published, the titles of both being framed as questions: "What makes great pedagogy?" (Husbands & Pearce, 2012) and "What makes great teaching?" (Coe et al., 2014). Inevitably, these reports are influenced by the purpose behind their publication and the criteria against which they measure effectiveness of teaching or pedagogy.

The review by Goe et al. (2008) was compiled for US policy makers to increase the understanding of what comprises effective teaching, how it is usually assessed and the strengths and weaknesses of these measures. After consulting research literature, policy documents and experts in the field, the authors proposed five broad characteristics of an effective teacher:

- Has high expectations of the students and helps them all to learn (measured for example through student tests)
- Contributes to positive academic, attitudinal and social outcomes (attendance, progress up the school, co-operative behaviour etc)
- Uses diverse resources, formative monitoring of progress, and many evidence sources to evaluate learning
- Enables diversity and civic-mindedness to be valued
- Collaborates with others (eg teachers, parents) to ensure student success (especially those with special needs or at high risk of failure)

According to the authors, this range of factors is not reflected in the literature. Most of the effectiveness research that they examined focused on the first point (student test performance), even though it would be possible to develop indicators for the other characteristics.

The subtitle of the Husbands and Pearce (2012) review "What makes great pedagogy?" is "Nine claims from research". Unfortunately, they give no detail about how the research was selected or assessed. They conclude that effective pedagogies (they use the plural to reflect the variety of pedagogical practices found in different classrooms) meet the following requirements:

- Give serious consideration to pupil voice
- Depend on behaviour (what teachers do), knowledge and understanding (what teachers know) and beliefs (why teachers act as they do)
- Involve clear thinking about longer term learning outcomes as well as short-term goals
- Build on pupils' prior learning and experience
- Involve scaffolding pupil learning
- Involve a range of techniques, including whole-class and structured group work, guided learning and individual activity
- Focus on developing higher order thinking and metacognition, and make good use of dialogue and questioning in order to do so
- Embed assessment for learning
- Are inclusive and take the diverse needs of a range of learners, as well as matters of student equity, into account

Using the yardstick that effective pedagogy should lead to students' progress in whatever outcomes are valued (not necessarily academic attainment), and drawing primarily on school-based research, the report by Coe et al. (2014) lists six indicators of effective teaching:

- Content knowledge (especially PCK) ie subject material and how students think about it, including misconceptions
- Quality of instruction eg questioning and assessment, scaffolding
- Classroom climate eg teacher/student interactions
- Classroom management eg behaviour, resource use
- Teacher beliefs eg why teachers adopt particular practices and what their theories of learning are
- Professional behaviours eg reflection, undergoing professional development

According to Coe et al. (2014), there is strong research evidence to support the impact on student outcomes of the first two elements (content knowledge and instructional quality), moderate evidence for the next two (classroom climate and management), and limited evidence for the final two (teacher beliefs and behaviours).

The James and Pollard (2011) publication differs from the other reviews because it draws on findings from the ten-year ESRC Teaching and Learning Research Programme rather than a literature review. From their reflections, they identify ten principles of effective pedagogy. These can be mapped to different elements of our four-part model (p14). Two relate to "pedagogy as content":

- Equips learners for life in its broadest sense
- Engages with valued forms of knowledge

Another two principles describe how teachers should operate with regard to students' background in the topic, and make it more accessible to them, thus supporting "pedagogy as knowledge":

- Recognises the importance of prior experience and learning
- Requires learning to be scaffolded

A further four are linked to the element "pedagogy as process", that is, how it unfolds inside (or outside) the classroom:

- Needs assessment to be congruent with learning
- Promotes the active engagement of the learner
- Fosters both individual and social processes and outcomes
- Recognises the significance of informal learning

The remaining two principles are that effective pedagogy (a) depends on professional development for teachers and trainers, and (b) demands consistent policy frameworks with support for continual learning as their primary focus. Neither of these fits comfortably within our proposed framework, and arguably they are preconditions for effective pedagogy rather than features of it.

The reviews differ in some of their underlying philosophy. Goe et al. (2008) criticise the practice of defining teacher effectiveness by gains on student test scores. They argue that, although attractive because straightforward to measure, there are two main drawbacks: it ignores the impact on student performance of factors unrelated to the teacher and it wrongly confines a teacher's influence to academic outcomes. This contrasts with Coe et al. (2014), who declare that "there must be some evidence linking the approach with enhanced student outcomes" to include it as an example of great teaching (p11). Whilst stating that this could be any outcome of educational value, nonetheless their report tends to focus on learning gains.

A few studies explore the characteristics of "effective" teachers who have been selected solely on the basis of their students showing superior learning gains. For instance, Askew, Brown, Rhodes, Wiliam, and Johnson (1997) classified primary school teachers as highly effective if their pupils had, during the year, achieved a higher average gain in numeracy than other classes from the same year group. Similarly, Stronge, Ward and Grant (2011) chose their sample of "effective" teachers from those whose students had the most improved mathematics and English test scores over a two-year period. This creates a tension within their study, since the authors acknowledge that effectiveness is "an elusive concept to define" (p. 340).

There are further contradictions around specific claims. For instance, Husbands and Pearce (2012) describe the evidence that effective pedagogy considers pupil voice as "robust" whilst Coe et al. (2014) claim that there is insufficient data to link it causally to an improvement in pupil outcomes. Furthermore, Coe et al. argue that non-modifiable characteristics have no place on a list of effective practices. This is their reason for excluding "great teachers have high expectations", one of the criteria cited by Goe et al. (2008), because they claim no strategy exists to raise teachers' expectations.

The reviews discussed here have similarities as well as differences. All identify scaffolding of learning and assessment of pupils as integral to effective pedagogy. Further common features, each mentioned in three reviews, are: recognising the importance of pupils' prior learning; factors relating to wider citizenship (being inclusive, valuing diversity); and enabling individual and group learning.

10. DEFINING CONCEPTS IN EMPIRICAL STUDIES

The conceptualisation of pedagogy

The issues around defining pedagogy have been discussed earlier in this review, so the lack of a consistent definition in empirical studies is no surprise. Indeed, few authors explicitly describe what they mean by "pedagogy", and in many cases this can only be deduced by extrapolating from the tools used to measure it. Elsewhere, definitions can be vague, for instance "the method and practice of teaching" (Coe, Aloisi, Higgins & Major, 2014) and "the knowledge of teaching and learning" (Hechter, 2012). It is only by digging deeper into such studies that a richer conceptualisation of pedagogy becomes apparent.

Earlier in this review (p. 14-15), we identified four elements in our working definition of pedagogy:

- Content (what students are given the opportunity to learn)
- Process (what occurs to bring about learning)
- Knowledge (of teachers about pedagogical content, processes and outcomes, including their students and the learning context)
- Decision-making (how and why teachers reach decisions about what will happen in their classrooms)

The epistemological and theoretical assumptions behind researchers' definitions of pedagogy and good teaching will affect the inferences they draw.

In Table 1, studies of pedagogy have been classified according to which of the four aspects they cover. Of the 29 studies we examined in this way, most linked to one or both of two pedagogical elements (28 to process and 25 to knowledge). It was less usual for a study to encompass content (15) or decision-making (10). Those studies that incorporated decision-making tended to adopt a broad concept of pedagogy that combined all four elements of our model (eg Elmendorf & Song, 2015; Marsh, Mitchell, & Adamczyk, 2010). Four studies confined themselves to just one aspect of pedagogy, invariably process.

Sonnert, Sadler, Sadler and Bressoud (2015) defined pedagogy implicitly through a survey given to students to evaluate instructors' pedagogical practices. Factor analysis identified three groups of characteristics: teaching practices (eg quality of explanations, questioning techniques); instructional technology (eg technology type, purpose of use); and ambitious teaching (eg group work, eliciting student explanations).

James and Biesta (2007) stress the flexible nature of good pedagogy. They argued that, although there are some common characteristics in the way it is manifested, there are also significant differences based on the learning sites and cultures, and also the individual tutors. Giving pointers about how to improve pedagogy, the authors highlight the role of creativity and reflection.

In their study of undergraduates' perceptions of course effectiveness, Tamim, Lowerison, Schmid, Bernard and Abrami (2011) equate pedagogy to nine items on their questionnaire that they link together through factor analysis as relating to course structure. Of the three factors they identify, pedagogy was the most powerful in improving learning in the classroom. The nine items associated with the factor relate mainly to process (eg the instructor encouraged collaborative or group work), as well as knowledge (eg presenting students with appropriate learning challenges) and, at a very low level, content (eg the material was meaningful and relevant).

Cavanaugh and Dawson (2010) asked science experts to help them refine the professional development modules they were developing for secondary school science teachers. The "science pedagogy rubric" focused very much on the content and process dimensions, including ratings of the clarity of learning objectives, alignment of content with benchmarks, consistency with the inquiry approach, and potential to motivate users.

Table 1: Mapping empirical studies onto four pedagogical elements

Study	Teacher participants	Content	Process	Knowledge	Decision-making
Askew et al. (1997)	Primary	✓	✓	✓	
Beatty et al. (2008)	Secondary	✓	✓	✓	✓
Cavanaugh & Dawson (2010)	Secondary	✓	✓	✓	
Darling-Hammond, Newton, & Wei (2013)	Primary and Middle	✓	✓	✓	✓
du Plessis (2016)	Secondary trainees		✓	✓	
Elmendorf & Song (2015)	Primary and Secondary	✓	✓	✓	✓
Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur (2012)	Primary and Secondary		✓		
Hechter (2012)	Primary trainees		✓	✓	
Lakkala & Ilomäki (2015)	Primary		✓		
Le et al. (2006)	Primary & Secondary	✓	✓	✓	✓
Lim & Kor (2012)	Primary		✓	✓	
Marsh, Mitchell, & Adamczyk (2010)	HE (Secondary trainees)			✓	✓
Maxwell, B. (2010)	FE/LSS trainees	✓	✓	✓	✓
McCaughtry (2005)	Secondary	✓	✓	✓	✓
McGuinness, Sproule, Trew, & Walsh (2009)	Early years		✓	✓	
McKenna & Yalvac (2007)	HE	✓	✓	✓	
Moss, Jewitt, Levačić, Armstrong, Cardini, & Castle (2007)	Secondary		✓	✓	
Petrarca & Bullock (2014)	HE	✓	✓	✓	✓
Polly & Hannafin (2011)	Primary		✓	✓	
Ruthven et al. (2016)	Secondary		✓	✓	
Sandretto, Kane, & Heath (2002)	HE	✓	✓	✓	✓
Songer, Lee, & Kam (2002)	Middle	✓	✓	✓	
Sonnert, Sadler, Sadler, & Bressoud (2015)	HE		✓		
Stevens & Hoskins (2014)	HE		✓	✓	
Stronge, Ward, & Grant (2011)	Primary	✓	✓	✓	
Tamim, Lowerison, Schmid, Bernard, & Abrami (2011)	HE	✓	✓	✓	
Tomas, Lasen, Field, & Skamp (2015)	HE (EY trainees)	✓	✓	✓	
Windschitl, Thompson, & Braaten (2011)	Secondary		✓	✓	✓
Zevenbergen, Niesche, Grootenboer, & Boaler (2008)	Primary		✓		

The conceptualisation of PCK in empirical studies

As with pedagogy, the definition of PCK is contested. Unlike pedagogy, there is a large body of literature debating it in some depth. There are a few exceptions, as Depaepe et al. (2013) discovered in their systematic review of empirical studies into PCK for mathematics education: six of the 60 articles they identified failed to define the term at all. The remainder showed broad agreement on certain points: content knowledge is a precondition of PCK; it connects content and pedagogical knowledge; it deals with knowledge of how to teach; and it is subject-specific.

From small-scale case study research, Veal, Tippins and Bell (1999) conclude that content knowledge is key to PCK, and pedagogical knowledge of lesser importance. PCK develops gradually through teaching experience in a complex, non-linear way.

Gess-Newsome et al. (2011) conceptualise PCK as a combination of knowledge and practice, and attempt to measure it across different methods of data collection: teacher reflections obtained in writing and by interview, and classroom observations. The reflections focused on eliciting what the authors perceive to be key aspects of PCK: connections between concepts, why the topic was important, what students knew and what they struggled with regarding the topic, and thoughts about any alternative teaching approaches they had considered.

Van der Valk and Broekman (1999), in their investigation of pre-service mathematics and science teachers, asked the trainees to prepare a lesson. They were subsequently questioned in line with the elements of PCK defined by Shulman (1986): what prior knowledge and difficulties they expected pupils to have; what materials and activities they would use; and what teaching strategies they would employ.

In their comparative study of mathematics teacher preparation across 17 countries, Tatto et al. (2012) designed a research instrument for trainees that attempted to measure, among other elements, their mathematical PCK (MPCK). Trainees at primary and secondary level answered questions on MPCK covering:

- Judgement about the appropriateness of the teaching strategy
- Evaluation of pupil work, identifying potential difficulties
- Analysis of pupil errors
- Use of concrete representations to support learning
- Understanding of why a teaching strategy would work and how far it could be generalised
- Awareness of common misconceptions

They found that there was considerable variation between countries, but the differences were not as marked as those they found for mathematical content knowledge. They also found that MPCK was higher for those trained as primary mathematics specialists rather than generalists, and for those trained as upper and lower secondary teachers rather than lower secondary only.

Likewise, Baumert et al. (2010) found that the CK and PCK of in-service secondary mathematics teachers depended on the type of training they had received. In Germany, where the study was conducted, teachers undergo preparation to teach in either the academic or non-academic track. The latter were found to be less competent in both CK and PCK.

Various measures were used by Baumert et al. to explore the link between CK, PCK and student performance in secondary mathematics. Although CK and PCK were highly correlated, they found that PCK was more strongly predictive of student progress. There were three dimensions of PCK in their test, defined as tasks (identify multiple solution paths, 4 items); students (recognise student misconceptions and so on, 7 classroom situations); and instruction (teacher knowledge of representations and explanations of mathematics problems, 10 vignettes).

Rohaan et al. (2009) used a group of experts to compile a test of PCK, which they defined as "the knowledge a teacher needs in order to make the transition from his/her own content knowledge to the knowledge and learning of pupils" (p. 332). For primary technology education, they identified the following aspects of PCK:

- Knowledge of pupils' prior knowledge, experience and (mis)conceptions related to technology
- Knowledge about the nature and goals of technology education
- Knowledge of pedagogical approaches and teaching strategies for technology education (p. 332)

The format of the test was to present teachers with a series of classroom scenarios and ask how to take each one forward choosing from four options. The responses were taken to represent 'high PCK', 'low PCK', exclusively pedagogical knowledge and exclusively content knowledge (both classed as 'no PCK').

Schmidt et al. (2007) divided mathematical PCK into instructional planning (before the teaching session); student learning (the learning processes in the classroom); and curricular knowledge (understanding how to sequence the development of student competence in the subject). They developed content and pedagogical knowledge scales to explore trainees' mathematical pedagogy, including questions asking them to identify and explain mistakes in students' work.

Various studies have explored the element of PCK that comprises teachers' understanding of students' difficulties or misconceptions. For instance, Viiri (2003) asked three engineering teachers in a Finnish polytechnic to provide their expectations of student answers and reasoning in an open-ended test on moments of force. The test was completed by 100 students. Although teachers proved quite good at predicting the answers, they were surprised by the reasoning behind any misconceptions. Williams (2007) administered a test to mathematics teachers and their pupils, asking the teachers not only to complete the questions but also to predict how difficult their pupils would find them, the type of mistake they would make, and how they would teach to overcome such issues. Teachers were more likely to struggle with this when they shared the misconception or assumed students needed more advanced content knowledge than was actually necessary. Similarly, Sadler, Sonnert, Coyle, Cook-Smith and Miller (2013) administered a multiple choice test to physical science teachers, asking them both to answer it and to predict what mistakes their students would make. They concluded that, although the teachers had reasonable content knowledge, they struggled to identify common student misconceptions.

Lee and Luft (2008) investigated conceptualisations of PCK through case studies of four experienced secondary science teachers. Although there was some personalisation, there were seven common components in the way they defined science PCK. All four said knowledge of science was the most important factor, then in varying priority order they listed knowledge of goals; students; curriculum organisation; teaching; assessment; and resources.

Hill, Rowan and Ball (2005) designed a study to investigate the link between primary teachers' classroom-relevant knowledge of mathematics and their pupils' performance. Although the authors discuss Shulman's concept of pedagogical content knowledge, they seem reluctant to adopt the term, referring instead to the "mathematical knowledge for teaching" (p. 399) which is needed to work successfully in the classroom.

Mahler, Großschedl and Harms (2017) hypothesise a third category of science teachers' professional knowledge distinct from CK and PCK. They term it curricular knowledge (CuK), which has been treated by other authors (eg Loughran et al., 2001) as an integral feature of PCK. Mahler et al. aimed to assess the interrelationship of teachers' knowledge and student academic performance (as measured by system thinking performance in biology). They used researcher-devised tests with open questions with regards to PCK, which they described as knowledge of teaching strategies and knowledge of student understanding. Although they found a significant relationship between teacher PCK and student performance, there was no such link for CK or CuK. Nevertheless, as well as using their evidence to argue for topic-specific PCK in initial teacher education, the authors retain their commitment to a separate CuK.

John Loughran and colleagues at Monash University have engaged in a considerable amount of work to articulate and advance science teachers' PCK (see also p. 21). They use their Pedagogical and Professional experience Repertoires (PaP-eRs) to make explicit the tacit component of PCK, by getting the practitioner – along with other teachers and researchers as relevant – to examine in detail a particular teaching episode. Important features to consider include the classroom reality (the teaching situation including the range of student responses); teachers' thinking (about content and student responses); student thinking (the links they make or fail to make); and how and why the content affects the teaching and learning (Loughran et al., 2001).

The Monash team also developed the Content Representation (CoRe) which considers a specific topic area or key idea and asks students to consider various aspects of it. These include why it is an important concept, what elements must be learned, and potential difficulties students may encounter (see p. 54 onwards for more detail).

The conceptualisation of espoused and enacted practices

A crucial distinction, increasingly discussed in the literature, is the contrast between espoused and enacted practice. These are, respectively, what teachers describe to others and use in their planning, and what they actually do in the classroom. The latter may be tacit, leaving teachers unable to articulate it because they are not consciously aware of it (Kane et al., 2002). In their literature review of studies into teaching at university level, Kane et al. found that in most cases beliefs had not been distinguished from practices. Many studies ignored what was actually happening in the classroom so that what teachers say they do was privileged over what they actually do, risking "telling only half the story" (p. 184).

Contradictory evidence exists as to whether espoused pedagogy is, in fact, reflected in the classroom. Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur (2012) and Lim and Kor (2012) are among those who claim that it is. However, participants in both these studies had been selected as teachers of a particularly high standard. This may explain why their conclusions differ from those of other researchers (Petrarca & Bullock, 2014; Polly & Hannafin, 2011) who found that - among motivated but otherwise unremarkable teachers - espoused beliefs were not always carried through into practice.

In his review of the literature on teacher educational research, Fang (1996) found that, where studies were based on hypothetical written tasks and teacher self-report, there was a strong sense that beliefs were enacted in the classroom. However, when more authentic research methods were used, such as classroom observations and stimulated interview, there was much more inconsistency between beliefs and actions. Fang concluded that classroom realities such as student needs, relationships, school culture and the curriculum led to teachers failing to translate their beliefs into practice.

This was also the conclusion of a more recent study. Petrarca and Bullock (2014) were early-career teacher educators looking to examine their own pedagogy more closely. Together they conducted a self-study, interviewing each other as well as engaging in collaborative writing and keeping personal journals. They concluded that they had been underestimating their trainee school teachers' ability to connect theory with practice. Instead the challenge, which they themselves shared when teaching the trainees, was to find the time and opportunity to enact the espoused ideals in the classroom.

Two more small-scale studies underline both the difficulty of translating espoused beliefs into enacted practice and the unreliability of teachers' self-assessment. One was conducted by Polly and Hannafin (2011). They studied two elementary school teachers undergoing professional development in learner-centred pedagogies. Videos of lessons belied teachers' beliefs that their instruction was becoming learner-centred showing them being more didactic and using less higher-level questioning than they thought. Even hands-on activities were used in a teacher-directed manner. Exceptions, such as when the lesson was co-planned with experienced project staff, led the authors to conclude that the amount of support and scaffolding necessary to bring about change in practice was considerable.

Du Plessis (2016) undertook case studies of four trainee teachers to look at the use of ICT in science classrooms and to compare teacher beliefs (espoused theories) with their classroom practice (enacted pedagogy, or what he termed "theory-in-use"). He found that, although the trainees claimed to promote learner-centred classrooms, data from their own responses, lesson plans and lecturer feedback showed them using ICT tools in a teacher-centred way. Du Plessis suggested this may have happened because the trainees' own experiences (in their lectures and at their placement schools) were in teacher-led environments, and their inexperience and possible lack of confidence may have steered them towards teaching approaches with which they were more at ease.

Ertmer et al. (2012) investigated how the pedagogical beliefs of 12 award-winning teachers matched their classroom technology practices. The findings showed a close alignment between beliefs and practices, in contrast to previous research. The authors suggest this might be because of ever-increasing access to computers, more digitally-aware students who teachers understand better, and the curriculum being more focused on 21st century skills. However, the research relied heavily on teacher self-report rather than actual observation. Other studies (Du Plessis, 2016; Polly & Hannafin, 2011) demonstrate that such evidence can be misleading.

Lim and Kor (2012) also studied exemplary teachers (six from primary mathematics who had received Malaysia's "Excellent Teacher" award). They used lesson observation, post-lesson interview and a reflective workshop. Five features that all these teachers held as espoused values of an effective lesson emerged, and these were also enacted in the classroom. The five were: meeting teaching objectives, pupils' improved cognitive development, pupils' interest and enjoyment, an emphasis on low attaining pupils, and ensuring active participation.

One of the aims of Sandretto et al. (2002) was to encourage 11 inexperienced science lecturers to make explicit their tacit theories about teaching without these being changed by the process of elicitation. After a set of initial interviews, participants underwent a course of ten weekly 2-hour sessions featuring videos of "excellent" science lecturers' teaching. The students then discussed what they had watched before listening to the filmed teachers' self-assessment of their practice. Stimulated recall interviews, featuring video clips of course participants' own teaching, followed. The evaluation concluded that the programme had been successful in helping the novices to express the intentions and beliefs that lay behind their teaching and to reflect on their practice.

So and Kim (2009) used the theoretical underpinning of technological pedagogical content knowledge (TPCK) to explore the challenges presented in designing technology-integrated lessons. They asked pre-service teachers to design lessons based on their knowledge of technology, content and pedagogy but found that participants struggled to translate their pedagogical understanding (espoused TPCK) into their lessons (in use TPCK).

Having completed a systematic review of PCK in mathematics education research, Depaepe et al. (2013) conclude that the distinction between static and situated definitions of PCK is important. Proponents of the static form of PCK conceptualise it as more explicit and cognitive, akin to Shulman's model (cross-ref to p. 21). They consider that PCK exists in a teacher's head, is separate from content knowledge and general pedagogical knowledge, and so has only a limited number of components. They believe PCK can be measured independent of context, for instance through a test. On the other hand, those who favour the situated perspective maintain that PCK is only meaningful in the classroom context, ie as "knowledge in action". It is multidimensional and the decisions made by teachers are based on subject-specific and pedagogical considerations. These researchers see classroom observation (perhaps with an element of teacher reflection) as fundamental to the exploration of PCK.

Kirschner, Borowski, Fischer, Gess-Newsome and von Aufschnaiter (2016) took account of both perspectives on PCK in the design of their study of the professional knowledge of physics teachers. They distinguished between three types of teacher professional knowledge:

- Declarative (facts, rules and principles) eg a teacher's ability to predict students' likely misconceptions in a topic

- Procedural (what to do in specific situations) eg how to continue a lesson after a failed experiment
- Conditional (knowing the reasons for different rules and processes and being able to judge different teaching situations) eg knowing the reasons for using experiments in lessons

Alonzo and Kim (2015) explicitly differentiate between declarative PCK (which teachers use in lesson preparation) and dynamic PCK (how the teacher acts during the lesson). Their study aimed to explore the use of videoed lessons in measuring the dynamic form in particular.

Even among researchers who recognise the existence of two such facets of PCK, pragmatic considerations can preclude studying it holistically. Despite acknowledging that PCK encompasses both what a teacher knows about teaching a particular topic and what actually happens in the classroom, Aydeniz and Kirbulut (2014) chose to measure only one of these:

> We chose to focus on espoused PCK only because measuring enacted PCK is very labour intensive and time consuming and like many science-teacher educators we lacked the human resources to assess 31 pre-service science teachers' topic specific PCK during enactment. (p150)

11 APPROACHES TO EVALUATING EFFECTIVE PRACTICE?

A variety of approaches have been applied to the evaluation of pedagogical practice. In their literature review, Coe et al. (2014) identify six methods used to explore pedagogy. They judged that three of these had moderate validity in assessing teacher effectiveness: observations (by peers, head teachers or external evaluators); value-added models (measuring the improvement in relevant student outcomes); and student ratings. They found only limited evidence for the validity of head teacher judgement; teacher self-report; and classroom artefacts and teacher portfolios. An earlier review by Goe et al. (2008) had reached similar conclusions (Table 2) but it should be noted that the two studies are not entirely independent since the Coe review used the previous work as one of its information sources.

Goe et al. (2008) used six criteria to evaluate the available measures. These were:

- Comprehensiveness (how many aspects of teacher effectiveness the instrument measures)
- Generality (scope of applicability)
- Utility (how appropriate for a given purpose)
- Practicality (of administration)
- Reliability (the consistency of the measure)
- Credibility (how convincing it is to stakeholders)

Table 2: Approaches to evaluating teacher effectiveness

Approach	Background	Goe et al. (2008)	Coe et al. (2014)
Classroom observations	Observations of lessons (live or videoed). Protocols vary in detail and specificity.	Lack of research on using observation protocols to evaluate teachers. Validity and reliability depend on sampling and replications, protocol, and training given to observers.	Moderate validity.
Evidence provided by the teacher	Eg lesson plans, student work, teacher portfolios.	Concerns about consistency so need good protocol to ensure reliable rating/scoring of complex materials. Can assess things not observable in classroom.	Limited evidence of validity. Teacher portfolios should be avoided as content is selected by the teacher.
Head teacher judgement	Classroom observations and background knowledge.	Head teachers/principals have valuable contextual knowledge but can also be more subjective and biased.	Limited validity. Only modest correlation with other measures.
Student feedback	Mainly surveys in HE, some in schools.	Some correlation with achievement. Variable reliability and validity. Students unqualified to assess some aspects of teacher performance.	Moderate validity in HE and to some extent in schools, but some instruments better than others.
Teacher self-report	Surveys, logs and interviews.	Pro: can measure unseen elements of teacher beliefs and motivations; cheap. Con: dependent on instrument used; teacher logs often differ from those completed by researchers.	Limited evidence of validity and low reliability. Have low correlation with other measures and may suffer from social desirability bias.
Value-added models	Test score gains are used to determine how a teacher has contributed to student learning.	Low burden because tests often routinely administered. Limited diagnostic use: may indicate teacher effectiveness but no information about why/how change has happened.	Moderate validity but need to ensure outcome measure is appropriate.

In her review of PCK studies, Kind (2009) advises that in planning such research, "consideration of the PCK model underpinning the work is important, as this contributes to selection of appropriate data collection methods" (p198). Partly as a result of its multiple and multifaceted definitions, there is no single agreed way of assessing PCK.

Different constituent elements of PCK feature in different studies, although some are common across several pieces of research. These include knowledge of teaching strategies (Lee & Luft, 2008; Mahler et al., 2017; Park & Chen, 2012; Rohaan et al., 2009; Tatto et al., 2012), student misconceptions (Baumert et al., 2010; Lee & Luft, 2008; Rohaan et al., 2009; Tatto et al., 2012), and student understanding (Lee & Luft, 2008; Loughran et al., 2001; Mahler et al., 2017; Park & Chen, 2012; Rohaan et al., 2009).

Table 3 identifies the main methods used in 53 studies of teacher pedagogy and PCK referenced in this document. This is, of course, neither an exhaustive list of studies nor of methods. Several of the studies used a case study methodology and had low sample sizes.

Teacher feedback via questionnaires and/or interviews were the most common approaches to data gathering, being present in 46 projects (10 of which used both methods). Evidence from teacher documentation (such as logs and journals) was only referred to in ten instances, almost always alongside teacher interviews. Observation was also popular (27 studies). Data from students was gathered less widely than from teachers, either in the form of feedback from surveys or focus groups (8) or as attainment data (16).

Some of the teacher questionnaires incorporated tests of PCK and/or content knowledge (for instance Cavanaugh & Dawson, 2010; Hill et al., 2005; Kersting, Givvin, Sotelo, & Stigler, 2010; Kirschner et al., 2016; Williams, 2007). Other techniques were present, such as using vignettes with teachers in questionnaires or interviews (Alonzo & Kim, 2015; Le et al., 2006; Sandretto et al., 2002; Veal et al., 1999); collaborative writing exercises (Petrarca & Bullock, 2014); and CoRes (Hume & Berry, 2010; Williams & Lockley, 2012).

In addition to the mixed content of the measurement, its form and nature also varies. Some researchers use only multiple choice questions (Hill et al., 2004/2005; Rohaan et al., 2009; Schmidt et al., 2007), others require open-ended answers (Baumert et al., 2010; Mahler et al., 2017), and yet others employ a mix of the two (Tatto et al., 2012). Some combine a number of methods including semi-structured interviews, classroom observations, and analysis of lesson plans (Lee & Luft, 2008; Park & Chen, 2012). Even within a single method, approaches differ. For instance, classroom observation protocols range across a spectrum from those that are tightly timed and finely detailed, to those that lack any pre-determined structure. A grounded theory approach, where themes and patterns arise from the data rather than hypothesising in advance then seeking confirmatory evidence, is favoured in several of the observation studies.

Table 3: Instruments used to evaluate pedagogy and PCK

Publication	Aim	Observation	Teacher questionnaires	Teacher interviews	Student performance	Student feedback	Teacher documents
Alonzo & Kim (2015)	Elicit declarative and dynamic (espoused and enacted) PCK			✓			
Alonzo, Kobarg, & Seidel (2012)	Explore how teachers use their content knowledge in student interactions	✓	✓	✓	✓	✓	
Askew, Brown, Rhodes, Wiliam, & Johnson (1997)	Identify what teachers know, understand and do to be effective mathematics teachers	✓	✓	✓	✓		
Aydeniz & Kirbulut (2014)	Design a PCK measure (espoused only)		✓				
Baumert et al. (2010)	Explore how teachers' subject knowledge affects their instructional repertoire		✓		✓		
Beatty, Feldman, Leonard, Gerace, St. Cyr, Lee, & Harris (2008)	Study teacher learning and pedagogical change	✓	✓	✓		✓	✓
Cavanaugh & Dawson (2010)	Design and evaluate professional development programme		✓				
Darling-Hammond, Newton, & Wei (2013)	Assess the validity of a measure to evaluate and develop teacher effectiveness		✓		✓		
De Jong & Van Driel (2004)	Explore how trainees regard different perspectives (macro, micro, symbolic) of chemistry topics	✓		✓			
du Plessis (2016)	Explore whether teacher beliefs are reflected in their classroom practice		✓	✓			✓
Elmendorf & Song (2015)	Develop an observation tool to evaluate pedagogy and technology integration	✓					
Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur (2012)	Explore whether beliefs and practice align and if not, what are the barriers?			✓			
Hechter (2012)	Assess impact of science methods course on teachers' perceptions of signature pedagogy		✓				
Hill, Rowan, & Ball (2005)	Explore whether teacher content knowledge is linked to student achievement		✓		✓		✓
Hill, Schilling, & Ball (2004)	Develop a measure of mathematics knowledge for teaching		✓				
Hume & Berry (2010)	Investigate the effectiveness of CoRes in developing PCK	✓		✓			✓
Janík, Najvar, Slavík, & Trna (2009)	Investigate nature of teachers' PCK	✓					
Kersting, Givvin, Sotelo, & Stigler (2010)	Explore correlation between teachers' knowledge for teaching and student learning		✓		✓		
Kirschner, Borowski, Fischer, Gess-Newsome, & von Aufschnaiter (2016)	Evaluate PCK test (also measured pedagogic and content knowledge)		✓				
Kuhn, Alonzo, & Zlatkin-Troitschanskaia (2016)	Develop PCK measure for business and economics		✓				

Publication	Aim	Observation	Teacher questionnaires	Teacher interviews	Student performance	Student feedback	Teacher documents
Lakkala & Ilomäki (2015)	Explore how practice transfers between more and less experienced teachers	✓		✓			✓
Le et al. (2006)	Assess the level of reform-orientation in mathematics instruction	✓	✓	✓	✓		
Lee & Luft (2008)	Explore experienced teachers' conceptualisation of PCK	✓		✓			✓
Lim & Kor (2012)	Identify what "effective" teachers consider effective characteristics	✓	✓	✓			
Loughran, Milroy, Berry, Gunstone, & Mulhall (2001)	Investigate and describe PCK			✓			
Mahler, Großschedl, & Harms (2017)	Establish how teachers' content knowledge and PCK relate to student performance		✓		✓		
Marsh, Mitchell, & Adamczyk (2010)	Evaluate the use of live videos of classroom practice in teacher training		✓	✓			
Maxwell (2010)	Explore how trainees integrate course and workplace learning	✓		✓			
McCaughtry (2005)	Examine teacher understanding and decision-making	✓		✓			
McGuinness, Sproule, Trew, & Walsh (2009)	Evaluate implementation of new curriculum on teaching practice	✓				✓	
Moss, Jewitt, Levačić, Armstrong, Cardini, & Castle (2007)	Evaluate the introduction of interactive whiteboards, including impact on teaching and learning	✓	✓	✓	✓	✓	
Nilsson & Vikström (2015)	Explore how learning study affects teachers' professional knowledge	✓		✓			
Park & Chen (2012)	Understand how different components of PCK inter-relate/integrate	✓		✓			✓
Petrarca & Bullock (2014)	Explore impact of collaborative self-study on pedagogy			✓			✓
Polly & Hannafin (2011)	Explore how well teachers adopt practices from professional development, and whether enacted and espoused practices match	✓		✓			
Ruthven et al. (2016)	Assess impact of classroom intervention based on dialogic teaching	✓	✓		✓	✓	
Sadler, Sonnert, Coyle, Cook-Smith, & Miller (2013)	Relate teacher subject knowledge to student misconceptions		✓		✓		
Sandretto, Kane, & Heath (2002)	Evaluate professional development focusing on reflective practice	✓	✓	✓			✓
Schmidt et al. (2007)	Improve pupil performance through improving teachers' mathematics PCK		✓				
Songer, Lee, & Kam (2002)	Identify the barriers to inquiry pedagogy	✓		✓	✓		
Sonnert, Sadler, Sadler, & Bressoud (2015)	Explore how pedagogic characteristics influence student attitudes to mathematics					✓	

Publication	Aim	Observation	Teacher questionnaires	Teacher interviews	Student performance	Student feedback	Teacher documents
Stevens & Hoskins (2014)	Evaluate a teaching approach that uses primary literature sources	✓	✓		✓	✓	
Stronge, Ward, & Grant (2011)	Measure effect teachers have on student achievement and identify practices of effective teachers	✓	✓		✓		
Tamim, Lowerison, Schmid, Bernard, & Abrami (2011)	Explore how course structure, active learning and technology use relate to perceived course effectiveness					✓	
Tatto et al. (2012)	Compare policy and practice in mathematics teaching cross-country		✓				
Tomas, Lasen, Field, & Skamp (2015)	Explore how blended learning affects knowledge and engagement		✓	✓			
Van Der Valk & Broekman (1999)	Use a lesson preparation task to investigate teachers' PCK			✓			
Van Driel, Verloop, & de Vos (1998)	Explore the value of PCK as a concept in science teaching	✓	✓		✓		
Veal, Tippins, & Bell (1999)	Describe evolution of PCK in trainee physics teachers	✓		✓			✓
Williams (2007)	Audit and evaluate teacher pedagogy		✓		✓		
Williams & Lockley (2012)	Examine the effectiveness of CoRe in enhancing PCK			✓			
Windschitl, Thompson, & Braaten (2011)	Discover what is useful in enhancing classroom practice and who benefits from tool-based approaches	✓		✓			
Zevenbergen, Niesche, Grootenboer, & Boaler (2008)	Develop a tool to evaluate reform pedagogy	✓					

Teacher self-report

Teacher self-report can be obtained from interviews, focus groups, surveys and reflective diaries among other instruments. They are cost effective and relatively easy to implement, making them among the most commonly used tools in pedagogical research.

However, there are methodological issues around the use of self-report. Coe et al. (2014) claim that all such tools "have only modest correlations with other measures of effectiveness" (p36). The key concern is inaccurate reporting, arising consciously or unconsciously. For instance, teachers can deliberately mislead by over-claiming use of certain pedagogical approaches which are seen as professionally approved methods. Or they might genuinely misinterpret their own practice as representing the strategy they are being asked about. This latter point underscores the importance of establishing a shared language between the researchers and the researched. Goe et al. (2008) also reports research where teacher- and researcher-completed logs do not correspond. Possible explanations include researchers' inadequate understanding of the classroom context or different interpretations of terminology. In conclusion, Goe et al. recommend that self-report methods in education should be subject to further examination, and advise that they should never be used as the sole source of data.

Similar conclusions have been reached in unrelated fields. For instance, Paulhus and Vazire (2007), referring to the use of self-report in personality psychology, conclude that it has advantages (gaining information and insights unique to this perspective) and disadvantages (responding to fit socially desirable norms). They stress that being able to corroborate with other methods is essential to improve confidence in this type of data.

Le et al. (2006) assessed the impact on teachers of reform-oriented teaching, which they defined as "a collection of instructional practices that are designed to engage students as active participants in their own learning and to enhance the development of complex cognitive skills and processes" (piii). They used teacher self-report (surveys and interviews) as well as classroom observations by trained researchers. The observation logs indicated the teaching practices being used were much more traditional than what was claimed in the survey. The authors discuss a number of explanations. These include: the observations were a one-off measure whereas teacher reports were collected over a longer timeframe; teachers mistakenly believed that they were implementing some of the reform strategies because they had a false understanding of what they comprised; and teachers defaulted towards the more conventional methods because of curricular pressures.

A lack of consistency between self-report and independent data also emerges in the exploration of classroom practice by Stronge et al. (2011). They divided a group of primary level teachers into more and less effective based on student achievement data. Participants were observed in the classroom by pairs of trained observers unaware of their "effectiveness" categorisation. They also self-rated their capabilities as regards instructional strategies, student engagement, and classroom management. There was no statistical difference between the "more" and "less" effective teachers on the self-rating, although the independent observations found significant differences on some dimensions.

Askew et al. (1997) were also interested in differentiating between the characteristics of effective and non-effective teachers. An initial questionnaire gathered background information on how participants planned and carried out their teaching, their training/CPD experience and their beliefs around numeracy and teaching mathematics. Semi-structured interviews probed these areas in greater detail, drilling down into their beliefs and awareness of good practice in teaching numeracy, and exploring discrepancies between their self-perceptions and findings from the lesson observations. The research tackled two other areas. Teachers drew concept maps to show how mathematical ideas inter-relate to probe their mathematical understanding. To discover how they interpreted pupils' learning, teachers were asked to think about triads of their pupils and identify a series of ways in which two members differed from the other one in their understanding of numeracy. This was done repeatedly and with different trios of pupils until a set of personal constructs was built up.

In her scoping study of how in-service trainee teachers construct knowledge and what knowledge they need in their everyday practice, Maxwell (2010) interviewed eight trainees from the FE or voluntary sector. She found that they drew on three areas. Firstly, knowledge of their subject/vocational area (gained from professional learning/experience and updating). Secondly, knowledge of generic teaching and learning processes (from participation in teaching and ITE, interaction with others, and embedded "ways of doing things"). And thirdly, their insight into specific learners and groups. Their existing beliefs, values and experiences were also a crucial influence.

De Jong and Van Driel (2004) examined the development of trainee secondary teachers' PCK , which they defined as knowledge of teaching difficulties and student-learning difficulties. They followed between two and four lessons taught by each of eight participants on a specific topic. Trainees were interviewed before the lesson about their lesson plans, anticipated student conceptual problems and likely issues in teaching. A post-lesson interview followed up on these themes.

Self-report through interviews and surveys is commonly used to gain detailed insight into the reaction to an innovation. It might be possible to measure impact in another way, but to discover how an initiative has been enacted and received it can be invaluable to obtain detailed feedback from implementers.

Teacher interviews and surveys were among the techniques used by Moss et al. (2007) to evaluate the impact of whiteboards on classrooms. In the initial interview, teachers talked about their perceptions and deployment of whiteboards. The second interview followed a lesson observation, and selected texts or resources from the lesson were used to prompt participants to reflect on their practice. The survey looked at teachers' use of the technology (frequency and purpose), what training they had received and their perceptions of and attitudes towards the interactive whiteboard, assessed via a series of agree/disagree statements.

Lakkala and Ilomäki (2015) conducted in-depth interviews with their case study teachers after a tutoring procedure to transfer practice from more experienced to novice teachers. Questions covered how the process had worked, how useful the resources and activities were, what the impacts of the training model were, and any suggested improvements.

To tap into how teachers responded to a technology-rich initiative in middle school, Songer, Lee and Kam (2002) included post-programme interviews with six of those taking part in the programme. Participants described what they had expected from the intervention, how it had operated in practice, and their perception of its impact on students.

Stevens and Hoskins (2014) administered pre- and post-training surveys to university teachers who were being introduced to a strategy designed to help their students access and critically engage with science literature. The questionnaires assessed the impact of the course on college tutors' likelihood to use various teaching approaches (eg small groups, establishing students' prior knowledge and misconceptions) and on their attitudes to science teaching (eg ability to understand related literature, appropriateness of different teaching methods for particular outcomes). They concluded that their workshops had changed participants' views about science education and teaching approaches.

Another study in the HE context (McKenna & Yalvac, 2007) relied on interviews with staff from five varied engineering faculties to examine pedagogy in the discipline. From these they identified some promising practices, but concluded that there was an over-emphasis on teacher-centred approaches because that is what the lecturers themselves had experienced.

Barnett and Hodson (2001) used interviews with six middle school science teachers to trial their model of pedagogical context (stet) knowledge. It proposes that exemplary science teachers draw on a mix of academic and research knowledge, pedagogical content knowledge, professional knowledge, and classroom knowledge.

Teacher tests

Numerous tests have been devised to assess teachers' professional knowledge. These vary in content, focus and format. One methodological issue is whether the assessment comprises open-ended or multiple-choice questions.

Baumert et al. (2010) decided that, to ensure validity, all their questions would be open-ended and no time limit would be imposed. The mean time taken by respondents to complete the test was two hours. Hechter (2012) also preferred the free response format. He reports an action research study exploring how pre-service elementary school teachers integrated technology, pedagogy and content knowledge in the classroom. Before and after a 12-session course on science methods, trainees were asked to give written responses to two open-ended questions. One asked for their understanding of the relationship between technology, content knowledge, and pedagogical knowledge in science teaching; the other asked how they would include this inter-relationship in their teaching.

Aydeniz and Kirbulut (2014) developed an instrument to measure pre-service teachers' PCK in the context of electrochemistry. Respondents were required to provide examples and comments linked to galvanic cells in response to a series of 30 statements related to either curriculum (eg teacher pays attention to relevance of curriculum to students' everyday lives), instruction (eg teacher uses analogies or metaphors to support explanations) or assessment (eg teacher asks open-ended questions). It took 90 minutes to complete, and was followed-up a week later by an hour's discussion among small groups of the trainees around their answers. From the tool, trainees were categorised as "naïve", "developing" or "sophisticated" in relation to their PCK. The authors concluded that the process could be used as a teaching tool to enhance topic-specific PCK of participants through developing a shared language, enhancing understanding and becoming more aware of the limitations of their own knowledge.

Kirschner et al. (2016) reported on their attempts to assess the professional knowledge of German physics teachers, focusing initially on mechanics. They developed a pencil-and-paper test divided into three areas – content knowledge, pedagogical knowledge and PCK. The paper deals with the 17, mainly open-ended, items used to measure PCK. These were categorised as representing three different types of knowledge: declarative (factual), procedural (measured primarily through vignettes describing teaching challenges) and conditional (reasoning about why particular teaching approaches are appropriate in certain situations).

Rather than following the open response approach, Schmidt et al. (2007) administered multiple-choice questions to explore mathematical PCK. Trainee teachers were given, for instance, a hypothetical student answer to a problem and asked to specify the nature of the error. Responses were used to determine the understanding of the maths content, the mathematical reasoning, and any common misconceptions.

Hill, Schilling and Ball (2004) developed and piloted multiple-choice items to measure elementary school teachers' growth in content knowledge for mathematics teaching and to explore its nature and composition. They differentiated between two kinds of teacher knowledge: straightforward subject knowledge, that any person familiar with the mathematics involved would have; and a combined knowledge of the learners and the content, including pupils' ways of thinking and common errors. Their final instrument had items covering both. An example of a teaching-specific question would be choosing between different approaches to solving a multi-digit multiplication sum, whereas one measuring wider mathematical knowledge would be solving the sum itself. A study by Hill et al. (2005) suggested that teachers who performed better on this measure had pupils who made more progress in mathematics achievement across two academic years.

Darling-Hammond, Newton, & Wei (2013) were also interested in the link between teacher and student performance. They analysed the relationship between beginner English and mathematics teachers' scores on the Performance Assessment for California Teachers (PACT) and their students' value-added performance across the year. The study focused on the final element of the PACT, for which the participant has to plan, teach and video a learning segment, analyse their own instruction and student learning, and reflect on their practice. The authors concluded that PACT scores were significant predictors of teaching effectiveness as measured by students' attainment, and that undertaking the PACT helped develop teaching effectiveness.

Kuhn et al. (2016) used a combination of open and multiple choice questions to measure the PCK of pre- and in-service vocational business and economics teachers at the secondary level in Germany. They adopted a three-part model of PCK that chimes with the model of professional knowledge described by Kirschner et al. (2016). Based on Shulman (1986), they divided PCK into three types of knowledge: propositional (basic knowledge about teaching), case (context-specific), and strategic (evaluating cases to choose appropriate action, sometimes referred to as "wisdom of practice"). Each of these has two aspects, one relating to teaching objectives, content and methods, and the other to students' learning processes. They created a 45-minute, 17-item test limited to the areas of lesson planning and responding to student statements. Only one of the three types of PCK they identified (case knowledge) was explored. They used a multiple-choice format to investigate participants' ability to analyse and apply general propositions, whereas open questions were used to address how they created solutions. Although Kuhn et al. maintained that their test was valid, they acknowledged that it was insufficient as a measure of PCK because it lacked any assessment of actual teaching performance.

Observing teaching practice

To studies such as Kuhn et al. (2016), which recognise the situated nature of PCK, finding a valid way to assess teaching practice is essential. The development and use of rigorous and relevant observation tools can form a key element of reflecting how the teacher operates in a particular pedagogical setting. Classroom observations vary in structure and detail. Sometimes they are used as a stand-alone instrument. Alternatively, they have been used in combination with pre and/or post-interviews with the deliverer(s) of the observed session. This can provide more insight into original intentions for the session and possible motivations behind subsequent actions.

It is crucial to develop an appropriate instrument to describe an observed teaching session. From their review, Coe et al. (2014) concluded that "content-specific practices tend to have more impact than generic practices on student learning" (p33). Consequently they argued that the observation tool should be partly subject-specific and partly generic. This was the approach followed by Elmendorf and Song (2015), who examined pedagogy through the lens of in-lesson technology use. An observation tool to evaluate pedagogy and technology and its integration in the classroom was developed through consultation with a range of experts. The study resulted in a list of 30 indicators categorised as pedagogical, technological or technological pedagogical. Pedagogical indicators included content knowledge, assessment, adjusting lessons to student needs and classroom management. The three technological pedagogical items measured whether and how technologies were integrated to support student learning.

Video recordings of 27 lessons taught by eight secondary school teachers on the topic "composition of forces" form the backbone of a study by Janik Najvar, Slavík, and Trna (2009) into the dynamic (in-class) nature of PCK. In their view, studying actual lessons is important because this is where PCK can be observed. The analysis of the videos was inductive, based on grounded theory, and resulted in a typology of how scientific concepts were represented (eg through experiments, symbols, words). One participant also provided a commentary on her lesson when watching clips afterwards to provide further insight into her PCK. The authors conclude that video analysis is an effective method for revealing dynamic PCK in action.

Alonzo et al. (2012) used lesson observations to explore teachers' use of content knowledge in their interactions with students. They listed the advantages of observation for examining PCK as follows: not having to rely on teachers to articulate tacit aspects of such knowledge; examining PCK where it is being applied during teacher-student interaction rather than indirectly through interviews or questionnaires; and directly reflecting the context-specific nature of PCK. In line with Stecher et al. (2006) they perceive it as the nearest to reality in a hierarchy of techniques. The researchers videoed two lessons from each of two physics teachers delivering 9th grade optics then focused the analysis on the use of content knowledge during teacher-student interactions. Within this, they identified three elements: flexibility, richness and learner-centredness. There was a short post-lesson check with teachers whose key purpose seemed simply to check that nothing had been atypical. The videos were coded using an intensive, grounded-theory-based approach, including double-coding half the videos.

In research reported by James and Biesta (2007), observations were adopted to explore what went on during teaching sessions. They used a flexible set of questions to focus the observations, and the resultant notes were shared with those observed and also fed into subsequent interviews.

A single, in-depth case study was carried out by McCaughtry (2005). He observed 38 physical education lessons taking fieldnotes rather than using a pro forma. After each lesson he conducted a lengthy (minimum 90 minutes) interview with the teacher. He concluded that the teacher based her decisions about how and what to teach on an understanding of students' social and cultural, as well as learning, needs.

In their research into the development of trainee teachers' PCK, De Jong and Van Driel (2002) audio-recorded lessons only as an additional, supporting data source because "we were interested in the student teachers' knowledge [collected via interviews], rather than in their classroom behaviour" (p482). The lesson discussions were mainly used as a means of understanding the teaching context.

Detailed analysis of classroom practice has been fundamental to studies of pedagogical good practice. For instance, a mix of observation schedules and detailed description of mathematics lessons was used by Askew et al. (1997) in their case studies of effective teachers. Some sessions were audio-recorded to allow transcription and even more detailed analysis. The variety of observation schedules was supplemented by details of the flow, content and context of lessons. The data collection and analysis took into account organisational and management strategies (eg keeping on-task and dealing with a range of attainment levels); teaching styles (quality of explanations, approaches to questioning); learning opportunities (tasks and resources); and pupil responses (how they work and how understanding is demonstrated).

Stronge et al. (2011) used classroom observations to study the practice of primary school teachers who had been identified either as higher or lower performing based on student gains in mathematics and English. Two trained observers visited each teacher for a 3-hour session. They categorised teacher and pupil questioning depending on cognitive demand, and noted the amount of time pupils spent on task. They gave each teacher a rating using an instrument developed from existing literature based on four over-arching dimensions: instructional delivery; student assessment; learning environment; and personal qualities. According to their analysis, high-performing teachers had better-managed classrooms and more positive relationships with students. There was no significant difference on instructional delivery or assessment. The authors suggest this might have been due to the low sample size.

To varying degrees, lesson observation has formed part of many evaluations. Back in 1998, Van Driel, Verloop and de Vos did some work to establish how a programme of CPD had affected science teachers' PCK. Their sample was 12 experienced secondary school chemistry teachers attending a workshop to improve the recognition of conceptual difficulties around chemical equilibrium and to encourage the use of strategies promoting conceptual change. Research data included audio-recording of lessons from two of the participants. PCK-relevant segments of the recordings were analysed by two researchers using a grounded theory approach. The authors argue that previous research has focused on the nature and development of PCK for science teaching, but its real value lies at the level of specific topics and practical experiences. According to the researchers, their study demonstrates the importance of giving trainee teachers the opportunity to study "the subject matter of specific topics from a teaching perspective" (p. 690).

Zevenbergen, Niesche, Grootenboer and Boaler (2008) constructed an observation tool to evaluate reform pedagogy, a style of pedagogy that emphasises developing understanding, problem solving and communicating ideas. To formulate an appropriate pro forma, three researchers watched a series of videos of lessons. From these, they created a means of rating the presence of key pedagogical characteristics in a lesson. Among these elements of practice were the facilitative role of the teacher, learners' control over their own learning, and the type and quality of group work.

In their study of classroom response devices, Beatty et al. (2008) aimed to observe two lessons per semester for 39 research participants across three years, each being bookended by short pre- and post-interviews to give additional context and insight. Although originally planning to code the lessons live to better appreciate the classroom dynamic, they found it impossible to adequately reflect the changes in their thinking whilst keeping to a rigid observation protocol. Instead they videoed the lessons to enable them to reflect their changing perceptions as the project progressed.

A small-scale exploration of science teaching by Nilsson and Vikström (2015) investigated the influence of a year-long learning study on teachers' thinking and behaviour. Six secondary science teachers worked in two groups to inquire into their own practice. The researchers held interviews and videoed lessons (on the same content) before and after the project. In the pre-interview, teachers were interviewed about their intended learning outcomes, instructional strategies (and reasons for their choice), and awareness of their students' prior knowledge and potential learning difficulties issues with the specific content. A few days later, with the help of video clips from their lesson, the post-interview explored teachers' awareness of the connection between the intended and enacted learning. Two researchers analysed each lesson and compared teachers' performance at the beginning and end of the project, focusing on elements such as organisation of content, examples used and how dialogue and interaction with the students influenced learning possibilities. Any changes were linked back to relevant responses in the interviews.

To assess how well college teachers had embedded information and communication technology (ICT) into their practice, Lakkala and Ilomäki (2015) analysed classroom practice using the Pedagogical Infrastructure Framework. This was developed for describing lessons involving technology-enhanced, collaborative knowledge creation. The observations were complemented by short interviews before and after the sessions, to ask teachers about the lesson goals, activities and ICT usage.

Segments of video from the teachers' classroom practice were divided into one of four categories:

- Technical (types of digital technology used)
- Social (co-constructive and collaborative practices)
- Epistemic (creation, usage and sharing of knowledge)
- Cognitive (tasks, activities and guidance used to promote pupils' cognitive engagement and metacognition)

When they compared more-experienced with less-experienced teachers, there was little difference between their performance on technical issues, but the latter spent more time organising pupils into groups rather than conducting more elaborate group work (social); tended to issue guidelines rather than encourage pupils to develop their own knowledge (epistemic); and, whilst they had similar cognitive practices, teachers with greater experience used modelling and pupil reflection more frequently.

Moss et al. (2007) used classroom observation as part of the case study element of their research into the use of interactive whiteboards. Each teacher was observed delivering a series of lessons in a particular topic area over the course of a week, allowing use of the whiteboards to be contextualised in the broader curriculum rather than separating the technology from the learning context and its purposes. A structured observation grid was designed to record the context that texts were being used in, what they were and how they were used, how pupils interacted with each other and the teacher's role in class. The grids were then analysed thematically.

In their evaluation of a dialogic teaching intervention, Ruthven et al. (2016) carried out one observation of most teachers. The observational instrument focused on nine markers of classroom dialogic activity, related to how ideas were solicited, articulated and discussed (eg "teacher draws out difference between pupils' ideas", "pupil gives a reason"). The presence or absence of the markers was noted during a sequence of 4-minute units, with the following two minutes being used for filling in the code sheet.

Songer et al. (2002), exploring the barriers to inquiry pedagogy for six middle school science teachers, observed 132 lessons in total. As well as detailing the timeline, the observation sheet recorded the participants, the classroom description, and the activities being performed.

Stevens and Hoskins (2014) trained lecturers in a strategy designed to improve undergraduates' understanding of scientific research and scientists while developing their critical thinking and analytical skills. Researchers then observed trained participants, rating the design and instruction in the session as well as the science content and nature of science coverage. There were 40 indicators in total. The Flanders Observation Protocol (Flanders, 1963) was also used to establish the degree to which the classroom was student-centred.

McGuinness, Sproule, Trew and Walsh (2009) used structured classroom observations to evaluate the implementation of a new early years curriculum in Northern Ireland. Over 140 observations were made using the Quality Learning Instrument (QLI) to explore whether teachers changed their practice in relevant ways. As the name of the measure suggests, the instrument is focused on the learning experience and the nine quality indicators are children's motivation, concentration, confidence, independence, physical well-being, multiple skill acquisition, higher-order thinking skills, social interaction and respect (Walsh et al., 2006).

Vignettes and video prompts

Vignettes provide an opportunity to recreate classroom conditions for research participants. A hypothetical or real-life situation can be described in writing or shown on video, and used to stimulate discussion of teaching decisions and choices. Although what is presented is usually standardised across the sample, vignettes provide an opportunity to respond to a fairly realistic context. Written responses are sometimes limited to a choice between options, but in other cases free-text responses are encouraged.

However, in his review of teacher education research, Fang (1996) found vignettes could be problematic because of the artificial settings, and because teacher judgements and scorer ratings lack consistency over time. In her 2009 review, Kind found far more studies that had used a real-life classroom setting rather than 'prompts' such as written or filmed vignettes to investigate science PCK. She warns that the choice of the examples used is key, because it determines the exact nature of the PCK explored.

As part of a study on reform-oriented mathematics teaching in the US (Le et al., 2006), Stecher et al. (2006) compared the rigour of four different evaluative approaches as indicators of teaching practice. In order of increasing perceived relationship to the reality of classroom practice these were surveys, teacher logs, vignettes (with set response choices) and lesson observations. Results from the vignettes and observations were similar enough to provide some supporting evidence for the validity of vignette-based measures in this context. However, the researchers found it difficult and time-consuming to create vignettes that were appropriate to, and comparable across, different topics or grade levels.

Veal et al. (1999) used two content-specific, situational vignettes to track the development of PCK in two trainees. The participants were interviewed about each vignette four times, with a gap of two or three weeks in between. The scenarios incorporated context in terms of the setting and participants, classroom interaction and dialogue, and an explanation of the problem. They dealt with pedagogical and content issues: behaviour management, multicultural issues, teaching approaches, student learning, and science content including some teaching inaccuracies. The researchers found this an insightful method of studying teachers' development of PCK. One unaddressed question about this research is how repeated exposure to the same stimulus material over a relatively short time period affected responses.

Kirschner et al. (2016) incorporated vignettes (which they describe as a common feature of German-language measures of PCK) in their 40-minute written test to assess physics teachers' procedural knowledge. Their five vignettes required mostly open-ended answers. As part of their mission to develop a comprehensive measure of PCK, the researchers recognised a need to make the vignettes more complex and to have a large bank of them, so that the teachers' own practice in terms of topic and year group taught could be matched more closely.

In their assessment tool for PCK relating to business and economics teaching, Kuhn et al. (2016) used vignettes that represented real-life classroom situations. There was a large sample (338 teachers, mostly pre-service and some in-service) based in the German vocational and high school sectors. Tasks included asking participants to amend a class exercise to make it more relevant to a particular group of students. The authors conclude that their test is valid but needs to be complemented by a video- and performance-based measure of PCK. Whereas the written task measures context-specific knowledge, they anticipate that a video or similar stimulus would assess more strategic reasoning and were working on developing such a tool.

Nicole Kersting and her colleagues have written extensively on video analysis of educational settings, mainly US secondary school mathematics classrooms. She used teachers' ability to conduct video analysis of clips from lessons as a proxy for their knowledge of teaching mathematics (Kersting, 2008). This study was developed into a larger piece of work (Kersting et al., 2010). Researchers scored teacher commentary on 13 video clips as to whether it included an analysis of mathematics content and/or student thinking, suggestions for alternative approaches, and the overall depth of interpretation. The quality of teachers' analysis was linked to both their knowledge of teaching the particular topic and their students' learning.

As part of their evaluation of a professional development programme, Sandretto et al. (2002) used video clips of exemplar teachers to prompt participants' discussion of good teaching practice, which they described as espoused theories of action. They also used stimulated recall, playing back video of participants' own teaching and asking them to explain their practice, terming this theories-in-use.

Alonzo and Kim (2015) designed some research to flush out the difference between the more fixed form of PCK (declarative) used by teachers in planning and reasoning and what they believed was a more fluid version (dynamic) employed in the unpredictable circumstances of the classroom. They too used videos to stimulate recall, playing back interviewees' own lessons so they could explain the thinking behind their actions. Acknowledging that this could reflect post-rationalisation rather than reproducing the thinking that had gone on at the time, they also asked participants to watch clips from other teachers' lessons.

Subsequent questions focused on what they would do if faced with the situations shown, in an attempt to elicit dynamic PCK by mimicking the type of spontaneous thinking teachers would have to employ in the classroom.

Marsh et al. (2010) evaluated the effectiveness of using live video-casting of lessons as a training strategy for pre-service teachers. The approach used interactive video technology to encourage reflection and allow discussion of critical moments in a lesson. Trainee science teachers watched live lessons on a video link, with explanatory commentary from a tutor. They saw experienced teachers in a variety of situations using a range of strategies, thus demonstrating "theory in action", with subsequent discussion (with the tutor and the lesson teacher) promoting the practice of reflection. The authors claim that a major benefit of videoing "was that the dynamics of the classroom were not affected as happens when observers are physically present in the school" (p272). However, it is likely that any impact was reduced rather than completely eliminated since those being observed knew that cameras were present. Thematic analysis suggested that the approach helped trainees to learn collaboratively, develop the language of pedagogy and adopt a more reflective practice.

CoRes and PaP-eRs

The techniques of Pedagogical and Professional experience Repertoires (PaP-eRs) and Content Representations (CoRes) grew out of work carried out by Loughran and colleagues to examine and develop the PCK of science teachers (p. 20). Previously they had based their research on case studies, but realised that PCK was too complex to be explained through single cases. Loughran et al. (2001) explain how the two instruments inter-relate and function together as follows:

> In concert with the PaP-eRs, the CoRe must be conceptualised as a necessary construction to codify and categorise the knowledge and content under consideration so that it might be manageable and useful for others. Well-constructed PaP-eRs should then bring this CoRe to life and shed new light on the complex nature of PCK both for teachers and educational researchers. This we see as one way of helping to create opportunities to better understand, and hence value, the specialist knowledge and skills of teachers and to make the tacit explicit for all audiences. (p. 304)

The CoRe template developed by Loughran et al (2001) is shown in Figure 4. This has formed the framework for other researchers to explore and expand PCK.

Hume and Berry (2011) were interested in how novice teachers can use the techniques to improve their practice. They found that lack of classroom experience limited the effectiveness of CoRes and, in an attempt to overcome this, designed a staged introduction. CoRe construction was supported across four 3-hour workshops involving nine pre-service chemistry teachers mainly working in small groups. The stages were as follows:

- Focus on identifying students' likely pre-existing ideas on a topic (including misconceptions)
- Identify the sequence of concepts and skills to be acquired
- Take a different topic, identify the necessary concepts and skills and 5-8 key ideas, and fill in the CoRe template accordingly
- Add resources, pedagogical strategies for addressing any misconceptions and so forth

The authors conclude that building CoRes could develop PCK in trainee teachers but this must be done via a lengthy and intensive scaffolding process.

Figure 4: CoRe template
(Loughran et al., 2001, p. 296)

	Important science ideas/concepts		
	Big idea 1	**Big idea 2**	**etc**
Why is it important?			
What do you intend the students to learn about this idea?			
Difficulties/limitations connected with teaching this idea			
Knowledge about students which influences your teaching of this idea			
Other factors that influence your teaching of this idea			
Teaching strategies (and particular reasons for using these to engage with this idea)			
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)			

Williams and Lockley (2012) built on Hume and Berry (2011) to further explore the potential of CoRes as a PCK development tool. They engaged early career secondary science and technology teachers in action research and asked each to develop a CoRe within their discipline. In the first of three phases, the teacher identified a topic and co-designed a CoRe alongside both a subject expert and a pedagogical expert. The teacher then worked with the researcher to plan and subsequently assess the impact of CoRe delivery. CoRes were less favourably received by the technology than the science teachers. Since they were designed for the science context they may be less obviously appropriate for areas that lack clearly-defined topics and involve procedural rather than conceptual knowledge. Like Hume and Berry, Williams and Lockley found the process very time-consuming. They propose that, to be scalable, the face-to-face activity may need replacing by online, collaborative workspaces.

In a two-year study of six teachers, Bertram and Loughran (2012) examined how CoRes and PaP-eRs might affect practice by influencing PCK. Despite finding the tools useful in developing their practice, teachers said they were unlikely to create their own in future because it was too laborious. The authors recommend further research on how the tools might help in specific situations, such as teaching unfamiliar content or as a training resource for pre-service science teachers.

Park and Chen (2012) designed the PCK Map as a less time-consuming alternative to CoRes. They drew a map to represent pictorially how various teaching components inter-related in the classroom practice of four biology teachers. The map used a five-element model of PCK covering: orientations towards teaching science, knowledge about student understanding, instructional strategies, the curriculum, and assessment. They developed the tool as a way of making PCK more explicit and enabling teachers to develop and reflect on their practice. The authors acknowledge that further refinement is needed as the map currently risks over-simplifying PCK. It should also be noted that, in their study, the PCK map was drawn up by the researcher without involving the teacher.

There are instances of CoRes being adopted solely as a research instrument. Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) used them in their exploration of subject matter knowledge within PCK. The researchers constructed CoRes for each case study teacher from data collected through lesson observations and interviews. The CoRes were analysed to help unpack key elements of PCK and allow the authors to interpret the role of subject matter knowledge, showing that the teachers prioritised procedural approaches over conceptual understanding.

Student feedback

Student feedback seldom featured in the studies examined for this review. Although Coe et al. (2014) found evidence that such feedback had moderate validity, Goe et al. (2008) warned that its reliability and validity was variable and that it was inappropriate for assessing some features of teaching. Similarly, Blackmore (2009) was concerned that student evaluations focused on the outward manifestations of pedagogy rather than the processes lying behind it, such as reflective and dialogic practice, that are not necessarily so visible to students.

Moss et al. (2007) carried out lesson observations and conducted focus groups with secondary school pupils to gather opinion about the lessons they were evaluating, including content, purpose and typicality. A pupil questionnaire about the use of and attitudes towards ICT and interactive whiteboards was also administered. Although these methods yielded other useful information, the pupils did not pick up on issues the researchers identified around lesson sequencing.

As part of their mixed methods evaluation of a blended learning module on science and sustainability education for trainee teachers, Tomas, Lasen, Field and Skamp (2015) administered an online student survey and held semi-structured interviews. The questionnaire was a mix of open and closed questions (eight in total) covering opinions of the teaching strategies, what the most and least effective aspects were, what other learning approaches they would have valued, and so on. The interviews probed aspects such as learning processes, online pedagogies and assessment tasks.

Makri, Papanikolaou, Tsakiri and Karkanis (2014) delivered a 6-month course on Technology Enhanced Learning through e-learning and face-to-face teaching. A 34-item survey of the students, who were pre-service teachers, gathered feedback on different aspects of the module: social (eg "online discussions help me to develop a sense of collaboration"), cognitive (eg "problems posed increased my interest in course issues") and teaching (eg "the instructor clearly communicated important course goals"). Each item was rated on a 5-point Likert scale for degree of agreement. Transcripts of asynchronous discussions from student forums constituted another source of data.

Examples of mixed methods

Many of the empirical studies mentioned employed a mix of qualitative and quantitative methods, ranging from focus groups and questionnaires to lesson observations to high-stakes public examinations. Although this allows triangulation by comparing findings across methods, the intensity and relatively high cost of data collection often leads to limited sample sizes. A few illustrative examples, drawn from studies already cited in the report, follow.

In their study of teacher effectiveness, Askew et al. (1997) used a predominantly case study approach, with the methods built up in layers. There was an initial blanket teacher survey in 11 participating primary schools, mostly selected as having existing effective practices in mathematics teaching. Pupils completed mathematics tests towards the beginning and end of the school year to calculate learning gains, which were then used to classify the 18 case study teachers (already identified with the help of the head teachers) by effectiveness. These teachers each had three lessons observed and participated in three interviews, one after each lesson observation. Additionally, their head teacher was interviewed based on issues arising from the teacher data. Teachers were also engaged in a concept mapping exercise using terms related to numeracy, to explore more deeply their mathematical understanding.

The aim of Le et al. (2006) was to measure the impact of reform-oriented teaching (designed to actively involve students in their own learning) in elementary and middle schools. Because the researchers were interested in different aspects of the teaching and learning, they used several measures. To assess teachers' understanding and engagement, they used teacher surveys, logs, interviews and classroom observations as well as responses to vignette-based questions. A range of assessment tests was administered to record student achievement. The study was unusually large scale, with a target of 20 schools in each of five regional cohorts, and on the whole these numbers were achieved.

Ruthven et al. (2016) reported on an intervention based around introducing dialogic teaching in mathematics and physical science classrooms at the early secondary level. The success of the pedagogical approach was based on three variables (learning gain, opinion of the module and shift in attitudes). These were assessed by pupil knowledge tests along with subject opinion and attitude questionnaires, as well as one lesson observation of most teachers and a teacher questionnaire. They achieved a sample of 34 mathematics and 36 science teachers, having originally designed the trial to have 60 teachers of each subject.

Windschitl et al. (2011) developed a protocol to help a group of 11 novice secondary science teachers assess their students' work, in the hope that such shared discussion would help them better understand how instructional features affect pupil learning. Their evaluation techniques included videoing the group sessions, observing lessons, analysing student work and interviewing teachers. In their analysis, they explored whether teachers adopted language from the protocol to discuss students' artefacts, and how the participants connected the artefacts with their pedagogical decisions.

In contrast, Park and Oliver (2008) studied experienced secondary science teachers. Although only three teachers were studied, the research was in-depth. The case studies comprised classroom observations, semi-structured interviews, lesson plans, teachers' written reflections, students' work samples, and researcher's field notes. Each teacher taught three units and at least four sessions were observed per unit.

In an HE context, Lock, Salt and Soares (2011) explored whether and how initial teacher training courses support students to develop subject knowledge and topic specific pedagogy. Course documents were analysed, and tutors and trainees were asked to complete questionnaires and interviews. Information collected included how trainees had prepared variously for a topic they were comfortable with, not comfortable with, and had never taught before. Tutors were asked about the course philosophy and the role of the mentor and school, among other matters.

The desire to develop a sophisticated mixed methodology can lead researchers to over-reach themselves. Beatty et al. (2008) proposed using a broad range of tools in their evaluation of a three-year professional development programme introducing classroom-based response systems (clickers) into secondary science and mathematics. The project initially involved 38 teachers and their students from six schools. A complex web of methods was proposed to enable triangulation of findings. Teachers were expected to write journal entries, complete daily implementation logs, fill in a monthly online survey about pedagogical perspectives, and have two teaching sessions per semester videoed with short pre/post interviews. Once a year, they were asked to participate in a survey and an intensive interview (90 minutes over two sessions). Their students were also given a survey to complete once a semester. These demands proved a considerable burden and the response suffered as a result, highlighting the danger of overloading participants. The quality of teacher journals, for instance, varied considerably and since it was a time-consuming measure the researchers chose not to insist on it. Ian Beatty (personal correspondence) acknowledges that the project was "afflicted by both misfortune and over-ambition in many ways … Ultimately, most of our findings came from case study analysis with cross-case comparison".

Moss et al. (2007) used mixed methods to evaluate the London Challenge schools whiteboard expansion project. Pupil performance was assessed from national records and equipment audited using a survey of all London secondary schools. Low (41%) and incomplete survey responses allowed only limited analysis of performance data linked to interactive whiteboard availability. More detailed information was collected through a case study approach focusing on 27 classes in nine schools. Research tools included videoing lessons and applying structured observation grids; interviewing teachers and heads of department; administering surveys to teachers and pupils; and running focus groups with pupils.

12. THEMES ARISING FROM EMPIRICAL STUDIES

This summary of the empirical literature shows that there is a considerable body of work reporting attempts to evaluate measurement or development of pedagogy and PCK, but it has three major limitations.

Firstly, as previously discussed, most of it is conducted in the context of school-level education, particularly in the realms of science, mathematics and information technology. Although there is considerable disciplinary overlap, the academic rather than vocational nature of learning tends to be emphasised. There is a particular lack of discourse around engineering.

Secondly, sample sizes are often low. This limits confidence in the reliability or validity and generalisability of results with small studies tending to be very context-dependent. Efforts have been made to overcome this using research syntheses but the issue of small samples is a widespread issue across this broad area of literature. Goldsmith, Doerr and Lewis (2014) found 66 studies linked to developing teachers' instructional practice in their meta analysis of the in-service learning of mathematics teachers. Of these, only ten were quantitative (including four with samples of 500+). Of the 56 using qualitative or mixed methods, 53 had a sample size of under 20, including 37 with five teachers or fewer. Likewise, in Blank and de las Alas's meta analysis of mathematics and science professional development (2009), 11 of the studies involved fewer than 20 intervention teachers, and just five had 20 or more.

The third issue relates to research methodology. For several reasons, mixed methods may present the best approach. Although teacher self-report is relatively easy to obtain (either using a relatively cheap survey tool or the more intensive method of interviewing), its reliability is questionable and triangulation with other data sources is essential. Furthermore, if it is accepted that practice splits into espoused and enacted, different techniques are needed to investigate each. Being tacit, enacted practice can be missed unless stimulus material such as vignettes of others' practice is used. Such labour-intensive methods take considerable time and effort from researcher and researched. This makes the research expensive and can represent an off-putting burden for potential participants. There is a need to find alternative methods or to narrow the focus of the research; for example, limiting a study to one topic/phase of teaching (Rohaan et al., 2009). Another option is to find a less time-consuming measure, such as using multiple choice rather than open questions (Schmelzing et al., 2013). Although the CoRe approach seems to work well for both developing and assessing PCK, its labour-intensive nature necessitates employing it judiciously as part of training and development. The search for more efficient research tools continues.

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