Operationalising
Technological Pedagogical Content Knowledge
in UK Teacher Professional Development

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Abstract

Weaknesses in extant modes of teacher professional development relating to the use of technology to support teaching and learning are identified and recommendations sought regarding more effective modes of delivery. Technological Pedagogical Content Knowledge (TPACK) is postulated as a theoretical lens through which to foster reflection and dialogue regarding teaching practice and a number of tools are developed to support a structured approach to professional development. These include a TPACK assessment tool to evaluate performance in each of TPACK's constituent subdomains and a new form of technology content representation, dubbed a 'T-CoRe', through which to scaffold thinking and practice relating to technology integration.

Through iterative refinement, the assessment tool was able to indicate and afford visualisation of aspects of practice. T-CoRes and associated discussion were able to evidence stimulation of high-quality reflection and foster application of higher-order thinking, here termed 'TPACK thinking'.

Impact was demonstrable both in terms of teacher practice and pupil outcomes. Teachers demonstrated a commitment to collegiality and reflected on their capacity to champion technology integration within their departments and schools.

This study therefore demonstrates the potential to operationalise TPACK within a UK setting and offers a toolkit of resources to support consideration of the pedagogical affordance of technology by teachers for wider scrutiny, use and development.

Key Words

TPACK, technology, professional development

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Abbreviations/ Glossary

Abbreviations

CK	Content Knowledge
FITness	Fluency with information technology
ITE	Initial Teacher Education
PCK	Pedagogical Content Knowledge
PGCE	Postgraduate Certificate in Education
PK	Pedagogical Knowledge
T-CoRe	Technology Content Representation
TCK	Technological Content Knowledge
TIDE	Teaching in a Digital Environment
TK	Technological Knowledge
TLR	Teaching and Learning Responsibility
TPACK	Technological Pedagogical Content Knowledge
TPK	Technological Pedagogical Knowledge

Glossary

Content Knowledge	Knowledge of subject matter
FITness	Fluency with information technology. Technological knowledge that permits someone to be able to 'apply it productively at work and in their everyday lives' (NRC, 1999, p.15)

Pedagogical Content Knowledge	Knowledge about forms of pedagogy that support the teaching of specific subject content
Pedagogical Knowledge	Knowledge about methods of teaching and learning
T-CoRe	A table containing stimulus questions to provoke thought about each of the components of the TPACK model whilst planning teaching activity. See appendix 3.
Technological Content Knowledge	Knowledge of the relationship between subject matter and technology (e.g. how new technologies have advanced knowledge within a subject discipline)
Technological Knowledge	Digital literacy, operational skills and ability to engage with/adapt to changing technology.
Technological Pedagogical Content Knowledge	Understanding of the complex interplay between each of the domains within the TPACK model
Technological Pedagogical Knowledge	Knowledge of how technology can influence teaching and learning (i.e. the pedagogical affordances of technology)

Preface

During a school-based career of nearly twenty years in which I mostly taught Science, I witnessed developments in power, miniaturisation and affordability that have paved the way for the introduction of affordable technology to classroom teaching. Key stages in this evolution have included:

- The adoption of standalone Personal Computers (PCs) for classroom data management
- The introduction of peripheral devices for data capture in the teaching of Science
- Classroom access to the World Wide Web
- The introduction of classroom display technology (e.g. projectors/interactive whiteboards)
- Simplification of software tools for the creation and use of computer simulations
- The advent of Virtual Learning Spaces and Augmented Reality to foster independent learning

Each of these represents a quantum leap in the potential of technology to support both teaching and learning. I have been lucky to work in a wide range of schools with many colleagues who have demonstrated both enthusiasm and initiative in tapping into the potential of new technologies and have helped make exploring new opportunities an integral part of my teaching journey. I will touch upon what I term the 'champion' effect at several points in the story unfolded here but, for me, the impact of being surrounded by creative practitioners led to an ongoing interest in exploring the affordance of new technologies to support teaching and learning. This, in turn, led me to take on a role as a teacher adviser during a government-funded initiative in the 1990s, and to review software and hardware for a range of educational, biological and biomedical publications as well as encouraging me to try to keep pace with the rapidly changing nature of the increasingly digital 'chalkface' in my own classrooms.

Educational research has presented many new challenges. I arrived to it from a firmly positivist tradition having trained as a biologist, gained practical research experience and subsequently taught Science and its associated methods throughout my school teaching career.

I hope the account offered here presents an insight into the substantial learning journey made as new territories were explored in this attempt to lift the lid and peer deeper into how opportunities presented by educational technology can be explored.

I am pleased to have already been able to share part of this story at the Teacher Education Advancement Network (TEAN) conference in May 2017 in Birmingham (UK). I look forward to sharing the findings more widely.

Perhaps the story told here may also serve as encouragement for others to make a similar leap of faith.

1 Chapter 1: Introduction

> Technology can amplify great teaching,
> but great technology cannot replace poor teaching.
>
> (OECD, 2015, p.4)

> A major part of effective use of ICT lies in the planning, preparation and follow-up of lessons, and in particular the pedagogical thinking that links teaching style, the selection of resources, the activities and the learning objectives.
>
> (Becta, 2003, p.34)

In this chapter, I outline the challenges for teachers relating to pedagogical integration of technology and the limitations of traditional approaches to professional development. The convergence of these ideas to form the nascent conceptual framework upon which the project is constructed is explored. An overview of each chapter is then offered to illustrate the geography of this thesis.

1.1 Teaching – a complex activity

Teaching is recognised as a complex activity requiring mastery of a wide range of knowledge and skills. Expertise is contingent upon flexibility regarding access to complex systems of knowledge (Mishra and Koehler, 2006). The relevance of Mishra & Koehler's contribution to situating technology within this knowledge base is highly significant and will be explored later.

In addition to an understanding of subject content and contextual factors (including a knowledge of the students, school policies and awareness of resources), teachers must be able to select, from a range of pedagogical approaches, those which might best serve the learning needs of their students.

Exploring the interplay between pedagogical understanding and subject content knowledge, Shulman (1986) introduced the concept of Pedagogical Content Knowledge (PCK) to provide a lens through which features of expert teaching can be identified.

PCK attempts to identify the different types of knowledge upon which successful teaching is contingent. Content knowledge articulates teachers' understanding of the subject being taught and their awareness of the requirements of the curriculum. Pedagogical knowledge represents the range of strategies upon which teachers can draw to facilitate teaching and learning. The overlap between these two knowledge domains represents the ability to select appropriate teaching strategies to support effective learning.

Shulman suggests that PCK includes:

> the most useful forms of representation of [topics], the most powerful analogies, illustrations, example, explanations and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible to others…Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult (Shulman, 1986, p.9)

PCK has traditionally been represented by two overlapping circles. The overlap represents specialised knowledge that links pedagogical understanding to the teaching of specific aspects of content. Later representations include a dotted perimeter line as shown in Figure 1 to acknowledge that PCK is context sensitive.

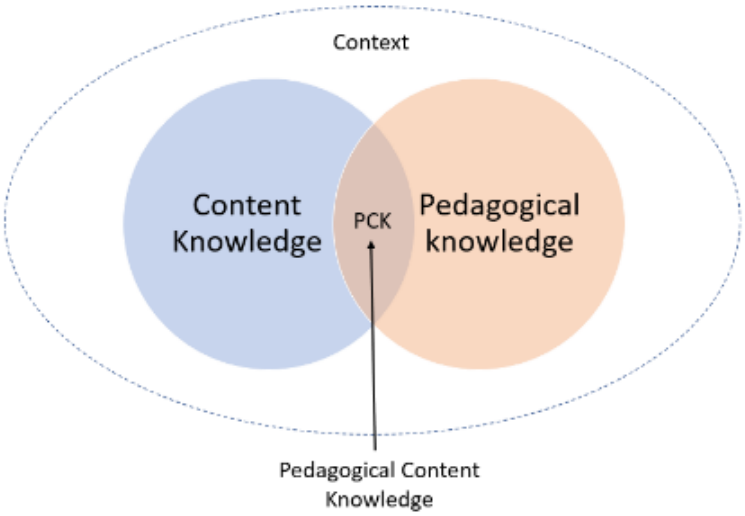


Figure 1: Pedagogical Content Knowledge

Previous work by my colleagues and I has reinforced my belief that PCK can be a useful lens through which to foster effective reflection by teachers regarding why certain concepts are best taught in particular ways (Simpson et al, 2012). Ongoing professional reflection throughout teachers' careers is seen as important to ensure that pedagogy remains aligned to content within an ever-changing curriculum. Curriculum content is regularly updated, particularly in subjects such as my own (science), to reflect developments in understanding (Wellcome, 2006).

Teachers' and departmental approaches to long-term planning are often defined by curriculum and assessment demands which are subject to change with political winds. Although keeping up to date with these changes is a prerequisite of effective teaching, it is the associated pedagogical decisions made by teachers that have greater potential to both engage students and facilitate learning.

The veritable explosion of technology and its classroom potential during my teaching career has provided a huge additional palette of pedagogical opportunities from which to select. Demonstrating good PCK, as a result, demands good understanding of the range of tools available from which to select an appropriate pedagogy. In an increasingly digital age, good PCK therefore not only requires an understanding of *how* to teach using technology but also *why*.

1.2 A digital revolution

The rapid pace of change regarding the availability of technology in the classroom means that teachers may be unfamiliar with new resources and therefore unwilling to consider their pedagogical potential.

Vacirca (2008) highlights that teachers may have to 'teach in ways in which they have not been taught themselves' (p.1). This presents two challenges: firstly, that effective pedagogical opportunities may be missed to the detriment of the quality of student learning; and secondly, that teachers may not model the sorts of digital literacy skills students will need to be successful in a contemporary or future workforce. Ng (2015) asserts that this is important to develop the 'competent', 'purposeful' and safe use of technology (p.125) that constitutes good digital citizenship or what was, in the US, termed 'fluency with IT' or 'FITness' (NRC, 1999).

Gurney-Read (2013) identifies digital literacy as a key functional skill. She cites Mark Surman, Executive Director of the Mozilla Foundation who suggested that 'we need to look at this fourth literacy as mainstream' (p.1). Similarly, Jenkins (2009) stresses the importance of '21st century literacy' which he defines as the 'set of abilities where aural, visual and digital literacies overlap' (p.29).

Hramiak (2012) considers the possibility that some teachers are reluctant to engage with technology in the classroom knowing that their digital literacy is inferior to that of their students. She suggests that as a result, the technological demand of students' work may lag behind their informal uses and have a consequent impact on levels of engagement.

Some teachers will have kept pace with emerging technology, but clear warnings are sounded that knowing a form of technology does not automatically translate into its effective use in the classroom any more than good subject knowledge automatically implies good PCK (Hramiak, 2012; Mishra & Koehler, 2006; Britten & Cassady, 2006). There is therefore a risk that digital literacy is reduced to consideration of just technical or 'operational' skills. Jenkins (2009) guards against this reduction of 'new media literacies to technical skills' suggesting that this would be a 'mistake on the order of confusing penmanship with composition' (p.31).

A clear difference thus emerges between teaching *about* technology and teaching *with* technology. Teachers must realise that teaching with ICT is not predicated on teaching ICT skills but on enhancing student learning through the use of forms of technology recruited for particular pedagogical purposes.

1.3 Technology for teaching

The pedagogical opportunities presented by forms of technology are referred to here as 'pedagogical affordances'. The term 'affordance' is attributed to Gibson (1977) to refer to the potential utility offered by resources. When applied to technology, Hutchby (2001) is credited with coining the term 'technological affordance'. Application of the term to educational settings is exemplified by authors including Hammond (2010) and UK projects such as that described by John & Sutherland (2006).

There is plenty of evidence that technology can contribute to pupil attainment (Becta, 2003; Cox & Abbot, 2004) but also an accusation that, although technology is used to good effect for administrative and presentational purposes, teachers are not quite so adept at making appropriate use of the pedagogical affordances of new technology (Vacirca, 2008).

New entrants to the teaching profession undoubtedly have higher levels of digital literacy than previous generations of teachers. This is recognised by the removal in 2012 of an ICT skills test as a pre-requisite for initial teacher training. Reinforcing a previous point, however, these tests focused on the operational skills inherent in the use of office software, email and web browsers (TDA, 2010), rather than including any focus on their pedagogical affordance (Ferrigan, 2011).

Rogers and Twidle (2013) note the difference between knowledge of available technology and its professional application, suggesting that even teachers who may have a high level of digital literacy might lack a practical understanding of the extent of the pedagogical affordances of technology in the classroom. For this reason, there emerges a need to include a focus on beginning teachers as well as those with significant experience.

Prior experience may reinforce barriers to the use of technology in the classroom. Becta (2003) note that 'teacher's own pedagogical beliefs and values play an important part in shaping technology-mediated learning opportunities' (p.3). Where consideration of pedagogy is sidelined in favour of teaching driven by habit or superficial inclusion of technology, Kinchin (2012) warns that the consequence may be 'technology-enhanced non-learning' (p.46), suggesting that the pedagogical affordance of technology may not be realised.

In order to integrate technology effectively into teaching, teachers therefore face a number of challenges:

- Their practice might be limited by a lack of awareness of or about the tools available to support teaching
- In order to harness the potential of new technology as an educational tool, they must align operational skills with pedagogical skills to translate digital literacy into effective technology-enhanced pedagogy
- There may be deep-seated attitudes to the use of technology for teaching influenced by prior experience

With advances in technology, the challenges for teachers are as current today as during the earlier stages of my career. There is therefore a need to develop teachers' thinking about the ways in which technology can be exploited to best effect in the classroom. This gives rise to thinking about professional development that might better support what Cornu (1995) termed 'integrated pedagogy' (p.7).

1.4 A problem with professional development

The earlier warning sounded by Jenkins (2009) regarding the risk of reducing 'new media literacies to technical skills' in the classroom (p.31) resonates strongly with the literature surrounding teacher professional development.

Rogers & Twidle (2013) assert that models of teacher professional development have long been dominated by isolated training events focusing on operational skills and, as a result, yielding limited longevity of impact. A possible contributory factor in this may

be that such training is often conducted individually through attendance at a course at a location other than the teacher's school. As such, it might be argued that such 'cascade' training (Younie & Leask, 2013) is something that could be perceived as being 'done to' teachers rather than fostering the personal investment and ownership required to develop professional capital.

Professional capital, as postulated by Hargreaves & Fullan (2012), comprises three factors: human capital (the competence of individuals); decisional capital (using good judgement to develop your capabilities); and social capital (the power of collaboration). Developing social capital appears to be particularly significant in developing professional capital (Leana, 2011), an argument supported by wide recognition of the need for more collegial approaches to training (Koehler, 2011; Preston & Cuthell, 2007; Jimoyiannis, 2010a; Voogt et al, 2013). The notion of professional capital provides a useful lens through which a holistic view of the components of professional development explored in later sections can be maintained. As such this deserves more detailed consideration in chapter 2.

Over the preceding thirty-year period, Preston (2004) noted that there had been twelve UK government initiatives relating to the use of technology in classrooms, some of which are explored in section 2.1.1. These are reported to have had very limited impact, again largely due to a focus limited to the transmission of skills to facilitate the use of technology. Teachers themselves reportedly recognised that they would benefit from professional development activities focusing on classroom practice rather than operational skills (Rodrigues et al, 2003) but this appeared to remain unfulfilled in subsequent years (Wellcome Trust, 2006) with many teachers reporting a degree of disillusionment with training received.

Problems therefore appear evident relating to the difficulties many teachers may have adopting and exploiting emergent technology to good pedagogical effect, and to approaches previously taken to professional development relating to their use of technology. Combined, these suggest that this is an area worthy of study and that more detailed consideration of relevant literature is merited.

1.5 Towards a conceptual framework

In synthesising ideas about the use of educational technology and approaches to professional development, emergent issues might be summarised as:

1. Rapid developments in the power and availability of technology in the classroom have left many teachers struggling to maintain pace with the level of digital literacy required to exploit its potential to best effect.
2. Traditional approaches to teacher professional development relating to the use of technology in the classroom have tended to focus on operational skills and therefore have limited impact beyond the immediate context of the training.
3. Beginning teachers may have highly developed operational skills but may have limited understanding of how to identify and exploit technology's pedagogical potential. There is therefore a need for a renewed focus by teachers on pedagogy and the choices they make with respect to the use of technology in the classroom.
4. Having a 'community of practice' is a strong contributory factor for securing teacher engagement, promoting reflection and developing professional capital.

The convergence of these ideas contributes to the conceptual framework upon which this research is constructed. In chapter 2, I explore the potential of Technological Pedagogical Content Knowledge (TPACK) to contribute to addressing these issues through an alternative approach to professional development and will draw together the conceptual elements underpinning the study.

1.6 Research questions

This project takes these ideas as a starting point and explores the contribution that more appropriate forms of professional development can make to teachers' attitudes towards, engagement with, and success using educational technology. This gave rise to the over-arching research question:

How can teachers be encouraged to take ownership of professional development regarding their use of educational technology?

In order to begin to understand this, I will explore teachers' perceptions of how technology is used in the classroom and how I can lead them into active reflection on their pedagogy. As such the project has two primary locations: the seminar room for collaborative teacher development activities; and participants' own classrooms as they enact their own ideas in the light of the training activities. An appropriate research design is therefore needed which acknowledges the complexities of the classroom, the individual interpretations of participants and the different locations of elements of the research activity.

In the next chapter, relevant literature is explored more fully to support the development of focused research questions upon which the project is based.

1.7 An original contribution

I venture that the original contribution made by this study is firstly to add to literature on assessing and operationalising TPACK; secondly that TPACK can be exploited both in terms of teacher professional development and Initial Teacher Education to support the pedagogical consideration of technology; and thirdly that this work is conducted in a context that, to date, is under-represented in relevant literature – namely the UK.

1.8 Overview of subsequent chapters

Chapter 2 – Literature review

The literature review explores more fully the identified problems with existing modes of professional development and the challenges of teaching with technology, and explores TPACK as a theoretical model to support pedagogical consideration. The emergent conceptual framework is refined and presented to support the development of an appropriate research design.

Chapter 3 – Methodology

Philosophical underpinnings are discussed, leading towards an abductive, pragmatic stance. An Action Research methodology is supported by both quantitative and qualitative approaches to data collection and analysis. These serve to explore and evaluate the potential of TPACK to support the goal of pedagogically driven professional development activities that promote professional capital. This is achieved through the development of assessment tools, and a combination of collaborative training activities and associated participant practitioner research which will be evaluated by impact assessment, teacher artefacts, group discussion and semi-structured interviews.

Chapter 4 – Findings and analysis

The efficacy of each of the resources developed for the toolkit of professional development activities is evaluated, demonstrating good capacity for stimulating the 'TPACK thinking' required for development of practice. Outcomes are considered both from the perspective of participants and from the quantitative perspective afforded by pre- and post-intervention use of the assessment tool.

Chapter 5 – Discussion

The three key themes that contributed to the conceptual framework, namely the challenges of teaching with technology, the shortcomings of extant modes of professional development and the potential for TPACK to provide a shared language for the pedagogical consideration of technology are revisited in the light of findings as viewed from the perspective of both established teachers and trainees. Evaluation of methods and the integrity of the research is offered.

Chapter 6 – Conclusions and recommendations

Conclusions and, where appropriate, generalisations are drawn in relation to the original research questions. The originality of any theoretical insight derived from the study is considered. A holistic view of the project is taken to support identification of next steps and new directions for research in this area.

2 Chapter 2: Literature review

The literature reviewed and offered here to support development of the conceptual framework employed in this study focuses on three key areas. Firstly, historical context is considered before exploring the challenges inherent in teaching with technology. Problems identified with existing models of professional development are then explored. Finally, the theoretical framework offered by Technological Pedagogical Content Knowledge (TPACK) is explored and its potential as a vehicle for professional development considered. These ideas are then combined to define the conceptual framework upon which the subsequent research design is based.

2.1 Teaching with technology

Teaching in the late 19th and early 20th centuries has been challenged as having given little attention to pedagogy, and emergent educational theory during this time is accused of not having been evaluated with any rigour in relation to its application in the classroom (Simon, 1994). The implication made is that teaching as an informed and 'scientific' activity is a more recent invention. Pedagogy, framed as the 'science of teaching', might therefore be considered to have evolved during the latter half of the 20th century. Technological advancement during this same period adds significantly to the new opportunities and challenges teachers may experience in attempting to enhance their pedagogical understanding and classroom skills. The pace of technological change in the classroom shows no sign of abating (Voogt & Tondeur, 2015). Becta (2010) referred to '21st century teachers' (p.3) and began to explore some of the characteristics they possess and activities they use to support learning, administration and assessment.

This section therefore explores the historical context of educational technology before considering some of the challenges and opportunities presented by technology, and the barriers teachers may need to overcome in order to be able to exploit technology to good pedagogical effect and become '21st century teachers'.

2.1.1 A historical perspective

The UK has one of the longest histories of government involvement in the implementation of educational technology (Selwyn, 2013). Selwyn offers a 'political economy view' (Selwyn, 2002, p.13) suggesting that the UK perceived itself as lagging behind other developed countries in terms of early commercial exploitation of technology during the 1960s and 1970s. In response, over the following decades, significant investment was made to reassert Britain's position as a pioneer in the use of educational technology.

The 1980s saw major transformation in the availability and adoption by schools of computers. Initially computer use was the preserve of teacher 'hobbyists' (Selwyn, 2002) but major government initiatives supported integration into both classrooms and curriculum. This, in turn, was supported by increasing utility as computer use moved beyond simple programming exercises into the use of commercial education programs. The first, and perhaps most significant initiative, implemented by the then Conservative government, was the 1981 'Micros in Schools' scheme, resulting in widespread school ownership of British microcomputers, notably the BBC micro produced by Acorn Computers. This was followed between 1984 and 1997 by stages of the Technical and Vocational Education Initiative (TVEI) which continued to support government economic ambition in recognition of the part computers would play in a global marketplace. The degree to which this was successful is challenged by a damning independent report by Stevenson (1997) which suggests that too great an emphasis was placed on resources rather than action.

The Stevenson report made an overarching recommendation that the government 'must make the act of faith and encourage the education sector to start using technology rather than talking about it!' (Stevenson, 1997, p.6). In response, the then Labour Prime Minister, Tony Blair, prefaced the introduction of the National Grid for Learning (NGfL) by stating that 'Technology has revolutionised the way we work and is now set to transform education. Children cannot be effective in tomorrow's world if they are trained in yesterday's skills' (DfEE, 1997, p.1).

The goal of NGfL was to 'bring the information age alive' (Selwyn, 2002, p.40) and, as a result, improved connectivity was a feature of technological development in schools in the 1990's, leading to the 'modernisation of the classroom' (ibid. p.42) typified by the rise of the 'computer room' and increased opportunities for computer-based independent learning. Further to the Education Reform Act of 1988, the introduction of the first UK National Curriculum in 1990 made the use of technology by students mandatory, although this was to be delivered discretely rather than embedded in subject curricula and was argued as having a vocational and technocentric focus (Watson, 2001). Younie & Leask (2013) suggest that this may have restricted teachers outside the prescribed Information Technology curriculum who subsequently had less opportunity than before to explore opportunities, as resources were directed towards a narrow curriculum focus.

Further criticism of these formative years surfaced, in the light of investment in UK technology, regarding the influence of 'Big Business' on educational policy (Selwyn, 2002). Selwyn highlights, for example, the potential influence of high-profile meetings between the prime minister (Tony Blair) and Microsoft pioneer Bill Gates, suggesting that the NGfL initiative had been 'hijacked' by private interests (ibid. p.60). Whilst certainly successful at raising the profile of the initiative, this might also be seen as a cunning and pivotal move to help secure the dominance of Windows-based PCs in UK school IT infrastructure. Somekh (2002) refers to difficulties caused by incompatibilities, for example between devices at school and home, as the 'second digital divide' (p.117).

The emphasis on resources rather than systemic use is highlighted by Hammond (2009) who suggests that 'computers came into many schools with no clear educational rationale, and it was easy for teachers to see them as a solution looking for a problem' (p.9), a sentiment previously raised by Scaife & Wellington (1993). To redress this issue, significant investment was made in the provision of training available to all UK teachers, facilitated by the New Opportunities Fund (NOF) via the National Lottery to the tune of £230 million between 1999-2003. The impact of the NOF scheme is considered in section 2.2. From 2000, ICT skills were embedded in

subject curricula (DfEE, 1998) and, in 2001, an ICT skills test became mandatory for all new entrants to the teaching profession in England (DfEE, 2000).

The 2000s were characterised by new forms of interaction, fostered by Web 2.0 technologies (typified by widespread and interactive use of the internet and interoperability across operating systems and platforms). The use of online forums for knowledge sharing has been described by Younie & Leask (2013) as 'communal constructivism' (p.7) but, despite previous interventions, there was still seen to be a discrepancy between practice in schools. This is, perhaps, not surprising given the rapid pace of change in terms of available technology and the diminishing role played by Local Education Authorities in coordinating practice in the years following the Education Reform Act of 1988. In response, in 2005, a new national strategy was implemented. The 'Harnessing Technology' e-strategy sought to develop online collaboration, engage students, and improve online services for connecting learners, parents and employers (DfES, 2005). This saw a move away from a focus on resources and towards personalisation of education as a precursor to the broader 2007 National Strategy 'Every Child Matters'. The Harnessing Technology strategy was extended from 2008 to 2014 to further these goals.

The British Educational Communications and Technology Agency (Becta), the government quango established in 1998 and tasked, for example, with implementation of the NGfL project, was subsequently abolished in 2011. There is some suggestion that, despite previous warnings, Becta continued to place too much emphasis on resources (Younie & Leask, 2013) and that they placed an unhealthy bias on restricting purchasing to a list of approved suppliers at the expense of fostering competition and innovation (McLean, 2009).

Since 2010, there has been a downturn in government spending on educational technology as it becomes more endemic in schools, but renewed emphasis on the place of computers in the curriculum. Messages emerging from successive Education Secretaries include recognition of the value of technology in Michael Gove's suggestion that new computer science GCSEs would form part of the English Baccalaureate and that computer science teachers would be supported by a 'Computing at School' initiative (DfE, 2014). His successor, Nicky Morgan, asserted that

the new Computer Science GCSE was 'on a par with the best in the world' (DfE, 2016b), but notably absent on this occasion was reference to developing pedagogical consideration of technology beyond the Computer Science curriculum. Most recently, the current Education Secretary, Damien Hinds, has called for the formation of 'strong edtech partnerships' between government, technology innovators and the education sector. Recognising research evidence, he does acknowledge the need for schools to 'have the power to choose the tech tools which are best for them and their budgets' (George, 2018) and suggests that online training will be developed in association with the Chartered College of Teaching.

Since the widespread introduction of computers into schools, it seems that economic and political emphasis has, hitherto, been placed on ensuring that schools are seen as technology rich. The resultant initiatives over subsequent decades embedded this ideal but have perhaps resulted in a mismatch between resources and effective use. Ofsted (2001) ventured that training initiatives had contributed to an increase in the use of computers in schools but that this was not matched by the development of pedagogical skills to lead to effective use in teaching and learning. Despite the best intentions of government initiatives, it is clear that teachers play a pivotal role in enacting desired change (Fullan, 1989). It is therefore prudent to consider the challenges, opportunities and barriers presented by technology for teachers to understand why this mismatch has occurred and to begin to consider how it might be addressed.

2.1.2 Challenges

Teaching is a complex activity whose success depends on teachers' abilities to draw on different types of knowledge including knowledge of subject content as well as an understanding of pedagogy – how choices relating to activities and the way knowledge is presented impact upon the learning process. It is also highly contingent on an understanding of context, being affected by the varied needs, experiences and attitudes of the learners, as well as resources, school systems and the demands on teachers of accountability. That teaching is described as a 'complex cognitive skill occurring in an ill-structured, dynamic environment' (Mishra & Koehler, 2006, p.1020) is therefore no surprise.

Twining et al (2013) suggest that appreciation of this complexity is a fundamental prerequisite to initial teacher education and continuing professional development and acknowledge that it is complicated by the ongoing and rapid development of technology. They suggest that a temptation exists to see technology as a bolt-on to teaching activity whereas it must instead be recognised as contributing to new pedagogical possibilities. This is affirmed by Rogers & Twidle (2013) who assert that, as new technologies emerge, 'the software and hardware simply remain tools, which, if they are to achieve teaching and learning gains, need the pedagogical input of the teacher' (p.235).

There is therefore a distinction to be made between *classroom* technology (that is, technology for administrative or presentational purposes) and *educational* technology which is selected and used because of its pedagogical affordance. In the literature, these are variously referred to as 'operational' and 'pedagogical' technology (Rogers & Twidle, 2013), 'Type I' and 'Type II' uses (Britten & Cassady, 2006) or 'professional' and 'instructional' uses (Groff & Mouza, 2008) respectively. I will persist with the term 'educational technology' since it is well defined by agreement with a range of authors as 'the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources' (Januszewski & Molenda, 2008, p.1).

There is a well-documented disparity between teachers' willingness to use technology for these different purposes (Groff & Mouza, 2008; Graham et al, 2009). One reason for this may be that, although teachers may consider the pedagogical potential of technology, 'they frequently lack the skills and dispositions to risk experimenting and playing with them in order to optimise their educational impact' (Koehler et al, 2011, p.148). Barriers to teachers' use of technology are considered further in section 2.1.3.

A danger thus emerges, in that technology in the classroom may 'dazzle' (BESA, 2015, p.12) but contribute little real benefit to the learning taking place. It is also worth heeding a warning that ill-conceived use of technology in classrooms may detract from the 'valuable human engagement' that plays an important role in fostering learning and higher-order thinking (OECD, 2015, p.3).

2.1.3 Opportunities

It is worth giving brief consideration, at this point, to the potential benefits of technology for teaching and learning before considering how appropriate professional development may help teachers make more considered use of available resources.

Building on the notion of classroom (administrative) and educational (pedagogical) technology, Becta (2003) identify three broad areas of use of technology in the classroom which they term complementary, enhancement and integrated:

> '**Complementary**' uses include the 'Type I' or organisational uses alluded to earlier but also include technology which takes on a supportive role. This may include, for example, posting homework on a virtual learning environment (VLE) or the use of multimedia quizzes. As well as mitigating some of the difficulties with personal organisation students may have, such uses may also serve to enhance student engagement and support assessment. These uses have little implicit pedagogical purpose but may support application of new learning.
>
> '**Enhancing**' uses include those exploited to help foster understanding. These may include new representations of concepts through, for example, the use of video, animation or simulation. Potential benefits include the ability to, for example, illustrate processes that previously could only be presented as a series of static images.
>
> '**Integrated**' use of technology implies a much more sophisticated convergence of intended learning, content and assessment (synonymous with what Biggs (2003) terms 'constructive alignment'). The implication here is that technology is very much part of lesson design and serves to support more complex aspects of teaching such as personalisation and differentiation.

Whilst more discrete use of technology in the classroom may have very clear and perfectly acceptable benefits such as supporting student access to materials or providing representations that support conceptual understanding, the enhanced focus on pedagogical content knowledge inherent in 'integrated' uses resonates strongly with the more holistic view of the potential of technology to support learning offered by Twining et al (2013):

> ICT offers new approaches to supporting learning and changes pedagogy in ways that often align better with new understandings of how children learn through constructivist and socio-cultural approaches. These changes increase the potential to transform, rather than simply support and extend, educational practice. (p.7)

To exploit technology to best effect and secure transformation of teaching practice, the suggestion is that it should be fully integrated into lesson design and considered in terms of how it can be used to support pedagogical choice in relation to the specific topics being taught at a given time. Reference to educational theory also reminds us of contextual factors that might need taking into account for example to ensure that learning is personalised.

Given the evident pedagogical affordance of a wide range of technology in the classroom, reasons for limited engagement with and exploitation of available technology by teachers merit exploration.

2.1.4 Barriers

It is easy to be bewildered by the overwhelming array of existing and emerging technology at teachers' disposal. The 2018 British Educational Technology trade show (BETT) featured some 850 companies and hosted over a hundred Ed Tech start-up businesses (BETT, 2018). The resource sharing website hosted by TES (www.tes.com) currently boasts over 700,000 resources.

Whilst electing to teach without technology may very well represent a valid pedagogical decision, Twining et al (2013) are somewhat emphatic in suggesting that

teacher development 'requires adopting a mindset that teaching is not effective without ICT and embracing associated practices' (p.3). This implies that existing teacher mindsets may present barriers to the development of professional practice. Whilst their assertion is, perhaps, extreme, it is apparent that barriers to the use of technology may very much be intrinsic in origin.

Such intrinsic barriers may include:

- Awareness: A working knowledge of available equipment and resources, either already available in school or beyond can limit its use by teachers

- Teacher beliefs: Teachers need to be convinced of the benefits of adopting unfamiliar technology and that the returns justify the effort involved (Becta, 2003; Groff & Mouza, 2008). This appears to have been a significant factor since the introduction of computers to schools (Scaife & Wellington, 1993) and was noted as a key feature in the 'ImpacT' report which evaluated the key government initiatives during the formative years of educational technology as described in section 2.1.1 (Watson, 1993). Similarly, teachers' existing knowledge may very quickly become outdated (Angeli & Valanides, 2008) leading to disillusionment.

- Confidence: This may be affected by prior experiences and compounded by teachers' awareness of the digital divide between their own competence and that of their students (Hramiak, 2012).

Many extrinsic factors can also affect teachers' use of technology (Groff & Mouza, 2008) such as:

- Obsolescence of resources: Once well-used equipment may become obsolete (for example, in Science, early datalogging equipment interfaced with computers via a 9-pin serial connector. As USB connectivity emerged, older peripherals were rendered obsolete).

- Technological factors: Systems may prove unreliable or unstable meaning, for example, that internet access cannot be guaranteed, or memory hungry applications may cause aging computers to crash. These may compound the lack of confidence alluded to above.

- Political factors: Government initiatives have been accused of focusing too heavily on operational skills and spending too much on infrastructure (BESA, 2015). Although well intentioned, some aspects of this were ill-conceived (for example, funding in the 1990s saw every UK school given a digital microscope. These were cheap, underpowered and of limited educational benefit, particularly to secondary schools). Curriculum change may present additional challenge as subject content is updated or as curriculum and assessment are affected by political changes associated with changes of government or education secretaries.

- School factors: Accessibility of ICT in schools may limit potential use. Although there is a move away from investment in computer rooms and towards more portable technology, access to technical support may be similarly limiting.

- Student factors: Behaviour can be affected by a wide range of factors and antecedents, and may affect ability or willingness to engage. If outside a teaching room with which the teacher is familiar, student management may pose unanticipated difficulties.

Overcoming many of these barriers may not be something that is easy for teachers to do in isolation and the notion of the 'digital champion' (George, 2017) has emerged. Described as a 'go-to expert', there is a sense that this is a school-wide role, likely to be fulfilled by a member of the IT department. Baran et al (2017) refer to 'role models' (p.3) in the preparation of pre-service teachers regarding their use of technology to support teaching and learning. Experience suggests, however, that this may also be a more local and informal role borne out of the enthusiasm of individual teachers,

occurring at a departmental level in schools with potential to influence the motivation and confidence of colleagues. Although this does not yet appear to have been explored to significant effect in the literature, it is a phenomenon that will be borne in mind during the study with possible potential for further investigation.

In addition to the support of departmental digital champions, more formal appropriate professional development may also address many of the barriers identified and potentially secure champions for the future. In this way, the impact of training may not only be enduring but also cascaded. In the next section, professional development is explored in terms of the challenges it presents and its potential to promote teachers' more considered use of technology.

2.2 Technology and teacher professional development

In consideration of how technology has been and is addressed in professional development activities for teachers, a number of issues emerge as significant. These include the potentially differing needs of teachers at different stages of their careers and the perceived problems with what might be seen as 'traditional' modes of professional development. These are considered in turn and then drawn together by considering the contribution the aspects identified can make to promoting professional capital.

2.2.1 Different needs, same problem

I use the term 'teacher professional development' to encompass both what is commonly termed 'continuing professional development' (CPD) for established teachers and Initial Teacher Education (ITE) for beginning (trainee) teachers. The challenges are slightly different but the goals the same at every stage of the career-long learning journey teaching entails.

Established teachers may have well-developed pedagogical content knowledge, accumulated through the trial and error implicit in significant experience, but may be less tech-savvy than their younger counterparts due to a lack of familiarity with

emergent technology (Hramiak, 2012). This reinforces the idea raised in the introduction that they may find themselves less able to exploit new technology in the classroom (Vacirca, 2008). Conversely, younger teachers (including the majority of trainees) may well be expected to have better digital literacy than their older counterparts but will be approaching teaching with a less well-developed understanding of pedagogy since experience plays a significant role in developing a teacher's Pedagogical Content Knowledge (PCK) (Shulman, 1986).

Regardless of where in their teaching journey a teacher may be, there appears to be an evident need to examine the synergy between digital literacy and pedagogical understanding.

2.2.2 The shortcomings of technocentricity

Traditional approaches to developing the technological skills of teachers have tended to focus on the operational skills required to help master particular pieces of hardware or software (Jenkins, 2009). Harris & Hofer (2011) take issue with what they term such 'technocentric' training, reinforcing earlier assertions that good technical knowledge of software or hardware does not automatically translate into good teaching (Mishra & Koehler, 2006; Britten & Cassady, 2006).

Of the many government initiatives that have been introduced in relation to developing the use of ICT by teachers, Preston (2004) notes that the predominant focus on the transmission of skills has not led to significant and sustained outcomes. There is also accusation that these initiatives channelled too great a proportion of available funding into hardware. In relation to the initiative funded by the government's New Opportunities Fund (NOF) between 1999-2002, the British Educational Suppliers Association identify a problem neatly summarised in the words of a local authority ICT adviser: 'We spent a lot of money on technology but not nearly enough on continual professional development and improving pedagogy' (BESA, 2015, p.6). The same sentiment was expressed in BESA's pithy evaluation of the 2008 introduction of the Harnessing Technology Grant to help schools develop their ICT infrastructure: 'there's little point buying a cart if you haven't got the horse to pull it'

(ibid. p.8). Transformation of practice is therefore not seen to be an automatic consequence of investment.

Insufficient training has been a repeated finding in BESA annual reports. The injection of cash into resources without appropriate training has led to limited evidence of impact with reports as late as 2012 suggesting that some teachers were still seen printing pictures and sticking these to interactive whiteboards, leading to the tongue-in-cheek description: 'interactive blu-tak' (BESA, 2015, p.8). This is somewhat contradicted by a later suggestion in the same report that 'from being seduced by computers at first, the education system has moved to a new, pragmatic understanding of ways in which technology serves education and not the other way round' (ibid. p.13) although this might still be argued to encompass the more unorthodox uses described.

The 2015 BESA report does make an important point perhaps encapsulated best in a comment by the Head of Education Strategy for Promethean (a supplier of interactive whiteboards) who advocates 'not letting the technology so dazzle you that you forget to ask how it will actually help teachers to improve lessons and raise standards' as something of which to be mindful in future (p.12). This is particularly poignant given that the rapid introduction of interactive whiteboards in the early 2000s is reported as not having the impact hoped for.

A slightly different situation is reported in Australia where a 2006 study revealed that 95% of teachers sampled rated their ICT skills highly. In resonance with UK findings, however, the majority also reported not feeling confident to use ICT to facilitate student learning (Department of Education and Training Western Australia, 2006). This, perhaps, reinforces the distinction made earlier between classroom technology and educational technology.

Of teachers identifying training needs in the Australian study, 81% recognised that they needed training relating to their use of ICT specifically within a classroom setting. A minority identified more basic training needs. Subsequent recommendations in the report highlighted the importance of training being focused on the integration of ICT

into teachers' subject areas. Very few teachers reported previously receiving any training of this nature.

We therefore inherit a situation where, despite initiatives to develop the profile and role of ICT in teaching, and despite a workforce with increasing levels of operational skills, there is still a disconnect between the increasing availability of technology that can be exploited in the classroom and teachers' consideration of its pedagogical affordance.

The OECD quote with which I open the introduction, summarises this to good effect and reinforces the motivation behind this study: 'in the end, technology can amplify great teaching, but great technology cannot replace poor teaching' (OECD, 2015, p.4). The key to addressing this problem would appear to be to move away from skills-based training and to establish a focus on the pedagogical affordance of educational technologies.

2.2.3 A one-shot deal

Traditional ICT CPD activities for teachers are recognised as having tended to be dominated by isolated training events which have been reported to yield limited longevity of impact (Rogers & Twidle, 2013). As far back as 25 years ago criticisms were levelled that CPD activities were generally too short (Sherwood, 1993).

Such activities were generally designed to be cost-effective for providers and therefore lent themselves to single events, delivered at a central location with numbers that might be larger than ideal. As such, this 'ballroom' training is accused of having little deep or long-standing impact on teachers' daily practice (Hargreaves & Fullan, 2012, p.92).

BESA (2015) identify sources claiming that the CPD provided for teachers in relation to their use of technology was 'not nearly enough' (p6). The drive to keep costs for schools down is recognised as a cause of the limited CPD on offer to support their teachers' effective use of new technology. The danger, despite the investment in

school ICT during the 1990s and early 2000s, was that schools were becoming technology rich but at the same time descending into pedagogical poverty.

The British Educational Communications and Technology Agency (Becta) was a former quango funded by the Department for Education who recognised, in a review of research literature, that 'long-term small-scale studies provide much better opportunities for examining the complex issues of the role of the teacher and interactions in the classroom' (Becta, 2003, p.21). This is echoed by Preston and Cuthell (2007) who, evaluating the NOF ICT training programme, concluded that an information transfer approach does not lead to sustained development of classroom practice, and recommend a more constructivist work-based programme. In addition to more protracted training opportunities, the importance of follow-up activities is highlighted by a number of authors (van Driel et al, 2012; Hargreaves & Fullan, 2012).

Whilst it might be tempting to turn towards online platforms through which to deliver training, and there have since been attempts to create online resources to evaluate teachers' use of technology (e.g. Schmidt et al, 2009), teachers are reported to show 'an overwhelming preference for a face-to-face delivery model' of CPD (Preston, 2004, part 3, p.25). It would therefore seem that there is evidence to recommend the provision of CPD to support teachers' use of technology which:

- Involves a face-to-face component
- Runs over an extended timescale
- Allows teachers to relate training to their own working context

2.2.4 Ownership

A 2006 survey found that teachers were often disillusioned about professional development (Wellcome Trust, 2006). There was a widely-held belief that CPD was important, yet teachers tended to rate training they had received poorly. A degree of scepticism was identified in which teachers were dubious about the potential value of the CPD on offer believing it focused, for example, on government initiatives rather than having relevance to their professional needs. Van Driel et al (2012) level a similar accusation that many professional development activities do not take into account the 'daily school reality' of participants (p.154). The implication of this is that the

traditional notion of CPD is flawed and there is room for a focus on more personalised forms of professional development.

In advocating a constructivist, work-based programme of CPD, Preston & Cuthell (2007) suggest that reflection would be an important feature of CPD designed to elicit sustained development of classroom practice. This strongly echoes Schön (1983) who asserted that reflection was key to unlocking the tacit understanding of practice required for professional growth.

Bianchi (2016, p.73) defines a 'trajectory of professional development' based upon five stages (pre-engage → participate → collaborate → co-create → and connect). The trajectory denotes an increasing level of ownership and autonomy regarding professional development activity and Bianchi implies increasing efficacy the further along the trajectory professional development is situated. Using this model, we might argue that simple one-shot training events limit engagement to the 'participation' or possibly the 'collaboration' stages. Higher levels on the trajectory involve a much higher degree of ownership of the focus and activity involved in the professional development experience. The increasing emphasis on collaboration can also be highlighted in the higher levels, which is explored further in the next section.

Koehler et al (2011) advocate the inclusion of opportunities for 'deep-play' in which participants have a degree of ownership of task and the freedom to develop the necessary operational skills to realise their ideas.

The opportunity for participants to influence the focus of their training lends a somewhat bespoke feel to it, allowing them to respond to training in an individualised manner and at an appropriate level. The implied warning is that one size does not fit all and that pre-determined activities risk being over-simplified or too complex, both of which may limit potential outcomes for the participant. In responding to the technological needs of participants, they suggest the need for them to engage with 'byte-sized chunks of complexity' (sic) (p.154) and reinforce that a degree of personalisation may well be important, particularly when participants in programmes of professional development will present with very different backgrounds, experiences and therefore needs.

Borrowing from the language of Meyer and Land (2003), the experience and expertise with which different teachers approach professional development may see them occupy different liminal states. To secure progress, each may need to overcome a different conceptual hurdle or 'threshold concept'. Cousins (2006) suggests that this is best achieved through a 'research-minded approach' (p.4) thereby reinforcing thinking that professional development activities should allow participants to explore new ideas in the context of their own practice and based on their own perceived areas of need.

Where opportunities for ownership are limited, the lack of personal investment required for innovation may present an 'impregnable barrier to implementation' (van Driel et al, 2012, p.130). In contrast, when teachers are responsible for and take ownership of change, outcomes are reported as being more effective (Hattie, 2011). There is encouraging evidence that teachers are generally intrinsically motivated to take risks and work collaboratively to develop their practice given the opportunity to do so (Bianchi, 2016).

The concept of ownership therefore becomes a significant contributory factor to enhanced professional development with potential to facilitate a shift from professional development that *enhances* practice to professional development that *transforms* practice.

2.2.5 A lonely profession

Hargreaves & Fullan (2012) argue that teaching is one of the loneliest professions in terms of professional isolation. Teaching, for some, may be enacted and developed behind closed doors with limited opportunities to share practice with colleagues and learn collaboratively from the hive-mind of experience present in any given department. Levine & Marcus (2010) note multiple studies leading to the conclusion that 'most schools develop norms of privacy, autonomy…and non-interference' (p.396) that limit sharing of practice and collegial learning. Rosenholtz (1989) termed this same concept 'professional estrangement'.

Whilst professional learning *can* take place individually, there is recognition that it also occurs significantly in 'interpersonal zones' (Koehler et al, 2011, p.152) which merits consideration of the affordance of working collaboratively within what Wenger (1998) refers to as a 'community of practice'. Teachers value working as part of a professional learning community when the opportunity arises (Vescio et al, 2008) and teachers working in highly collegial environments are reported to be more enthusiastic and innovative (Levine & Marcus, 2010).

There is a significant body of evidence suggesting that collegial forms of CPD are more effective than those undertaken in isolation (Koehler, 2011; Preston and Cuthell, 2007; Jimoyiannis, 2010a; Loveless, 2007; Voogt et al, 2013; Gu et al, 2015; Twining et al, 2013) which cannot be ignored in choices made regarding the CPD proposed within this study.

In evaluating CPD on teachers' use of technology, Preston & Cuthell (2007) are particularly strong advocates of working in a community of practice, highlighting Wenger's identification of four components that contribute to success: meaning; practice; identity; and design. These strongly support the notion of ownership outlined in the previous section but Wenger (1998) also highlighted the importance of community within a social theory of learning. It is therefore important to acknowledge the contribution that can be made through collaborative activity to foster *shared* meaning, *shared* practice, *shared* identity and *shared* design.

Hargreaves & Fullan (2012) suggest that working collaboratively can usefully reduce individualism or professional isolation but warn against the risk of 'plunging…into groupthink' (p.111) and losing the individuality of members of the community of practice. They go on to venture that 'In the best professional learning communities…strong collaboration and distinctive individuality go together in vibrant communities of innovation and growth' (p.111). This implies that support and challenge are strong features of collaborative work that may support the conceptual development needed by individuals to master threshold concepts. Jang & Chen (2010) support the idea that the peer coaching inevitable in such circumstances can enhance collegiate understanding and plays an important role in 'strengthening the ownership of change' (p.556). This appears to be even more potent when colleagues work

together to shape professional development so that they 'co-construct learning collaboratively' (Gu et al, 2012, p.22). Peer coaching both in CPD and ITE has great potential and there is similarly strong support for shared design and practice between pre-service and experienced teachers (Voogt et al, 2013).

Fielding et al (2005) identify four features of effective 'joint practice development' (p.32) which reinforce the importance of developing participants' agency:

1. Relationships – to foster collaborative opportunities
2. Identity – to promote individual responses even within groups
3. Engagement – through involvement in planning activities
4. Understanding time – confidence that there is sufficient time to learn and embed new practice, often through collaboration

Later, I will develop these perspectives on developing ownership and agency to include the *shared language* potentially afforded by the inclusion of TPACK as a theoretical lens through which to explore practice relating to the use of technology.

There is therefore strong recommendation for professional development opportunities that are collaborative whilst preserving the opportunity for individuals to retain ownership of the focus of activities undertaken.

2.2.6 Developing professional capital

A number of ideas about successful professional development have emerged from this literature review so far:

- A need to develop links between digital literacy and pedagogical understanding at all stages of teachers' careers
- Moving away from skills-based training and towards more structured consideration of the pedagogical affordance of technology
- Retaining face-to-face training as part of an extended programme of professional development as opposed to an isolated training event
- Fostering ownership to promote professional development done *by* rather than done *to* participants
- Working within a community of practice has good transformative potential

These can be further evaluated in terms of their potential to contribute to developing teachers' 'professional capital'. Hargraves & Fullan (2012) explore the idea of capital in schools, defining two broad views: business capital and professional capital.

Educational systems rooted in what they term 'business capital' are prone to seeking a quick fix to problems, reducing teaching to a series of simple skills that may largely be driven by a focus on performance data. Business capital may recognise the potential of technology but expect this to make up for gaps in teachers' pedagogical understanding. As a financially-driven strategy this may make sense, meaning that teachers might require less training (Hargreaves & Fullan, 2013), but this sits at great odds with the message coming across clearly that technology cannot replace the professional experience and judgement of teachers (OECD, 2015; BESA, 2015; Mishra & Koehler, 2006; Britten & Cassady, 2006). Unfortunately, findings suggest that opportunities for teacher professional development have, of late, been limited by austerity measures and school accountability (Bianchi, 2017).

In contrast, Hargreaves & Fullan commend thinking relating to professional capital. Professional capital, they suggest, comprises three factors:

- Decision capital – reliant on professional reflective capacity
- Human capital – the talent of individuals
- Social capital – which explores ways of working collaboratively

This is encouraging and refreshing thinking which suggests that empowering teachers may lead to more significant transformation and development of practice than the top-down approach reported as often being experienced by teachers (Wellcome Trust, 2006).

In terms of the emergent conceptual framework, decision capital can be developed through active consideration of the pedagogical aspects of technology use and participants' identification of need through reflection. Human capital can be expanded through ownership of professional development and linking this to the needs identified. Social capital develops through collaboration and 'gives you access to other

people's human capital' (Hargreaves & Fullan, 2012, p.90). The development of human capital is enhanced by collaborative working and Hargreaves & Fullan therefore assert that social capital strategies represent a fundamental factor required to foster transformation of the teaching profession. There is the suggestion that teaching as a profession has responded to this idea in terms of designing classroom activities for pupils but that 'the concept has not yet been applied to the performance and success of teachers' (ibid, p.91). In the light of previously cited evaluative evidence of support for collaborative professional development, their statement seems a little over-zealous but will be taken as acknowledging that professional development based on collaborative approaches has been under-utilised to the detriment of social capital in schools.

Empowerment of teachers and transformative professional development experiences are therefore seen as fostering the development of professional capital which can be achieved by nurturing human capital, decisional capital and social capital. An advantage of this empowerment is that it helps avoid the prospect of teachers allowing technology to determine pedagogy and themselves merely taking a facilitator role and becoming guilty of 'passing the leadership role to the ICT' (Becta, 2003, p.31).

This reinforces motivation to assimilate the key findings from each section above to support development of an improved approach to professional development.

2.2.7 Improving professional development

Capacity-building for teachers relating to their use of technology to support teaching and learning, regardless of career stages, is 'not a simple effort' (Voogt & Tondeur, 2015, p.532).

The Department for Education recently convened a Teachers' Professional Development Expert Group to review evidence relating to best practice in professional development and develop a Professional Development Standard to support teachers as they maintain and develop their practice in the light of the current set of Teachers Standards (DfE, 2011). The resultant Standard for Teachers' Professional Development

(DfE, 2016) highlights an expectation that teacher professional development should 'have a focus on improving and evaluating pupil outcomes', be 'underpinned by robust evidence and expertise', 'include collaboration and expert challenge', and 'should be sustained over time' (p.3). Associated guidance includes emphasis that training should seek to link pedagogy and subject knowledge (p.8) and include 'focused discussion about practice' (p.9). It also acknowledges that one-shot training is less effective than sustained activity, suggesting that effective professional development 'is iterative, with activities creating a rhythm of ongoing support and follow-up activities' (p.10). Twining et al (2013) add 'experimental' to their own similar list of recommendations based on an extensive literature survey relating to professional development activity, as well as suggesting that evaluation may be an important aspect of follow-up activity.

It is pleasing that these recent additions to the literature add weight to the findings outlined in previous sections and bear helpful resemblance to one of the more detailed sets of recommendations in a study identified earlier (van Driel et al, 2012).

This review which specifically aligns to my own subject area, identified six core features of effective professional development activities (p.131-134):

- They include a focus on Pedagogical Content Knowledge – to affect teacher cognition and classroom practice
- They involve active and inquiry-based learning - to enhance perceived relevance and usefulness
- They are collaborative – to facilitate interaction and potentiate teacher learning
- They occur over a sustained period of time - to foster intellectual and pedagogical change
- They offer coherence with the professional working context of the participants
- They are supported by school organisation – to ensure that time and location are conducive to professional learning

Similarly, Angeli & Valanides (2008) identify four features of knowledge construction in developing the use of educational technology by student teachers: awareness; engagement in real-world authentic tasks; collaboration; and opportunities to discuss with an expert. Professional development that embraces the ideals derived from these sources can provide opportunities beyond merely enhancing operational skills, and lead towards challenging teacher values. This mirrors a shift from what has been more generally described as 'knowledge for practice' towards 'knowledge of practice' (Vescio et al, 2008, p.88).

In terms of capacity to teach with technology, these ideas can also be seen to support the development of what Loveless (2007) identifies as 'accomplished' teachers who are

- Ready (possess vision)
- Willing (are motivated)
- Able (knowing and being able 'to do')
- Reflective (able to learn from experience)
- Communal (willing to act as a member of a professional community)

Each member of a community of practice can make a significant contribution to the group through discussion and peer coaching but supporting this may require the use of flexible approaches as advocated by Preston (2004) who asserts that a one-size-fits-all approach may not benefit all participants.

In additional to time and money identified in earlier sections, poor prior experience, additional workload and even guilt about leaving colleagues to cover classes are identified as barriers to engagement with CPD (Wellcome Trust, 2006). This reinforces the need for professional development activities to have perceivable relevance to teachers' working contexts (van Driel et al, 2012).

Van Driel et al also identify that there is no empirical evidence that professional development is more effective if situated entirely in school (ibid, p.134) which may suggest that a hybrid approach is worth considering. This would add welcome flexibility that may be required to foster effective communities of practice, particularly when comprising teachers from a range of schools.

A clearer picture therefore emerges of the types of professional development that may foster transformation of practice, as well as the attributes of successful practitioners and 'users' of professional development. These ideas are carried forward into the research described in later sections which aims to establish vision, equip, afford reflection and offer a supportive community of practice.

TPACK is next explored in terms of its practical affordances as a theoretical lens to support professional development activity.

2.3 TPACK

A number of ideas can be found in the literature that have potential to support thinking about, and to offer some insight into, teachers' use of technology. Notable suggestions include Calvani et al (2008) who developed a conceptual model relating to the notion of digital competence and an associated assessment instrument, albeit for use with students. Alsofyani & bin Aris (2011) developed a system for identification of pedagogies employed by teachers whilst using technology. This was, in essence, a tick-list which perhaps did not take into account the possibility that *not* making use of technology could be a valid pedagogical decision.

Technological Pedagogical Content Knowledge (TPACK) is a model which adds technology as an additional dimension to the established model of PCK (Mishra and Koehler, 2006) with a variety of assessment strategies offered including one to which I will refer again later by Archambault & Crippen (2009). Britten & Cassady (2006) developed measures of technology integration by teachers based on TPACK which were subsequently developed further by Harris et al (2010) and claimed to be more 'pedagogically inclusive' than earlier measures (Harris et al, 2010, p.1) although this was based on assessment of only some of the aspects of practice the model articulates (see 2.3.1).

It is clear that there is a range of models that can be used to gain an insight into technology use and that these, in turn, offer a range of strategies for attempting to

assess practice. Calvani et al (2008) stress that the most important aspect when choosing an instrument is 'awareness about the nature of the entity that has to be assessed' (p.188). They also warn that digital competence cannot be assessed by looking at a single metric and that a flexible, integrated approach is needed.
Becta (2003) similarly emphasise the inter-relatedness of different aspects of teaching:

> A major part of effective use of ICT lies in the planning, preparation and follow-up of lessons, and in particular the pedagogical thinking that links teaching style, the selection of resources, the activities and the learning objectives. (Becta, 2003, p.34)

For the purposes of this research project, a theoretical model is required which not only affords the ability to identify and assess teachers' understanding and integration of technology but also to stimulate thinking about how pedagogy and technology are related. Of the models encountered, Technological Pedagogical Content Knowledge (TPACK) offers a particularly promising way of exploring the different dimensions of teaching both individually and in combination.

2.3.1 Introducing TPACK

It is clear so far clear that, for effective technology integration, teachers require both a sound knowledge of appropriate technology and a secure understanding of how it can be exploited to best effect. A challenge exists to not only train teachers to use new forms of technology but also to engage them in consideration of the pedagogical affordances of new technology. TPACK has generated significant interest since its introduction in 2006, building on the established model of Pedagogical Content Knowledge (PCK) (see section 1.1). TPACK is a theoretical framework which facilitates consideration of the relationship between technology, pedagogy and the curriculum, and is explored here as a vehicle to develop a shared understanding and common language for engaging teachers in a more meaningful form of professional development.

Since its introduction over thirty years ago, there is still significant ongoing interest in PCK as a lens through which to explore and evaluate practice, particularly in my particular field of Science teaching given the abstract nature of many of the inherent concepts, as can be seen from conference proceedings (e.g. the strand on professional development at ESERA, 2015). As a result of sustained interest, a number of the tools introduced for this purpose are well-developed. One of these, content representations ('CoRes') developed by Mulhall et al (2003), is explored later in terms of its potential for adaptation to meet the additional demands imposed by the addition of technology to the equation.

Responding to the idea that 'research in the area of educational technology has often been critiqued for a lack of theoretical grounding' (p.1017), Mishra and Koehler (2006) expanded the well-established model of PCK to include technology as a third domain. This creates a model with three discrete but overlapping domains representing different types of understanding needed for effective teaching.

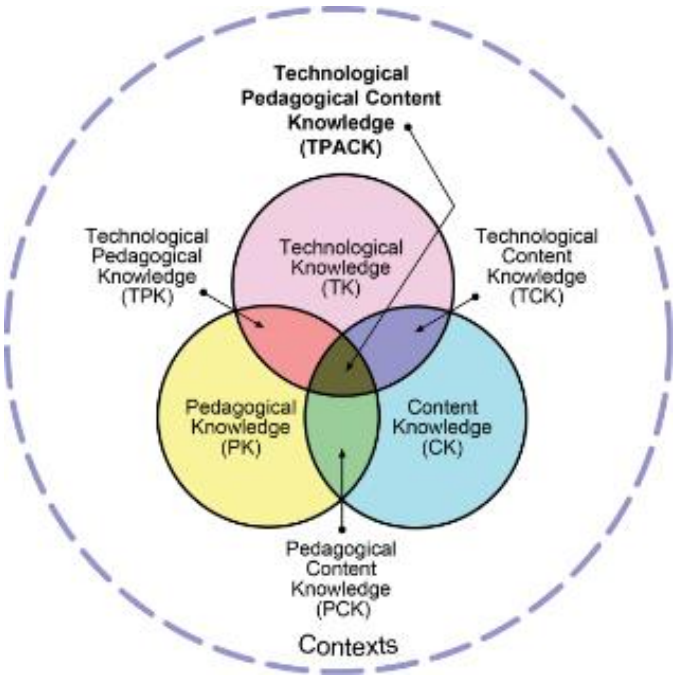


Figure 2: TPACK

The introduction of the technology domain creates three new blended subdomains:

- Technological Content Knowledge (TCK) – knowledge of the relationship between subject matter and technology (e.g. how new technologies have advanced knowledge within a subject discipline)
- Technological Pedagogical Knowledge (TPK) – knowledge of how technology influences teaching and learning (i.e. the pedagogical affordances of technology)
- Technological Pedagogical Content Knowledge (TPCK) – understanding of the complex interplay between all three domains

TPCK was deliberately changed to 'TPACK' to not only render it simpler to vocalise but also to attempt to emphasise the holistic nature of the concept rather than the simple combination of its substituent parts, this being expressed as the 'Total PACKage' (Thompson & Mishra, 2007).

At the heart of the diagram, TPACK is

> a contingent, flexible kind of knowledge that lies at the intersection of these knowledge bases, requiring teachers to develop deep, complex, fluid and flexible knowledge of all three components of the framework (Koehler et al, 2011, p.149).

Representing TPACK in this manner fosters consideration of the individual components that contribute to expert teaching as well as the more holistic view of how these components interact intended by the authors.

2.3.2 Understanding TPACK

Although a succinct representation, there has been considerable debate in the literature regarding the apparent difficulties involved in interpreting and applying the model. Voogt et al (2013) recognise that 'TPACK is an intuitive and easy-to-communicate concept' but do acknowledge that 'from a theoretical perspective, TPACK is a very complex concept and causes scholarly debate' (p.118).

Part of the problem appears to be that, although it is easy to define what lies at the centre of each of the seven subdomains within the model, it is harder to articulate the types of practice that might lie at the boundaries of the subdomains where they overlap. Jimoyiannis (2010b) asserts that 'the boundaries between [subdomains] are still quite fuzzy' (p.1261) and his notion of fuzziness is widely used in this respect. Schmidt et al (2009) assert the importance of developing 'reliable assessment approaches for measuring TPACK and its components' (p.126) but this has subsequently proved difficult. A range of strategies have been developed, based on self-report, performative judgements of teaching artefacts or observation of teaching practice (Britten & Cassady 2006, Koehler et al, 2007, Archambault and Crippen 2009, Schmidt et al, 2009, Harris et al, 2010, Abbitt 2011a, Sadaf et al, 2012, Koh and Chai 2014) but there is, as yet, no consensus regarding the most effective, or indeed useful, way to measure TPACK. A number of strategies employed by a variety of researchers are, however, worthy of note.

Prior to publication of the TPACK framework, a number of tools did exist to attempt to explore the extent to which technology was integrated into teachers' practice. Britten & Cassady (2006) developed a 'Technology Integration Assessment Instrument' which supported consistent judgements about teachers' integration of technology in their lesson planning. Although meaningful, judgements on each of a number of aspects of lesson design were limited to four levels: technology was not present; use of non-essential technology was evident; supportive technology was used; or technology was an essential component of the lesson. Broad judgements about what we might now term TPACK were possible, although the model seems flawed in that teachers may have valid pedagogical reasons for not choosing to use technology. It might therefore be useful to be able to consider the individual contribution the subdomains make to teacher choices as well as taking a more holistic view.

The originators of the TPACK model attempted to do this by isolating and quantifying statements made by teachers during collaborative course design activities. By analysing communication at three stages during this process, they reported a change in the quality of discussion based on the frequency of statements corresponding to each of the seven TPACK subdomains (Koehler et al, 2007). Although Krippendorf

(2004) suggests that content analysis is a useful tool, being both unobtrusive during data collection and that it can handle unstructured data, Abbitt (2011a) suggests that it is too labour intensive for practical use in the field of TPACK and that researchers may be drawn to alternatives.

Archambault & Crippen (2009) developed a self-report tool which they used in two ways. A series of statements were prepared that bore explicit links to each of the domains within the TPACK framework. Participants scored themselves for each item yielding, on analysis, a measure of confidence in each domain. Subsequently, participants were introduced to the TPACK framework and attempted to identify the domains to which each statement belonged. They concluded that, although participants were able to distinguish easily between the three core domains, the inherent 'fuzziness' of the blended domains made distinction difficult. Archambault subsequently questioned the existence of these domains in practice (Archambault and Barnett, 2010).

Harris et al (2010) returned to Britten & Cassady's instrument to develop a 'Technology Integration Assessment Rubric' and reported success using it to make judgements about teachers' lesson planning. They suggest that external performative judgements may be preferable to self-assessment due to the difficulty distinguishing performance from confidence.

Voogt et al (2013) evaluated the reliability and validity of a number of published self-assessment instruments and noted differences in the ways in which they assess different constructs within TPACK. They assert that:

> Teachers need to demonstrate what they can actually do with technology in their subject for enhancing teaching and learning. Such instruments, however, are not very well developed, at least not for research purposes. (p.119)

More recently, Koh and Chai (2014) developed a 'TPACK for Meaningful Learning Survey Instrument', which shares a number of features with Archambault and Crippen's (2009) tool, as a means of assessing the TPACK of both trainee teachers and teachers undertaking in-service CPD. This comprised an online test in which participants were asked to rate a series of features directly and explicitly linked to

each of the TPACK subdomains. They report success in eliciting and evaluating development in teachers' and trainee teachers' TPACK. Contrary to Archambault and Barnett's (2010) comment regarding the possibly dubious nature of some of the subdomains, they note that there is significant potential for further study in this area to link theory and practice relating to TPACK.

A range of models therefore exist, most of which suggest that TPACK is a tangible construct and that it may be possible to quantify aspects in a meaningful way. Further development is needed (Voogt et al, 2013) and perhaps a shift in focus is needed, away from the need to simply measure TPACK but to exploit it to allow teachers 'to demonstrate what they can actually do with technology in their subject for enhancing teaching and learning' (ibid, p.119). Rather than being the theoretical preserve of researchers, TPACK may have an equally significant role to play in developing the pedagogical foresight needed to help teachers use technology to enhance learning.

2.3.3 TPACK for teacher development

Although there is no consensus regarding the most effective way to measure TPACK, it appears to be an endeavour worthy of persistence (Schmidt et al, 2009) and instruments trialled to date appear to offer convincing evidence that the framework can be beneficial in developing teacher practice (Jimoyiannis 2010a, Koehler et al, 2011).

In addition to its theoretical appeal, there is the suggestion that practical application of TPACK is something to which researchers still aspire (Abbitt, 2011a; Voogt et al, 2013) and something that warrants further investigation (Jimoyiannis, 2010b). A number of studies appear to suggest that a combination of assessment and professional development activity can permit quantification of aspects of TPACK and that it is relatively easy to promote and record development in the PCK, TCK and TPACK domains (Graham et al, 2009; Abbitt, 2011b; Koh Chai & Tsai, 2013). Harris & Hofer (2011) also suggest that TPK can be strongly influenced using lesson design activities. Although the potential of TPACK to influence the types of professional

development activity for both pre-service and in-service teachers is recognised (Schmidt et al, 2009; Akkoç et al, 2008), there appears to be limited attention paid to how TPACK can be used to lead to these changes as opposed to merely being the lens through which change is observed.

2.3.4 TPACK: unfulfilled potential?

Although Jimoyiannis (2010b) suggests that TPACK has 'largely remained in the theoretical realm' (p. 1260) and Cox & Graham (2009) venture that 'there is still much work to do to fully understand the framework's complexity' (p.69), I am, however, left with the conviction that TPACK is a potentially highly valuable vehicle for developing a common understanding and language linking pedagogy and technology and that collegial approaches to CPD will be instrumental in bringing about changes to teacher practice that are effective and long-lasting.

Abbitt (2011a) ventures:

> although it is critical to continue to examine, define and refine the TPACK framework, it will be through the efforts to work toward the practical application of the TPACK framework that will enable its use in improving teacher preparation for technology integration (p.298).

Such literature as there is relating to the operationalisation of TPACK appears to largely derive from the United States and from Singapore, suggesting that there appears to be a gap in the literature relating to the application of TPACK in the UK. This provides a challenge regarding the operationalisation of TPACK in UK teacher development and I feel that the language afforded by TPACK may well prove significant in fostering collaborative evaluation of practice and planned development. In this respect, it is possible that TPACK may yield value both as a tool and as a driver for developing educational practice.

My interest in technology-enhanced learning stems from a previous career teaching science in schools and therefore centres on potential applications within the science

classroom. Few of the studies in the literature relate to application of TPACK in specific subject areas (Voogt et al, 2013) although there is clear recognition that knowledge is situated and that subject context is important. Of the limited number of subject-specific TPACK studies identified, the majority do appear to relate to the sciences (Wu, 2013).

Jimoyiannis (2010b) suggested that he was the first to consider TPACK exclusively in the context of science education and proposed the term 'Technological Pedagogical Science Knowledge' or 'TPASK' although this term has not caught on and I am reluctant to adopt this since there will be many overlapping technologies and pedagogical affordances with other subject areas. To limit scope for consideration seems unwise. Science, however, with its many abstract concepts does provide a fertile ground in which to consider the role technology can play in enhancing learning and in exploring the potential of TPACK as a platform upon which to construct professional development activity.

2.3.5 TPACK – a self-limiting construct?

Rogers and Twidle (2013) remind us that, as new technologies emerge, 'the software and hardware simply remain tools, which, if they are to achieve teaching and learning gains, need the pedagogical input of the teacher' (p. 235). The implication is that technology has potential to add to what we might consider a teacher's pedagogical 'toolbox' becoming one of many resources upon which teachers may draw in order to support learning to the best of their ability.

Cox and Graham (2009) suggest that, as ICT use becomes integrated into teacher practice, 'TPACK transforms into PCK' (p.64). We must remain mindful, however, of the warning that knowing how to use technology does not automatically translate into effective teaching (Mishra & Koehler, 2006; Britten & Cassady, 2006) and place the emphasis in Cox & Graham's statement on 'integration' rather than 'use'. In a similar vein, Paiva et al (2016) suggest that 'the information age has reached maturity' (p.226) and that, as technology becomes ubiquitous, it will ultimately become 'invisible'. They suggest that 'e-learning' will simply become 'learning'.

These ideas perhaps fail to recognise that new technology continues to emerge and teachers will inevitably continue needing to develop their technological knowledge through the acquisition of new operational skills. With new technological opportunities, there remains a need to consider pedagogical affordance. The development of practitioners' TPACK must, therefore, be a never-ending journey.

2.4 Conceptual framework

'Reviewing literature is essentially an act of interpretation' (Vescio et al, 2008, p.88) but it is hoped that the conclusions offered from the literature explored here provide a broad, honest and secure base upon which to construct subsequent research.

In considering the challenges of teaching with technology and supporting teachers to do so, a number of significant points emerge as summarised in Table 1.

In aspiring to construct professional development to support teachers' abilities to integrate technology in teaching and learning, it therefore seems that appropriate activities will:

- Focus on *why* rather than just *how* to use technology
- Be collaborative
- Be relevant, affording the opportunity for ownership of tasks
- Provide extended opportunities to engage rather than an isolated event

Within this structure, the language of TPACK is seen as ideally suited to this challenge and its potential as an operational framework rather than simply a theoretical framework is very attractive.

1	The adoption of technology by schools may mean that teachers are having to teach in unfamiliar ways (Vacirca, 2008, p1)
2	Students tend to outpace teachers in understanding new technology and teachers need to be more active in bridging the divide between their digital literacy and that of their students (Hramiak, 2012)
3	Technology may be used but may not be exploited to the best pedagogical effect (Koehler et al, 2011; BESA, 2015)
4	Knowing how to use technology does not directly translate into effective teaching (Jenkins, 2009; Groff and Mouza, 2008; Mishra and Koehler, 2006)
5	Technology provides the tools, but teachers are still responsible for pedagogical decisions (Rogers and Twidle, 2013)
6	A range of barriers may exist affecting teachers' beliefs and preventing effective use of technology in the classroom (Becta, 2003; Groff & Mouza, 2008)
7	Teachers at different stages of their careers bring different experiences but face similar challenges in developing links between digital literacy and pedagogy (Vacirca, 2008; Hramiak, 2012)
8	'Technocentric' or transmissive forms of CPD tend to have limited longevity of impact (Harris and Hofer, 2011)
9	Teachers want professional development activities to help enhance their classroom practice rather than simply to teach them operational skills (Rodrigues et al, 2003).
10	CPD activities are often too short to have lasting impact and isolated training events are less effective than those with follow-up activities (Sherwood, 1993)
11	Teachers prefer face-to-face training to all-online training (Preston, 2004)
12	Training should afford teachers the opportunity to relate it to the daily reality of their teaching so that it fosters personal reflection (Preston & Cuthell, 2007; Schön, 1983; Koehler et al, 2011)
13	Ownership of aspects of training fosters personal investment reducing barriers to implementation (van Driel, 2012)
14	Collegial forms of CPD tend to be most effective (Koehler et al, 2011; Preston and Cuthell, 2007; Jimoyiannis, 2010a; Voogt et al, 2013), developing social capital and allowing participants to tap into the human capital of others (Hargreaves & Fullan, 2012)
15	TPACK provides a useful vehicle for considering the relationship between complex forms of knowledge required for the integration of technology (Koehler et al, 2011)
16	TPACK has great theoretical appeal but evidence of practical application is limited (Jimoyiannis, 2010a)

Table 1: Conceptual summary

To summarise how the conceptual ideas behind the research, identified in Table 1, are related and provide a logical underpinning to the proposed research, components can be rationalised into a flowchart as shown in Figure 3.

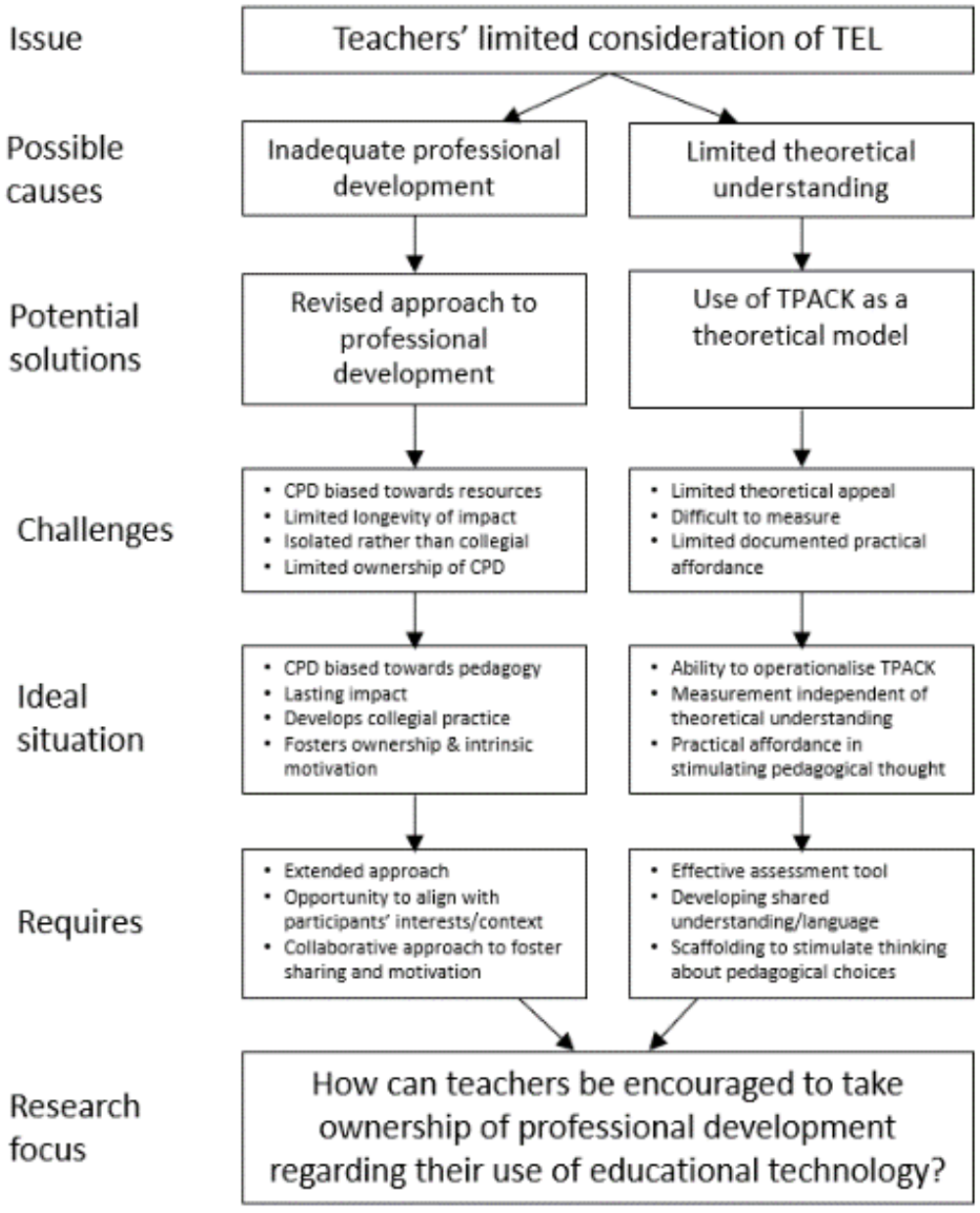


Figure 3: Conceptual framework

Further to this, the additional consideration of professional capital as an important perspective, that has emerged from deeper thinking as the project developed, allows representation to be made of how different aspects of the conceptual framework support each other to contribute to a holistic notion of developing practice.

Through the shared language afforded by TPACK and through shared professional development activity, it is hoped that participants' professional capital can be enhanced by development in each of its constituent dimensions: human capital, social capital and decisional capital.

The contributions that different components of professional development activity might make to each dimension can be summarised as follows:

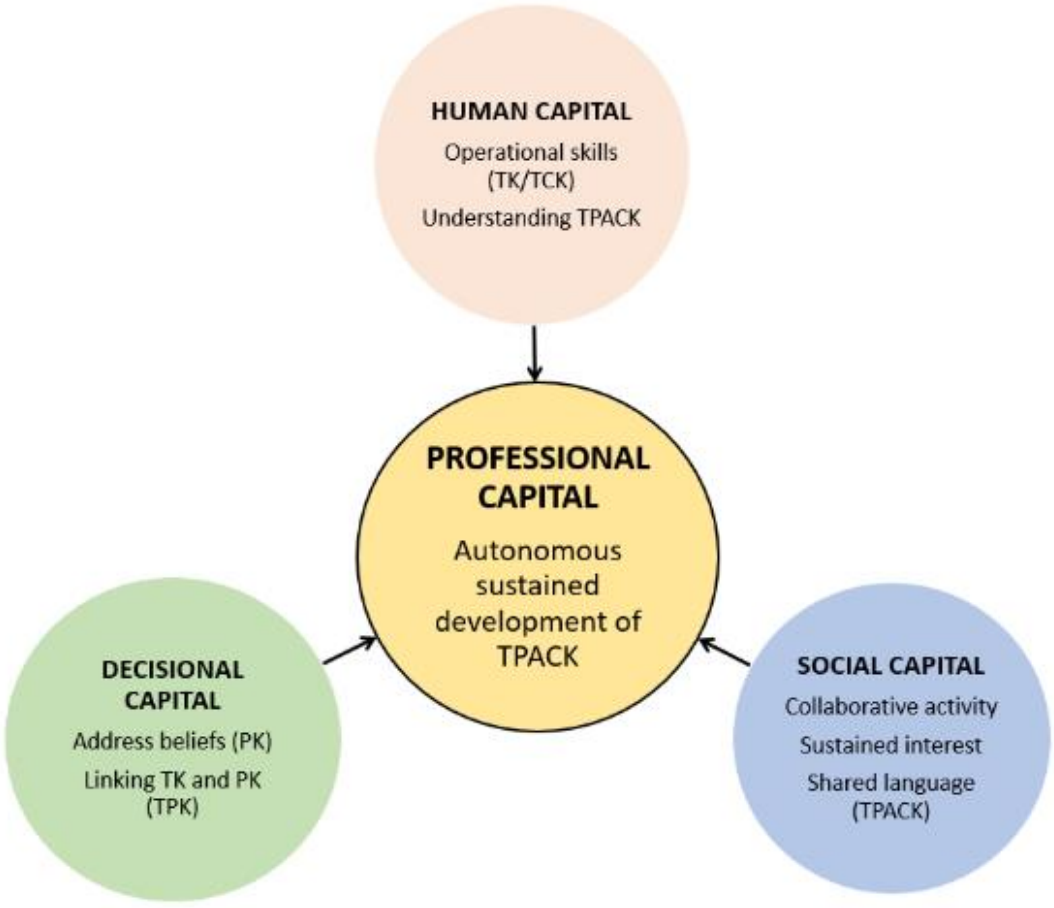


Figure 4: Developing professional capital

Consideration is given in chapter 6 to how the overarching research focus shown in Figure 3 (as presented during the ethical approval process and so left unchanged here) might have been reconsidered in terms of professional capital.

The utility of professional capital as a perspective through which to unite aspects of this project, is revisited as a helpful lens through which to consider the findings.

Out of the conceptual framework developed from the literature review, several researchable questions emerge:

> RQ1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology?
>
> RQ2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development?
>
> RQ3. To what extent is a community of practice important in securing sustained impact of professional development?
>
> RQ4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination of practice?

In the next chapter, the conceptual framework is used to scaffold creation of an appropriate research design to address these research questions. This involves the development of a professional development experience and a range of tools to support thinking, reflection and assessment of impact.

3 Chapter 3: Methodology

3.1 Introduction

In this chapter, I will explore the philosophical underpinnings needed to support the development of an appropriate research design. A pragmatic abductive stance leading to an action research approach using mixed methods for data collection is presented and justified in relation to the aims encapsulated in the research questions. The development of the tools created to allow the research to be performed are described and a timeline of research presented. Issues relating to validity and trustworthiness of results are explored, and analytical and presentational techniques are outlined. Finally, ethical issues associated with this research are considered.

> While knowledge of TPACK will advance through the study of teacher practice, researchers must consider the methodologies that are best suited for this line of inquiry… the examination of teachers' TPACK is a complex process that requires teasing out the various components of TPACK in addition to the classroom-based evidences of those components. Future studies should address some of these complex issues. (Polly & Brantley-Dias, 2009, p.46)

Underpinning the design process is recognition, derived from the literature explored in chapter 2, that there is no consensus regarding how teachers' Technological Pedagogical Content Knowledge can be assessed or how this knowledge can be used to foster development of practice. Tools developed for assessment must be developed flexibly and assessed for validity, and the complexity of teachers' work accounted for in the interpretation of findings. The potential to make a positive contribution to existing literature in these areas makes this a worthy challenge.

3.1.1 A philosophical journey

In this section, I reflect on the significant journey required from my starting point as a scientist to my arrival at an informed and secure standpoint upon which to base research methods adequate for this study. This journey takes me beyond an initially binary perception of research paradigms and leads, via pragmatism and process philosophy, towards abduction as the philosophical stance upon which the subsequent methodology is based.

3.1.1.1 A life scientific

As a scientist with some previous research experience in the field of neurochemistry, it is perhaps inevitable that I initially approached educational research with a somewhat fixed view of the nature of 'reality' and the tools by which this might be explored, putting me in the realm of what Baert (2005, p.61) terms 'methodological naturalism'. This somewhat archaeological perspective on research, that the truth is there waiting to be simply 'dug up', quite clearly holds little currency in a realm such as education where the reality of a given situation needs to be understood as being viewed from one of many perspectives and where there are too many variables to be controlled. A risk faced by scientists such as myself is therefore that we may previously have approached research from the constraints of a single paradigm which is so established that little consideration is given to the ontological or epistemological assumptions that have been made.

In the positivist tradition of scientific research, adequate methods lead to reproducible outcomes and the development of theory. Theory tends towards being labelled as fact in the absence of disproof. This test of 'falsifiability' (as described by Karl Popper in 1935, reprinted in English, 1977) established the basis of contemporary Scientific Method.

In educational and social settings, we must acknowledge that there are a significant number of variables and that attempting to control these may influence the nature of what can be discovered. This 'observer principle' is an important admission in any social research design. The ability to control variables involves first recognising what

these variables are, which may be easier when the nature of research is to perform a simple empirical investigation, but social situations are generally more complex than this.

Another difference between scientific research and research within the social sciences concerns the location of the researcher in relation to the object of study. In science, the researcher is generally seen as external and objective but, in the social sciences, the researcher may be more deeply involved and have greater influence over outcomes. For critical theorists, for example, a motivation for research is not just to explain but also to elicit change (Cohen et al, 2000; Newby, 2014).

The nature of truth within social research can therefore be seen as more subjective and, before the ability to generalise results can be explored, the philosophical underpinnings of this research deserve consideration.

3.1.1.2 A social jungle

'Social science is a terminological jungle' (Lofland & Lofland, 1984 cited in Verma & Mallick, 1999, p.45) and a new language for researchers from a positivist tradition but, at the heart of research philosophy, lies the interplay between ontology (the nature of reality) and epistemology (what can be known or discovered about that reality). The relationship between what can be researched and what can be discovered may differ for researchers from different standpoints. These differences are often ignored in scientific research, considered immaterial in the light of the requirement for reproducibility of results. Facts are seen as fixed and waiting to be discovered. In ontological terms, this is described as objectivism whereby facts exist 'beyond our reach or influence' (Bryman, 2008, p.18). Consistent results may lead to the formation of theory and the nature of accepted theory might, for example, only be considered limited by the availability of suitable techniques. As new techniques emerge, theory is refined. This objective, positivist approach carries with it a set of assumptions which, in turn, dictate an accepted set of strategies for research which collectively form the normative paradigm within which scientific research operates.

Although some social scientists do operate in the realm of positivism, for example exploiting quantitative techniques to make sense of big data and invoke causal determinism, much research in the social sciences must account for the complexity of the world it seeks to explore. In these cases, there is an understanding that, despite any ontological assumptions about reality, the nature of what can be known is highly dependent on context. It may be construed that the nature of reality is a product of the construction of meaning made by 'actors' in the social world. This gives rise to the notion of constructivism as an epistemological position. This may sit uneasily with scientism (Baert, 2005, p.78) but educational research often involves research about people and therefore brings many variables into play such as demographic, ethnographic and temporal considerations as well as individual factors such as social cognition and affect. In such cases, the perspective of the researcher in relation to this may similarly affect perception, unconscious bias and interpretation, rendering judgements and conclusions subjective at best.

This researcher effect *is* acknowledged in a modified form of positivism known as post-positivism which validates the use of qualitative methods in the previously positivist domain (Giddings, 2006). Whilst, as researchers, we attempt to reduce factors such as unconscious bias through careful construction of methodology, much educational research perhaps needs to go further, acknowledging this inherent subjectivity but also recognising that conclusions are constrained by time and place as well as other uncontrollable variables. These constraints lead to an ideographic understanding of the object of research which is interpreted as honestly as possible by researchers through a set of research values and established approaches which can be collectively described as the interpretivist paradigm.

Given the nature of this research project, there needs to be acknowledgement that the research is constrained by time and context since it focuses on the current experiences of a select group of experienced and pre-service teachers. Findings and conclusions can be related to the set of contexts by which the study is bounded and influenced by my own ability to analyse and interpret the data collected. Similarly, the participants who form the object of this research will have their own perceptions and understanding of issues which will colour the information that can be derived from

them via questionnaire or interview. The notion that individuals may make sense of the world in different ways and, by implication, shape the information that can be mined from them, forms the basis of phenomenology which is 'one of the main intellectual traditions that has been responsible for the anti-positivist position' (Bryman, 2008, p.15) and validates the assertion that a subjectivist approach may be more appropriate in this study.

3.1.1.3 A tale of two camps?

Given its resonance with the implicit epistemological assumptions made regarding this research study, it might be tempting to nail my colours to the interpretivist mast at this point. There appears to be a tendency in research methods literature (particularly introductory research methods texts) to simplify ontology and epistemology as concepts that are inherently binary (objectivism vs. subjectivism; nomothetic vs. ideographic; positivist vs. interpretivist; qualitative vs. quantitative; or inductive vs. deductive). Historically, positivism and interpretivism appear to have been considered mutually exclusive and incompatible as approaches to research (Johnson & Onwuegbuzie, 2004), fuelling what Gage (1989) called the 'paradigm wars'.

Post-positivism goes some way towards bridging this divide in that qualitative data and methods may find valid use alongside the perceived security of quantitative methods but, given that part of the object of this research is to promote and assess change rather than merely attempt to determine what 'is', a more pragmatic stance is perhaps required. Pragmatism suggests an epistemological viewpoint in which knowledge is best characterised by its practical application and advocates the use of multiple perspectives to arrive at a realistic representation of the social world, tempered as it is by context, time and human factors.

Morgan (2014) extends the notion of pragmatism as a separate paradigm, suggesting that 'knowledge is not about an abstract relationship between the knower and the known' (p.1049) and even questions whether a focus on the metaphysical constructs of ontology and epistemology make any difference to the knowledge created by research. He ventures that pragmatism links beliefs and actions, implying that research

need not be framed as a series of 'commitments to an abstract set of philosophical beliefs' and that 'it is time to put metaphysical issues behind us' (p.1051). Johnson & Onwuegbuzie (2004) are not quite so dismissive but provide a convincing summary of arguments for pragmatism which leads them to assert that 'research approaches should be mixed in ways that offer the best opportunities for answering important research questions' (p.16).

Another interesting epistemological puzzle develops the notion of *what* can be known and considers *how* the truth can be seen. Process philosophy, as an extension of pragmatism, suggests that reality can best be described in terms of perceivable change rather than attempting to view it as a fixed idea in which important issues may be camouflaged. It takes a holistic view of human experience and attempts to combine objectivity and subjectivity to gain an insight into the nature of reality based on multiple perspectives.

Process philosophers of relevance here include the pragmatists Charles Peirce, who suggests, as paraphrased by Hustwit (2018), that truth is 'the unattainable goal of a never-ending process of inquiry' (section 1a), and William James who emphasises both the 'strong individuality' and 'important internal interconnectedness' of events as described by process philosophy (Jones, 1998, p.vii). Jones suggests that a focus on subjective experience articulates what the process philosopher Alfred North Whitehead described as 'intensity'. Using the lens of intensity affords a process view that can reconcile multiple perspectives into a representation of reality whilst acknowledging that the picture constructed in so doing is never complete. In a lecture of 1927-28 Whitehead (1978) suggested that the picture we might attempt to present of reality is blurred by 'weakness of insight and deficiencies of language' (p.4). Perhaps overcoming this can be likened to using multiple angles to build up a representation of a three-dimensional whole. Recognising that this representation is not perfect but comprises many individual parts, Jones (ibid.) terms this composite view 'satisfaction' (p.23). An infinite perspective would lead to a 'satisfied actuality' in which the object of study exists as a discrete entity rather than an incomplete representation. Whilst this is a very simplistic interpretation of what feels far more reductionist (process philosophy being used, it seems, as a synonym for 'atomistic metaphysics'), it lends

weight to the idea that objectivity and subjectivity can be reconciled and that multiple perspectives provide a useful means of elucidating the Big Picture (a process Jones terms 'concrecence').

William James' pragmatic method stems from a belief that philosophical theories should not simply be a response to pre-existent facts but should be responsive to emergent ideas or perspectives. He argued that 'theories thus become instruments' (James, 1975, p.32) suggesting that philosophy is an evolutionary process and reinforcing the notion that the philosophical goal of research is to use available perspectives to support concrecence and achieve 'satisfaction'.

The responsiveness of such methods to emergent findings, and the perceived benefits of taking multiple perspectives resonates strongly with the intentions of this research which seeks to develop tools and evaluate their use. To arrive at the philosophical stance adopted for this study, one further step is required. The methodological responsiveness of process philosophy and its pragmatic roots have further developed into an alternative worldview to the inductive insights afforded by interpretivism and the deductive insights of positivism, this being known as abduction.

3.1.1.4 Abduction

At its heart, abductive reasoning is summarised most simply by the logic inherent in:

> *D is a collection of data*
> *H explains D*
> *No other hypothesis explains D as well as H does*
> *Therefore, H is correct*
> (Josephson et al, 1986, p.459)

This highlights the inherent value of multiple perspectives and the consideration of alternative explanations. For this reason, abduction is often described as 'inference to the best explanation' (Biggs, 2011, p.283).

Abduction therefore identifies consequences and seeks, through the consideration of multiple perspectives, to construct reasons. In contrast, deduction begins with a rule or hypothesis and seeks to confirm or falsify, and induction starts with an identified pattern and develops inference about an explanatory rule. In this respect, induction and abduction can both be regarded as 'ampliative' (Harris & Hoover, 1980, p.329) in contrast to deduction, which is described as 'explicative', although abduction is infused with a 'logic of discovery' (Niiniluoto, 1999, p.440).

Biggs (2011) simplifies abduction as a process, suggesting three stages:

1. Identification of a phenomenon that requires explanation
2. Generation of theories with potential to explain the phenomenon
3. Identifying the theory that best explains the phenomenon
   (p.293)

The inferential principles applied to rank possible theories are based on notions of simplicity and comprehensiveness. Abduction does not claim to uncover absolute truth (certainty) but to lead to 'hopeful suggestion' (Frankfurt, 1958, p.597) and a greater probability that aspects of truth have been uncovered (confidence or a 'threshold of belief') (Bybee, 1994, p.415). Niiniluoto (1999) terms this 'probabilistic inference' (p.440). Hintikka (1998) suggests, however, that inference to the best explanation is a 'seriously over-simplified' view, and therefore the properties of abduction as an epistemology are worth exploring a little more fully here.

One of the strengths of abduction compared to other modes of inference is its recursive nature, meaning that research oscillates between observation and theoretical generalisation. Methods can be adapted to support the development of better interpretations based on emergent findings.

Adherence to classical methodologies of positivism or interpretivism may be responsible for limiting the field of view of research and causing researchers to ignore some of the surprises that crop up. A tendency to play down anomalies or 'quirks' to limit the influence of counter-examples to a preferred hypothesis is referred to by Tavory & Timmermans (2014) as 'monster-barring' (p.71), whereas they argue that abductive analysis allows theory to be refined iteratively to accommodate unexpected

data thereby by ‘domesticating’ the monster. They similarly refer to the notion of ‘luminosity’ of data in that, when viewed from multiple perspectives, some ideas may increase in brightness emerging as significant and worthy of discussion or further investigation.

Despite often committing to one camp or the other, there is a strong suggestion that, to an extent, all researchers ‘theorize on the go’ (ibid, p.6), reinforcing the need for a flexible approach combining logical inference with creative insight. Abduction fosters this ‘theoretical pluralism’ and responsive capacity whilst providing a ‘coherent epistemological position that is centred on the relationship among theory, method and observation’ (ibid, p.6). Meaning making, argue Tavory & Timmermans, ‘is not an abstract but a practical achievement, occurring in action’ (p.23).

This distinctive recursive spiralling semiotic notion of meaning-in-action, together with the concrecence afforded by multiple perspectives, makes a pragmatic abductive approach the strategy of choice for this research. One perceived danger of probabilistic inference is that judgements may be made, albeit in good faith, from a limited range of perspectives implying that inference may be made to the best of limited data and research treated with an unjustified sense of completeness. Whilst well-intentioned, it is possible that the licence offered by abduction for probabilistic inference may make it difficult to generalise findings to contexts beyond the immediate scope of the study. It is therefore appropriate to consider the notion of generalisability before moving onto consider research design.

3.1.2 Generalisation

In interpreting findings and attempting to draw conclusions, there will be a temptation to generalise. This is acknowledged as a ‘major aim of educational research’ (Verma & Mallick, 1999, p.198) but also an area where a failure to acknowledge the complexity of context may lead to generalisations that lack credibility. For this reason, this aspect of the research process has been described as ‘delicate and complex’ (ibid. p.43). Bassey (2001) similarly recognises the potential to extrapolate as not being easy given the difficulty of controlling the myriad variables inherent in educational research. He

goes on to validate the notion of 'fuzzy generalisation' (p.5) with the caveat that context and evidence be clearly presented so that they can serve as a guide for other practitioners or researchers. Baert (2005) hints at a potential problem associated with interpreting research findings that perhaps cautions us to be careful with fuzzy generalisation, by referring to 'conmen' in the social sciences whose interpretations may not be wrong but, as a result of being guarded in their explanations, might not be 'clear enough to be wrong' (p.62).

Fuzzy generalisation may be acceptable, but clarity of context is needed to ensure that generalisations are suitably bounded. Williams (2000) refers to such generalisations as 'moderatum generalisations' suggesting that transparency and consistency in research design and analysis provide 'some kind of guarantee that the operationalisation represents the reality of those for whom it is intended' (p.222). Although a significant goal of this project is to provide tools that may work in other contexts and therefore generalisation may be offered, there can be no guarantees that the insights gained from this research will translate to all contexts. The findings and tools derived from this study are therefore offered for evaluation by others with full license for their adaptation.

3.1.3 Summary

Although initially falling prey to what I suspect is an early researcher trap, particularly for those from a positivist tradition attempting to engage with the social sciences, it is clear to me that a methodology was needed that met the demands of a transformative agenda. As such, a binary view of research paradigms (positivist vs. interpretivist) proved unhelpful. The potential for abduction to allow the creation of 'meaning in action', redefining theory as a story unfolds, and allowing theory and method to recursively and creatively 'intertwine and amplify' (Tavory & Timmermans, 2014, p.2) makes this the philosophical standpoint of choice for the focus of this research.

As an ampliative epistemology chosen for its capacity to help make sense of the complex world in which teachers operate, I acknowledge that the nature of the outcomes I will describe in later chapters will be highly dependent on both the

participants involved and the methodology chosen. Similarly, my own thinking and expectations have the potential to influence outcomes.

Since one of the intended measurables is the effect on participants' practice, a degree of impartiality is necessary whilst communicating the theoretical framework I have used as a basis for driving their self-improvement. If I present certain knowledge as worthwhile and necessary as a tool to facilitate change, I must be careful as there may be a temptation to place undue emphasis on the theoretical framework being used rather than its operationalisation.

Habermas (cited in Cohen et al, 2000) describes three factors that may render knowledge worthwhile which he labelled technical, practical and emancipatory. The use of the proposed theoretical framework has, I believe, transformative potential in each of these three areas. Firstly, the acquisition of technical knowledge will enable participants to develop their understanding of the pedagogical affordances of the technology under consideration. Second, a collaborative and practical approach to implementing new ideas and evaluating their transformative potential allows evaluation of the transformative potential of the theoretical framework once operationalized. Thirdly, it is hoped that, armed with new knowledge and strategies for implementation, a degree of emancipation and ownership of subsequent development of practice will emerge.

The adaptive and creative merits of abduction give me the confidence to select and refine what are seen as the most appropriate and complementary methods from the many tools available to address the research questions posed in this study as honestly as possible. Having adopted a pragmatic abductive stance, the next section will explore how the research questions have led to the development of an Action Research methodology employing mixed methods to generate rich and meaningful data.

3.2 Research design

Polly & Brantley-Dias (2009) acknowledged that exploring teachers' TPACK is a tricky process, requiring methodologies that are capable of addressing the complex relationship between theory and practice. Doing so will involve exploring teachers' perceptions of how technology is used in the classroom and leading them into active reflection on their pedagogy.

As such, this research is based in multiple locations including the seminar room and teachers' own classrooms. It requires exploration of teachers' understanding and values, using TPACK as a theoretical model to support a common language, as well as opportunities for teachers to explore and evaluate ideas in action in their teaching practice.

Research design therefore needs to include two significant approaches:

1. Creation, refinement and use of tools to support assessment of aspects of participants' TPACK and to scaffold teachers' thinking during face-to-face training activities
2. Practitioner research as teachers apply thinking and ideas derived from training and discussion

This research is therefore necessarily iterative in design so that process and practice inform each other in line with the principles of abduction and so that it can facilitate the ongoing development of a training package whilst supporting the development of participants' practice. The emphasis on practice, the intention to bring about change and the need to evaluate actions formatively in context strongly advocate the use of an Action Research methodology (Gorard, 2013; Bryman, 2014).

A distinction is made between methodology and methods, the first articulating a research approach and the latter the means or techniques by which data will be obtained (McNiff, 2013). As such, the use of multiple methods for data collection sits comfortably within Action Research (Brannen, 2008) and mixed methods are described as 'particularly appropriate' for action research methodologies (Bryman, 2013, p.136). Brannen does acknowledge that there may be allegations of 'paradigmatic conflict' in

making use of mixed methods (2008, p.186) due to the mixing of qualitative and quantitative methods but this is defended convincingly within Action Research approaches (Cresswell, 2009; McNiff & Whitehead, 2011; Bryman, 2013).

McAteer (2013) draws attention to misappropriation of the terms qualitative and quantitative as methodologies, reasserting that they refer simply to data types and that plurality of research methods adds to flexibility within action research approaches.

Given that action research has been described as an 'intellectual elephant' (Ennals, 2013, p.415) of which 'blind scholars' can only seek to grasp a part from which to show understanding, a more detailed consideration of how this study adheres to the accepted principles underpinning Action Research is given in the next section before exploring the contribution that is made by the use of multiple data collection methods within each cycle of activity.

3.2.1 Action Research

The notion of the teacher as researcher is central to the development of practice in schools as advocated by Stenhouse (1975). Stenhouse suggests that 'it is not enough that teachers' work should be studied: they need to study it themselves' (ibid. p.143). His implication is that understanding teaching is key to improving teaching and that it is the practitioners themselves who are best placed to do this. He claims that the sort of highly contextualised, participatory and theoretically grounded activity he advocates leads to transformative potential and raises teachers to a level he refers to as 'extended professionals', typified by teachers who demonstrate capacity for 'autonomous professional self-development through systematic self-study, through the study of the work of other teachers and through the testing of ideas by classroom research procedures' (p.144). The ideals of reflective capacity and ownership of self-improvement resonate strongly with the features of more effective professional development advocated in section 2.2.

Schön (1983) makes a distinction between 'reflection on action' and 'reflection in action' suggesting that 'when someone reflects-in-action, he becomes a researcher in the practice context' (p.68). His notion of the reflective practitioner in combination with that of research in action or 'learning by doing' (Bryman, 2013, p.630) lies at the heart of what has become accepted as action research.

The traditional picture of action research is based upon its origins in the work of Kurt Lewin who characterised it as 'a spiral of steps, each of which is composed of a circle of planning, action and fact-finding about the result of the action' (Lewin, 1946, p.38). Evaluation is formative leading to further trial and subsequent evaluation. This process-oriented view of action research is often illustrated as a spiral of activity as shown in Figure 5 (based on a popular representation by Kemmis & McTaggart as presented in Bloomfield et al, 2004, p.363).

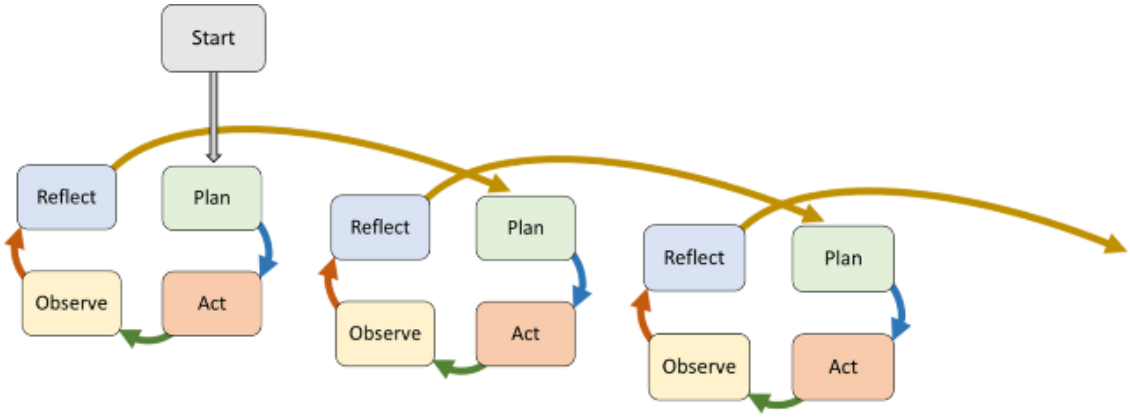


Figure 5: Spiral of Action Research

Although this model embodies the iterative and reflective nature of action research, Townsend (2013) warns against a simplistic mechanical adoption of this process view suggesting that it may act as an 'instrumentalised straitjacket' (p.26) which limits the flexibility of the process. The dangers of a 'recipe' based approach to action research are similarly highlighted by Aragon & Castillo-Burguete (2015, p.14) who suggest that there is a risk that researchers give in to 'instrumentalizing tendencies' instead of planning research which is flexible and responsive to emergent themes.

Within this study, inflexibility might be seen as contradicting the perceived value in the recursive nature of abduction as presented earlier. Townsend, however, cites cases in which action research may consist of incomplete cycles and examples of studies in which some of the phases represented in Figure 5 operate simultaneously, suggesting that instead of dogged adherence to process, action research is instead characterised by subscription to a set of underlying principles. This is clearly not intended to offer licence for taking methodological liberties; a fear that led to accusations that action research lacks rigour (Bryman, 2008). In response, Newby (2014) highlights the need for rigorous assessment in each cycle via pre-planned data collection and review strategies, but Townsend's suggestion is that Lewin himself did not see action research as rigid in its operation but as a commitment to iteratively focus on the interplay between observation and reframing problems.

The use of sequenced approaches to action research within education has, since being championed by Corey (1953), been subject to further criticism (Costello, 2003; Gorard, 2013), not in relation to its potential to understand and transform practice but that adherence to a simple process view has led to a more dilute form of 'participatory reflective progressive problem solving' (Gorard, 2013, p.154) which neglects to take a principled approach. The accusation is that what results is perhaps trial-and-error by individuals which is dressed as research, albeit with some potential to foster reflection and development of practice. A danger of this is that, although capable of fostering personal or professional learning, a lack of solid theoretical grounding may place excessive emphasis on action at the expense of research (McNiff & Whitehead, 2011), limiting the transformative potential of action research as an identified methodology.

This study differs in that it does not deal with the activity of a single teacher (or small group) within a single working context but seeks to understand how practice can be understood and influenced across a variety of teachers' contexts. Change is therefore explored in relation to systems that operate within the contexts under study rather than focusing solely on the individuals or organisations themselves. This form of action research is sometimes referred to as 'action learning' (Newby, 2014, p.65). As I am external to the classroom contexts in which the participants work, this study can also be described as 'second-person' action research (Bradbury, 2015, p.6).

The value of such initiatives has been demonstrated in teacher education programmes (Hine, 2013) and can therefore be used with confidence. The systemic approach this entails, however, demands a focus on the underlying principles of action research to ensure appropriate focus on intended aims.

3.2.1.1 A principled approach

Drawing upon a range of models, Townsend (2013, p.33) suggests eight principles to underpin robust action research, each of which is considered here in the context of this study to offer justification of action research as the selected methodology:

(1) Action research is concerned with changing and improving actions.

Whilst critical theory involves research to inform future change, action research includes enacting and responding to change. Exploring mechanisms through which to enact change and the evaluation of resultant impact are key features of this research.

(2) Action research involves, in some way, research.

Townsend considers applied research in terms of 'research *on, of* or *for* action' (p.35) but suggests that action research moves beyond this in that there is a reciprocal relationship between action and research in which action is seen as research and vice versa. In this study, the tools through which participant research is enacted are also an object of research. In researching the efficacy of the tools, it is hoped that a concomitant impact is seen on participant practice. Reciprocity between action and research is therefore a fundamental goal of this research.

(3) Action research is located in professional, cultural and social contexts and
(4) Action research is an inherently participatory process.

This work is located in the professional context of local participants who engage both as individuals and as groups to explore and share practice and professional learning pertinent to themselves and the different contexts in which they work. Multiple individual and group perspectives are taken in this study to offer a form of perspective triangulation and help overcome the potential limitations of 'individualistic interpretations' (Townsend, 2013, p.36) without downplaying the importance of individual voices. McNiff (2013) refers to this as thinking about

participants as a 'collective of 'I's working together' (p.8) rather than research with the researcher having a singular perspective. To this end, this project is positioned as research *with* rather than research *on* my participants. In addition to these professional and social contexts, the study seeks to challenge the cultural norms perceived in terms of the manner in which professional development relating to technology in education has been enacted.

(5) Action research is consciously and deliberately reflexive and
(6) Action research is a self-critical and socially critical activity.
These principles acknowledge the relationship between the researcher and the object of study and that they influence each other. The recursive nature of this research, rooted as it is in abduction, ensures reflexivity by allowing outcomes to influence methods and tools formatively. This serves to allow thinking to evolve throughout the study and hopefully reduces the risk that results are interpreted by a set of immovable preconceptions. It will later become clear that some of the development of the tools employed has been influenced by acknowledgment that my own understanding of the theoretical model employed has similarly evolved.

(7) Action research is in itself educative.
This reinforces that the educational ideal applies to all professional contexts in which action research might be employed. In schools and other educational contexts, this is implicit in terms of outcomes for participants and their students but might also be taken as relating to the learning derived from reflective practice both on the part of the participants and the researcher.

(8) Change through action research involves leadership.
Whilst leadership may contradict the sentiment behind principle 4, it challenges thinking about the role of the researcher. In this study, I am responsible for setting up the professional development experience but have attempted to create learning opportunities that confer a degree of ownership and autonomy to participants. In doing so, the process makes use of tools of my design but does not limit the participatory nature of the research. Key to fostering group reflexivity is my ability to develop a relationship with the group and its participants. Newby (2014) highlights potential problems with action research approaches including a challenge to address

weaknesses in the democratic process inherent in collaborative research, suggesting that compromise in determining revised actions between cycles can weaken the extent to which the research is seen as rigorous. Whilst needing to be mindful of this, I venture that compromise may be a valid response within the abductive stance taken given the centrality of the participants to the 'action' as noted in principle 4 above. Leadership may also concern what happens with the findings from the research together with the ethical consideration this demands. It is hoped that the tools developed through this study can be offered for consideration and use by colleagues both in schools and in the wider research community.

As a participatory research approach with a focus on reflective practice and enacting change, action research provides a suitable vehicle through which to address the research goals of this study. It provides a means for researching both tools and outcomes, affording an insight into both the systems and practice that form the objects of this research. Having established action research as a principled approach, it is now appropriate to consider the process by which it can be applied to my research questions.

3.2.1.2 Application of an action research approach

This study comprises three cycles of action research, aligned to consecutive academic years, to support the two themes key to addressing the research questions posed. These themes are firstly the development of a toolkit of resources to support assessment of practice and demonstration of impact, and secondly the implementation and exploration of professional development activity to enhance teachers' pedagogical consideration of educational technology.

Contrary to the diluted 'participatory reflective progressive problem solving' postulated by Gorard (2013, p.154) referred to earlier which may give rise to a simplistic notion that action research cycles may consist of repeated cycles of similar activity with minor adjustments, the systemic approach taken here acknowledges assertions that action research may be composed of action-reflection cycles that differ

in focus (McNiff & Whitehead, 2011) to develop a coherent and staged approach to tackling the questions under consideration. The focus may be internal (related to my own learning to inform development of resources), external (concerned with social action and transformation of practice) or both.

The three cycles of action research activity undertaken in this study can be summarised as shown in Table 2 (research questions appended for reference):

	1st cycle	2nd cycle	3rd cycle
Time	Academic year 2014-15	Academic year 2015-16	Academic year 2016-17
Focus	Internal	External and internal	External and internal
Research issue	Understanding how TPACK can be used to explore and assess practice	Using toolkit developed in 1st cycle to support and evaluate professional development. Ongoing development of toolkit.	Using toolkit developed further following 2nd cycle to support and evaluate professional development. Ongoing development of toolkit.
Participants and activity	Pilot group of trainee teachers test resources. Evaluation and development.	Cohort of trainee teachers use resources during planned intervention. Evaluation and development.	Cohort of trainee teachers use resources during planned intervention. Teacher research group convened and resources used for planned professional development activity. Evaluation.
Research question(s)	RQ2	RQ1, RQ2	RQ1, RQ2, RQ3, RQ4

Table 2: Action research cycles

RQ1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology?

RQ2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development?

RQ3. To what extent is a community of practice important in securing sustained impact of professional development?

RQ4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination of practice?

A challenge encountered regarding action research relates to the question of when to stop. It would not be prudent at any point to suggest that research is complete, so the question perhaps instead should be 'when is it enough?'. Whilst the journey may be ongoing or, indeed, never-ending, incremental steps are made which afford 'increasing confidence in the inference and generalizations that we draw from our research data' (Corey, 1953, p.377) and there must come a point when findings are worth communicating.

The three cycles of activity in this study have allowed for development and demonstration of the efficacy of the toolkit as well as collection of a substantial set of data relating to the social dimension of the research. These are addressed in this study in the spirit of ongoing creation highlighted by McNiff (2013) who suggests that 'we are aiming not for happy endings as much as new beginnings' (p.126).

The methods used to generate appropriate data for the purposes of these aims tabulated above are described in section 3.3 but, having asserted that action research approaches can make good use of mixed methods for data collection (Cresswell, 2009; McNiff & Whitehead, 2011; Bryman, 2013), further explanation is perhaps necessary and offered in the next section.

3.2.2 Mixed Methods

3.2.2.1 Rich data

In section 3.1, an abductive pragmatic stance is posited, suggesting an epistemological viewpoint in which knowledge is best characterised by its practical application. This advocates the use of multiple perspectives to support probabilistic inference within the social world, influenced as it is by context, time and human factors.

In this study, the use and potential of tools to identify aspects of participants' TPACK are explored both for pre-service teachers and experienced teachers. The tools that have been developed and have evolved over the course of the study are described in the next section but comprise an instrument designed to offer a baseline assessment of participants' TPACK and with which to assess any movement following the intervention, and a novel form of 'content representation' or 'CoRe' (which I have called a 'T-CoRe') which participants have used to scaffold their thinking about the use and application of technology in their teaching. Between them, these tools will generate a substantial amount of both quantitative and qualitative data relating to practice and underlying thinking.

Other rich seams of data derive from group discussions about the tools in use during each cycle of activity. Given that it was intended that participants were able to take ownership of training activity, licence was given to use the resources to support an agenda of their own design. Individual narratives are therefore also important and are secured through semi-structured and stimulated recall interviews.

Within the structure of the cycles of action research that support iterative development of resources, the valuable contribution both quantitative and qualitative approaches to data collection can make to the project and the potential methodological triangulation afforded by the use of both quantitative and qualitative methods strongly advocates the use of mixed methods for data collection.

3.2.2.2 Mixed methods

The fallout from the paradigm wars alluded to in section 3.1.1 means that the landscape of educational research now looks somewhat different. The use of mixed methods for data collection is more widely accepted but, given that pockets of resistance might be encountered, some justification is worth offering here.

Gorard (2013) advocates consideration of all the tools available to researchers, suggesting that clinging to a single type of research strategy (e.g. 'qualitative') may betray a tendency towards habit or incompetence which could lead to unintentional bias. Baert (2005) supports this notion, suggesting that:

> It would be erroneous to hold that there is something intrinsic to the social that necessitates a single method of inquiry because this would be tantamount to making the blatantly absurd assertion that a single method serves all cognitive interests. (p.141)

Giddings (2006) warns against the binary positioning of the terms 'qualitative' and 'quantitative' as this could lead to decreased awareness of the methodological diversity of each. Whilst she is cautious, questioning whether mixed methods research is simply 'positivism dressed in drag' (ibid, p.195), she recognises that mixed methods now occupies a place on the 'world stage' as a 'third methodological movement' (p.197).

Williams (2000) supports the notion of 'methodological pluralism' suggesting this is an 'inevitable conclusion if we accept that sociology has a nomothetic and an ideographic dimension' (p.221). This implies that, if particular methodologies are seen to have limits, it is wise to be open to alternative methodological approaches combining aspects of both approaches. Cresswell (2015) is careful to point out that 'mixed methods' is not a label to be attached to research simply because it involves the collection of qualitative and quantitative data but that it stresses the strengths of each aspect and integrates findings to provide a richer picture of the object of study.

3.2.2.3 Mixed methods in action

Quantitative methods are initially used in this study with the pilot group of trainee teachers in cycle 1, this group referred to hereafter as 'T1', both to develop tools to explore and visualise TPACK and to assess and develop the validity of the assessment instrument. The resources are then used by two distinct groups of practitioners.

Two successive cohorts of trainee science teachers, 'T2' and 'T3', used the resources during an intervention activity designed into their course of study. Each group completed pre- and post-intervention assessments, used the resources to support planning and teaching using technology, and reported on their use of the materials during whole group and small group discussions.

During the third cycle of activity, alongside trainee teacher cohort T3, a group of teacher participants was recruited to undertake a training programme comprising three twilight sessions exploring TPACK in more detail, between which they completed two cycles of classroom-based practitioner research. Qualitative evidence was generated from recorded discussions and teaching artefacts.

During the first and last of the twilight sessions, participants were asked to complete the TPACK assessment instrument to explore whether the intervention had led to perceptible change during the timescale of the project. At the end of their second phase of classroom research, participants took part in semi-structured and stimulated recall interviews from which a rich narrative can be derived and compared with the story told by the quantitative methods. In this way, I am able to gain multiple perspectives and generate sufficient data to allow realistic measures of validity to be applied to the assessment instrument.

The methods used can be mapped onto the cycles presented in Table 2 as shown in Table 3. In referring to quantitative and qualitative aspects of data collection, use is made of an idea drawn from Johnson & Onwuegbuzie's (2004) 'mixed method design matrix', in that capitalisation is used to assign weight to data collected in different phases of the research.

	1st cycle	2nd cycle	3rd cycle
Activity	Pilot, evaluation and development of resources with trainee teacher cohort T1.	Intervention activity with trainee teacher cohort T2. Evaluation and development of resources and activities.	Intervention activity with trainee teacher cohort T3 and teacher research group. Evaluation of resources and activities.
Data collected	Assessment instrument yields data about confidence and ability to distinguish the different domains within TPACK (**QUAN**) Discussion activities to support ongoing development of resources (**qual**)	Pre- and post-intervention use of assessment instrument (**QUAN**) Discussion activities to support ongoing development of resources and activities (**QUAL**) Teaching artefacts (e.g. T-CoRes) (**qual**)	Pre- and post-intervention use of assessment instrument (**QUAN**) Group discussion activities to support ongoing development of resources and activities (**QUAL**) Teaching artefacts (e.g. T-CoRes) (**qual**) Interviews with teacher participants to evaluate professional development activity (**QUAL**)

Table 3: Data collection methods within action research cycles

The intervention activities within cycles two and three are described in the next section but can be summarised as shown in Figure 6 using a representation modified from Cresswell (2015, p.42).

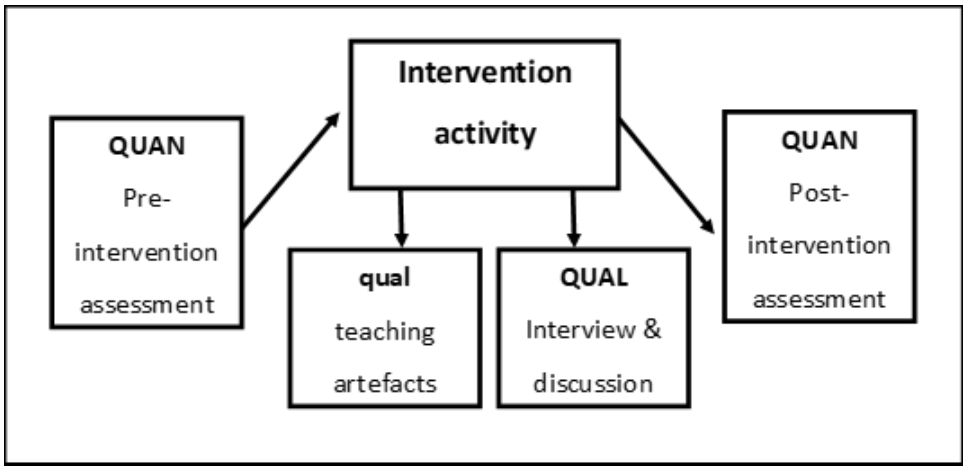


Figure 6: An intervention design

The complementarity of methods and the methodological triangulation afforded in this way are two significant aspects of the potential rationale outlined by Johnson & Onwuegbuzie (2004) for mixed methods research. In attempting justification of the use of mixed methods, Cresswell (2015) also suggests that several key features need to be addressed as shown in Table 4.

The use of mixed methods for data collection therefore allows exploration of the validity of the tools, assessment of both individual and group outcomes, perceived usefulness of the intervention experience and potential for ongoing use and development.

Paiva et al (2016) summarise Beal and Bohlen's model of technology adoption (dating back to 1955) which is still cited by authors exploring technology adoption and comprises: awareness, interest, evaluation, trial, acceptance and adoption. The use of mixed methods within the action research approach proposed is hopefully seen as having potential to address each of these stages and therefore potential to both explore and evaluate the use of technology by teachers.

In the next section, the methods used are described in the context of the each of the components of research activity.

Feature	How it is addressed in this study
Mixed methods research should be defined	See section 3.2.2.2
Consider whether qualitative and quantitative data are collected and analysed in response to each research question.	RQ1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology? **QUAL + quan** RQ2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development? **QUAN + qual** RQ3. To what extent is a community of practice important in securing sustained impact of professional development? **QUAL** RQ4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination of practice? **QUAL + quan**
Maintain rigour in both qualitative and quantitative methods	Quantitative methods include assessment of internal consistency reliability of multidimensional data relating to the different domains within the TPACK framework. Results can also be considered at both individual and group levels to explore patterns. Qualitative methods include thematic and magnitude coding to contribute to understanding of individual participants as well as aspects that might afford moderatum generalisation.
Consider how qualitative and quantitative data are combined or integrated.	Data will be integrated during analysis affording methodological triangulation.
Consider whether the study is framed within a philosophical perspective.	The study takes a pragmatic abductive stance as described in section 3.1.1

Table 4: Justifying a mixed methods approach

3.3 Research methods

In this section, the development of the instruments making up the proposed 'toolkit' for professional development is described. The intervention processes for both pre-service and experienced teachers are then outlined, and consideration given to how the interview schedule used with participants aligns to the research questions. The timeline of research activity is then illustrated.

3.3.1 Translating the research questions

Addressing the weaknesses in transmissive modes of professional development and the challenges of operationalising TPACK presents a number of challenges. To maintain focus on the research questions identified, methods relevant to each are considered:

1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology?

   An introduction to the practical elements of the project will entail the familiarisation of participants with the TPACK framework to develop a shared understanding and a common language that affords meaningful discussion about technology as a pedagogical tool. Evidence that will help address this question will include quantitative analysis of participants' use of the assessment instrument to indicate whether any transformation of practice has occurred, and qualitative analysis of the content representations they produce during practitioner research activity. Participants' comments and reflections will also offer useful insights which will be derived from recordings made of group discussions and individual interviews. Through potential to affect personal and decisional capital, TPACK may elicit evidence of ownership of professional development activity.

2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development?

   The development of a TPACK assessment instrument is fundamental to the project. In use, the instrument will yield quantitative data which will afford the possibility to compare aspects of practice pre- and post-intervention. Development will be informed by analysis of the efficacy and validity of the tool after each iteration of use and also be supported by discussion of its use in practice by participants.

3. To what extent is a community of practice important in securing sustained impact of professional development?

   The large contribution social capital can make to developing professional capital is noted in section 2.2.6. Collaborative activities will hopefully contribute to the notions of shared meaning, practice, identity and design identified as important in Wenger's (1998) notion of a community of practice. This can be assessed through the quality of discussion during group activities and evaluated through individual interviews at the end of the project.

4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination of practice?

   Once teaching challenges have been identified by participants, a variety of approaches may be taken based on design-based tasks. The approach taken to develop a professional development experience can be contrasted with more traditional approaches highlighted earlier in the literature review.

It is felt that the approach identified in section 3.2 is consistent with the demands of the research questions. In the next section, the development of the resources contributing to the 'toolkit' to support professional development is described.

3.3.2 Research tools

In preparation for the pilot study in the first action research cycle, two important tools were developed and trialled: a TPACK assessment instrument to allow magnitude to be assigned to each domain within the TPACK framework; and a new form of TPACK content representation which I have termed a 'T-CoRe' to support thinking about aspects of TPACK during participant classroom research activity. These underwent further development during the formative use of the intervention activities with trainee teachers in cycle 2 and in subsequent activity with both teachers and trainee teachers in cycle 3.

The evolution of the tools across the three cycles of activity are presented here whereas broader evaluation of their use from the perspective of the participants is presented with other findings in chapter 4.

Plans for ongoing development are discussed in chapter 6.

3.3.2.1 Development of the TPACK assessment instrument

A number of strategies were considered to support assessment of teachers' TPACK as described in section 2.3.2. One of the biggest issues influencing the choice of tool was that, on initial use, participants may have little or no understanding of TPACK, so methods based on assigning weight to each named domain may be complicated by the need to ensure that participants are familiar with definitions of each subdomain. This in turn is rendered more complex by the notion that, whilst it may be easy to define what lies at the centre of each subdomain, the edges are widely acknowledged as being 'fuzzy' and harder to define.

It was therefore felt appropriate to develop a model of assessment in which prior knowledge of TPACK was unnecessary. In the pilot phase of the study, a TPACK assessment instrument was developed based on a tool described by Archambault & Crippen (2009). This tool used a series of statements, tacitly coded to different subdomains. Users therefore respond to the statements and their responses are back-coded to the subdomains they represent.

An implicit challenge exists to ensure that the links between questions and subdomains are correct so that questions correspond to the appropriate focus of analysis and the results can be deemed accurate. Over the three cycles of use, the validity of the instrument was assessed to ensure fitness for purpose and to overcome Drummond & Sweeney's (2017) challenge that insufficient care had been taken in this area in many previous TPACK studies.

Archambault & Crippen's tool was constructed with statements appropriate to the context of their study, namely online distance education in the United States. This needed adapting to fit the context of users in UK schools in terms of curriculum, the group dynamics implicit in classroom practice and the use of language that is easily understood by UK practitioners at all career stages.

Permission was sought from, and given by, the creators of the original tool to modify its use – see appendix 2.

Changes made to the assessment instrument are highlighted in Table 5.

Two additional questions, Y and Z, were included to strengthen the representation of blended domains in the instrument.

	TPACK domain	Original statements Archambault & Crippen (2009)	Revised statements used in pilot materials
A	TK	My ability to troubleshoot technical problems associated with hardware (e.g. network connections)	My ability to troubleshoot technical problems associated with hardware (e.g. network connections)
B	CK	My ability to create materials that map to specific district/state standards	My ability to create materials that map to specific statements within the National Curriculum
C	PK	My ability to use a variety of teaching strategies to relate various concepts to students	My ability to use a variety of teaching strategies to relate various concepts to students
D	CK	My ability to decide on the scope of concepts taught within my class	My ability to decide on the intended learning outcomes in my lesson planning
E	TPACK	My ability to use online student assessment to modify instruction	My ability to use online student assessment to modify instruction
F	PCK	My ability to distinguish between correct and incorrect problem-solving attempts by students	My ability to distinguish between correct and incorrect problem-solving attempts by students
G	TK	My ability to address various computer issues related to software (e.g. downloading appropriate plug-ins, installing programmes)	My ability to address various computer issues related to software (e.g. downloading appropriate plug-ins, installing programmes)
H	TPK	My ability to create an online environment which allows students to build new knowledge and skills	My ability to create an online environment which allows students to build new knowledge and skills
I	PCK	My ability to anticipate likely misconceptions within a particular topic	My ability to anticipate likely misconceptions within a particular topic
J	PK	My ability to determine a particular strategy best suited to teach a specific concept	My ability to determine a particular strategy best suited to teach a specific concept
K	TPACK	My ability to use technology to predict students' skill/understanding of a particular topic	My ability to use technology to predict students' skill/understanding of a particular topic
L	TPK	My ability to implement different methods of teaching online	My ability to implement different methods of teaching using ICT
M	CK	My ability to plan the sequence of concepts taught within my class	My ability to plan the sequence of concepts taught within my class

N	TPK	My ability to moderate online interactivity among students	My ability to manage students' use of ICT during a lesson
O	TCK	My ability to use technological representations (i.e. multimedia, visual demonstrations, etc.) to demonstrate specific concepts in my content area	My ability to use technological representations (i.e. multimedia, visual demonstrations, etc.) to demonstrate specific concepts in my content area
P	TPK	My ability to encourage online interactivity among students	My ability to inspire confidence in the use of ICT by students
Q	TK	My ability to assist students with troubleshooting technical problems with their personal computers	My ability to assist students with troubleshooting technical problems with their computer/tablet
R	PK	My ability to adjust teaching methodology based on student performance/feedback	My ability to adjust teaching methodology based on student performance/feedback
S	PCK	My ability to comfortably produce lesson plans with an appreciation for the topic	My ability to comfortably produce lesson plans to satisfy learning objectives for the topic
T	TCK	My ability to implement district curriculum in an online environment	My ability to implement the use of an online environment in my teaching
U	PCK	My ability to assist students in noticing connections between various concepts in a curriculum	My ability to assist students in noticing connections between various concepts in a curriculum
V	TCK	My ability to use various courseware programmes to deliver instruction (e.g. Blackboard)	My ability to use various courseware programmes to facilitate learning (e.g. a school's virtual learning environment)
W	TPACK	My ability to use technology to create effective representations of content that depart from textbook knowledge	My ability to use technology to create effective representations of content that depart from textbook knowledge
X	TPACK	My ability to meet the overall demands of online teaching	My ability to meet the overall demands of teaching using ICT
Y	PCK		My ability to choose the most appropriate teaching strategy for a particular concept
Z	TCK		My awareness of the variety of hardware or software tools available to enhance my teaching of particular topics

Table 5: Adaptation of Archambault & Crippen's TPACK assessment instrument

3.3.2.1.1 Assessing confidence

To allow self-report against each of the domains a differential scale was required. Archambault & Crippen's original tool included a five-point differential scale (1= poor, 5= excellent) used by participants to respond to the question 'How would you rate your own knowledge in doing the following tasks associated with teaching in a distance education setting?' (Archambault & Crippen, 2009, p.75). Operating in a different context required that the question be revised and, in this process, the opportunity was taken to consider a range of alternative rating models based on ideas derived from a range of researchers. To illustrate the variety of criteria upon which assessment might be based, the differentials inherent in a number of significant models are compared in Table 6.

A common problem I perceived with many of these is that there is an assumed understanding by the user of each rubric of what each level looks like in practice. Whilst this might be fine for performative judgements being made by an external party familiar with the criteria and descriptors, I venture that, in the absence of such familiarity, this renders them less usable for a self-report tool.

In considering whether there was a metric that afforded greater standardisation between participants, the use of Biggs' 'Structure of observed learning outcomes' or 'SOLO' taxonomy (introduced by Biggs, 1982, cited in Biggs & Collis 2003) was considered and trialled. This was considered of interest with the pilot group, since the use of SOLO taxonomy was familiar to them having been explored during earlier taught sessions as a mode of assessment for pupils in the light of removal of pre-existing levels from the UK national curriculum, leaving schools with the challenge of assessing pupil progress in a culture that became widely known as 'assessment without levels'.

	Low proficiency →	→	→	**High proficiency**
Britten & Cassidy (2006) Technology integration assessment instrument	**Technology not present**	**Non-essential technology component**	**Supportive technology component**	**Essential technology component**
Groff & Mouza (2008) I[5] model	**1**	**2**	**3**	
	Limited understanding	**Limited proficiency**	**Proficient**	
Harris et al (2010) Technology Integration Assessment Rubric	**1**	**2**	**3**	**4**
	Not aligned; Does not support; Inappropriate	**Partially aligned;** Minimally supports; Marginally appropriate	**Aligned;** Supports; Appropriate but not exemplary	**Strongly aligned;** Optimally supports; Exemplary
Dwyer et al (1991)	**Entry**	**Adoption**	**Adaptation**	**Appropriation**	**Invention**
Rogers & Twidle (2013)	**Non-user**	**Adopter**	**Adapter**	**Innovator**	**Creator/mentor**
Biggs & Collis (1982) SOLO Taxonomy	**Prestructural**	**Unistructural**	**Multistructural**	**Relational**	**Extended abstract**
Ward & McCotter (2004) reflection rubric	**1**	**2**	**3**	**4**
	Routine; Self-is disengaged from change	**Technical;** Practical response to specific situation, no change in perspective	**Dialogic;** Cycle of situated questions and action; active consideration of others' perspectives, new insights	**Transformative;** Fundamental questions and change
Fraser et al (2013)	**Entry** Confident with basic activities	**Core** Basic skills and confidence to support learning	**Developer** Active interest in developing digital literacy, advanced skills	**Pioneer** Integrates technology into teaching, reflective, supports others

Table 6: Potential differential tools

SOLO uses a differential of the form:

SOLO level	Prestructural	Unistructural	Multistructural	Relational	Extended Abstract
Numerical identifier	1	2	3	4	5
Meaning	No current grasp. Needs support	Has a relevant idea. Limited understanding	Has several relevant ideas. Emergent understanding	Ideas are linked. Developed understanding	Ideas are integrated and developed. Enhanced understanding

Table 7: SOLO taxonomy

To test the instrument, it was therefore piloted with a cohort of 21 trainee Science teachers on the Postgraduate Certificate in Education course with which I work.

Once results for each participant were grouped according to the subdomains reflected by each question, both individual and group responses were considered. The tool proved capable of identifying differences in relative confidence in the different subdomains as demonstrated by the chart in Figure 7.

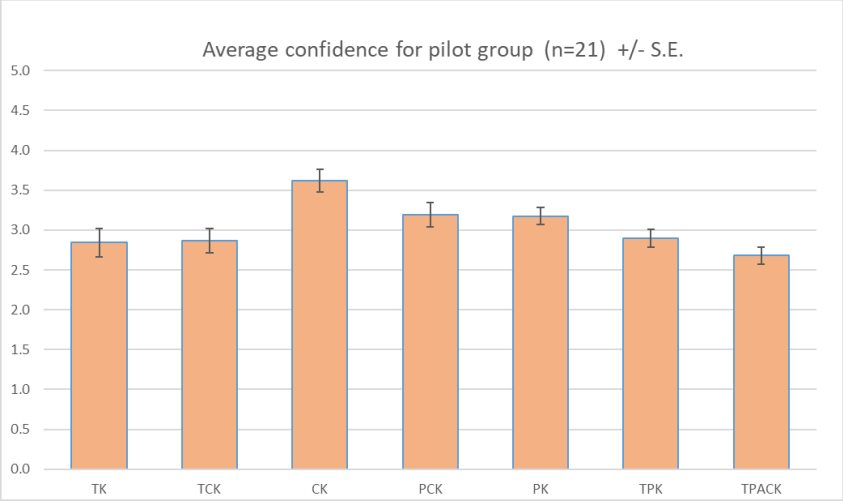


Figure 7: Ability of assessment instrument to identify confidence levels

More detailed consideration of how the analysis was undertaken is given in section 3.5.

In group feedback, students appeared to have struggled with and therefore ignored SOLO in favour of the numerical differential to simply reflect confidence. Following the use of these statements in the assessment tool with the pilot group, the use of SOLO as an additional second theoretical lens was rejected in an attempt to avoid unnecessary complication for participants who were only just being introduced to TPACK as a new theoretical construct. Similarly, if used by a wider range of participants, the addition of SOLO taxonomy may unnecessarily complicate the tool for those unfamiliar with the concept.

In revisiting the intended aims of the questionnaire (to allow participants to gauge themselves against a series of statements that were tacitly coded to the TPACK domains), it was deemed prudent in subsequent versions of the assessment instrument to keep this as simple as possible so that an honest response could be given without the potential for over-thinking or unconscious bias. A simple Osgood 5-point semantic differential rating scale was therefore used in subsequent iterations of the questionnaire to allow participants to assign a confidence score, ranging from 1 (low) to 5 (high). The use of the Osgood approach with a cardinal semantic differential is argued to remove the potential subjectivity in the interpretation of more complex Likert type scales (Crano et al, 2015).

3.3.2.1.2 Assessing ability to distinguish domains

In addition to an attempt to gain quantitative insight into participants' understanding of TPACK, participants were asked to attempt to identify the subdomain to which each statement corresponded. This allowed subsequent analysis to explore the notion of fuzziness around each subdomain, as raised by Jimoyiannis (2010b), providing useful information about participants' abilities to interpret the TPACK model and also about whether the descriptions I had selected for each domain were adequate or potentially ambiguous.

Correct responses (compared to the expected answer) were scored as '1' and incorrect answers as '0'. Collated responses averaged for each subdomain could then be calculated for individuals and across groups with an average score of 1 representing perfect scores across the board (see Figure 8).

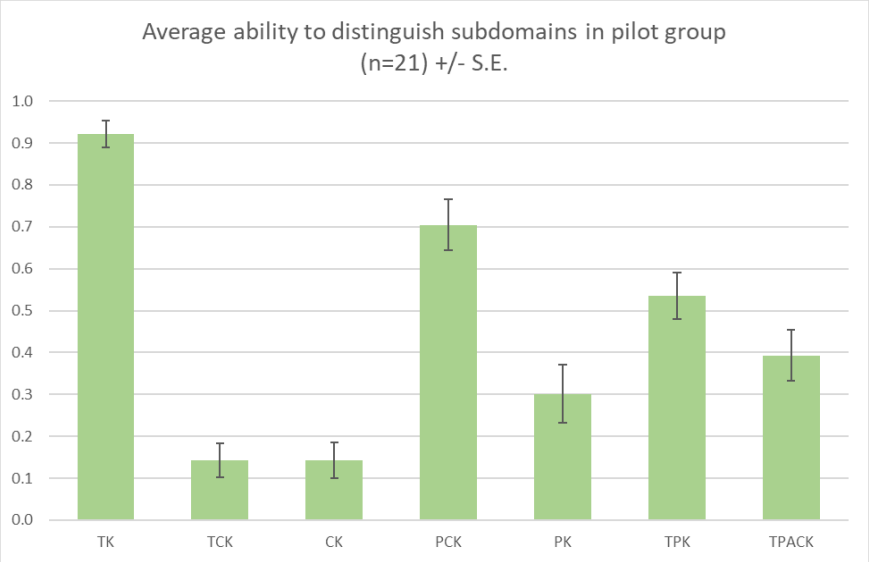


Figure 8: Participants' ability to distinguish domains

It is not surprising that some aspects are easier to identify, for example, technological knowledge (TK). Other single domains (CK and PK) may have been complicated by participants' anticipating blended domains by attempting to contextualise statements in the light of their own practice. Conclusions at this stage must, however, be guarded.

During use by the cohort of trainee teachers in the pilot activity, however, it was noted that there were *significant* difficulties across the group of participants in identifying particular blended domains. This very much echoes difficulties encountered in the literature regarding definition of what lies anywhere except at the centre of each domain (Jimoyiannis, 2010b; Archambault and Crippen, 2009).

Of course, it is difficult to separate whether the difficulties evident in Figure 8 are inherent problems with the mapping of questions to the domains or if they typify the difficulties of beginning teachers in identifying aspects of their practice.

Following the pilot, during review of the first cycle of activity, the first revision of the assessment tool was made which involved making the change from SOLO as a metric to a simple Osgood scale to indicate confidence. Given that analysis was coincident with first use by the second cohort, the questions remained unaltered at this stage. Unsurprisingly this led to a similar picture in terms of ability to distinguish the domains as shown in the first data series in Figure 9.

For this reason, questions identified as being particularly low scoring and therefore particularly problematic were identified by assessing those for which common alternative responses were given. An initial assessment of the contribution these made to the potential picture painted by the data was made by their removal from the calculation of averages with little impact on the overall pattern and the risk that the number of questions corresponding to some domains was reduced, amplifying the significant contribution made by individual questions. The deleterious impact this had is evident from the second data series shown below.

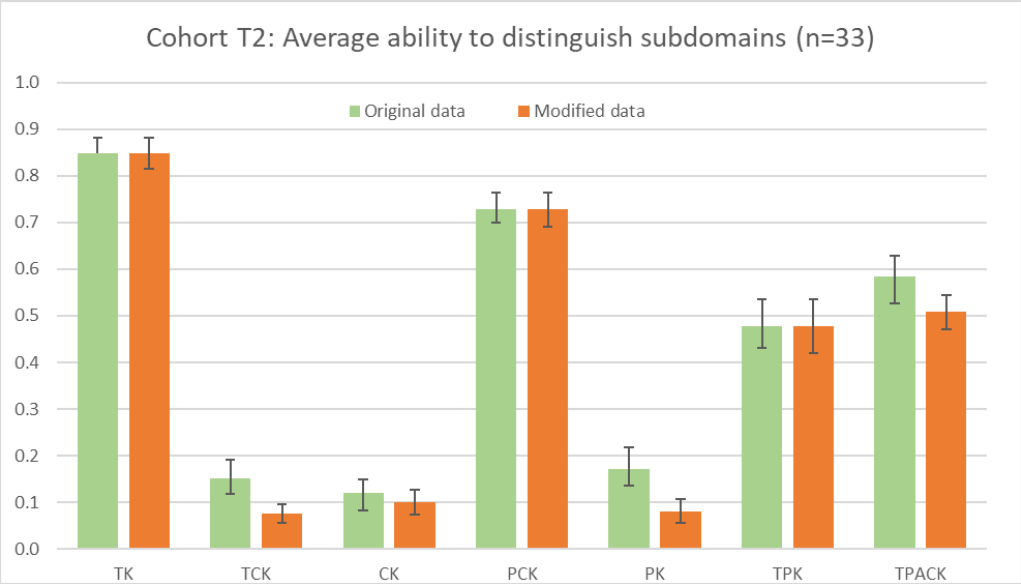


Figure 9: Ability to distinguish domains - cohort T2

To ensure that the questions within the tool were as robust as possible in articulating the intended subdomains, problematic questions were reassessed and revised where this was felt appropriate prior to use in the third cycle of activity with cohort T3 and the group of teachers. Revision rather than removal also ensured that each subdomain would still be represented by multiple questions.

Seven questions were identified as problematic and worthy of attention:

> C - 'My ability to use a variety of teaching strategies to relate various concepts to students' targets PK but reference to concepts implies matching teaching strategies and therefore mirrors PCK

E - ‘My ability to use online student assessment to modify instruction’ was originally presented as an example of TPACK but the relation to content is implicit rather than explicit and might therefore be seen as TPK

J - ‘My ability to determine a particular strategy best suited to teach a specific concept’ was presented as PK but, again references concepts so might be interpreted as PCK

M – ‘My ability to plan the sequence of concepts taught within my class’ relates to CK but reference to teaching may be taken as implying PCK

T – ‘My ability to implement the use of an online environment in my teaching’ mistakenly references TCK but this is TPK.

V – ‘My ability to use various courseware programmes to facilitate learning (e.g. a school’s VLE)’ was written to represent TCK. Some may infer a pedagogical choice in this and therefore reference it as TPACK

Z – ‘My awareness of the variety of hardware or software tools available to enhance my teaching of particular topics’ links technology and content for TCK but this might be related to the idea of pedagogical choice and so also represent TPACK.

In undertaking the review, in addition to those identified below, attention was also merited in consideration of the lower scoring domains in the chart above. Given that, at this time, I also felt that my own ability to use and interpret the TPACK framework had developed since the development of the initial tool, all statements were revisited.

Pamuk et al (2013) reported having similar difficulties ensuring content validity (see section 3.4) in their own model of assessment, resulting in a number of the statements they had used to articulate TPACK domains being deleted or revised. In replacing some of the content of problematic items in my own tool, some of the thinking articulated in their research was drawn upon to support development.

Content Knowledge (CK) is hard to articulate without direct reference to 'subject knowledge' or 'content'. I would, however, argue that some of Pamuk's suggestions, e.g. 'I can make connections with content I teach and daily life', are ambiguous. The ability to relate content to context is an important pedagogical skill so this could be interpreted as PCK. TCK is similarly very difficult to isolate when those using the questionnaire are teachers and will naturally interpret statements in such a way as to imply subject content.

The adjustments made are shown below and are intended to preserve the sense of the intended domain to which they refer rather than explicit activity suggested in the original statements. Deletions are struck-through, additions are underlined, and revised statements highlighted.

Statement	Intended response	Most common 'wrong' answer	Adjustment required	Statement
A	TK			My ability to troubleshoot technical problems associated with hardware (e.g. network connections)
B	CK	PCK	Remove reference to planning lessons which may imply pedagogy	My ability to interpret specific statements in the National Curriculum ~~to allow me to start planning lessons~~
C	PK	PCK	Remove ref to concepts	My ability to use a variety of teaching strategies ~~to relate various concepts to students~~
D	CK	PCK	Remove ref to planning to focus on working with content	My ability to articulate ~~decide on~~ ~~the~~ age-appropriate learning objectives ~~intended learning outcomes in my lesson planning~~
E	TPACK	TPK	Remove ambiguity by including ref to subject content	My ability to use online student assessment to modify ~~instruction~~ teaching of a particular concept
F	PCK		Reinforce PCK by including task design	My ability to design tasks so that I can distinguish between correct and incorrect problem solving attempts by students

G	TK			My ability to address various computer issues related to software (e.g. downloading appropriate plug-ins, installing programmes)
H	TPK	TPACK	Is content implicit here? Notion of differentiation borrowed from Pamuk	~~My ability to create an online environment which allows students to build new knowledge and skills.~~ My ability to use technology to meet the needs of different students
I	PCK			My ability to anticipate likely misconceptions within a particular topic
J	PK	PCK	Remove ref to content. Notion of differentiation borrowed from Pamuk	My ability to ~~determine a~~ choose classroom strategies to meet students' needs ~~best suited to teach a specific concept~~
K	TPACK		'Predict' may cloud the issue → 'assess'	My ability to use technology to assess ~~predict~~ students' skill/understanding of a particular topic
L	TPK	TPACK	May be interpreted with content in mind?	My ability to implement different methods of teaching using ICT
M	CK	PCK	Notion of teaching sequence implies pedagogy	My ability to ~~plan the sequence of concepts taught within my class~~ make links between ideas in different parts of the curriculum
N	TPK	TPACK	Not related to subject content so statement stands	My ability to manage students' use of ICT during a lesson
O	TCK	TPACK	Demonstrate concepts might lead towards pedagogy	My ability to use technology ~~technological representations (i.e. multimedia, visual demonstrations, etc.) to demonstrate specific concepts in my content area~~ to present subject matter in different ways
P	TPK			My ability to inspire confidence in the use of ICT by students
Q	TK			My ability to assist students with troubleshooting technical problems with their computer/tablet

R	PK	PCK	Content not implicit but pedagogy may be suggested by content. Borrowed from Pamuk	My ability to ~~adjust teaching methodology based on student performance/feedback~~ use a variety of approaches to assess students' learning - & respond…?
S	PCK		Remove potential ambiguity	My ability to ~~comfortably~~ produce lesson plans ~~to~~ which satisfy learning objectives for the topic
T	~~TCK~~ Change to TPACK	TPACK	Change statement so it fully addresses TPACK and so that TPACK is represented more than TCK in questionnaire.	~~My ability to implement the use of an online environment in my teaching~~ My ability to use technological representations (i.e. multimedia, visual demonstrations, etc.) to support the teaching of ~~demonstrate~~ specific concepts in my content area
U	PCK			My ability to assist students in noticing connections between various concepts in a curriculum
V	TCK	TPACK	Taken as implying teaching activity	My ability to ~~use various courseware programmes to facilitate learning (e.g. a school's virtual learning environment)~~ use technology to access additional resources related to the curriculum
W	TPACK			My ability to use technology to create effective representations of content that depart from textbook knowledge
X	TPACK			My ability to use/adapt ICT resources to help students achieve intended learning outcomes
Y	PCK			My ability to choose the most appropriate teaching strategy for a particular concept
Z	TCK	TPACK	This is about awareness of general resources	My ability to recognise potential links between new hardware or software opportunities ~~to enhance my teaching of particular topics~~ and curriculum content –link this to **finding** resources instead

Table 8: Revision of statements in assessment tool

During the revision, it was also felt necessary to adjust the balance of questions referring to each subdomain to reinforce the thinking required about the interplay between the components of TPACK as shown in Table 9. Having strengthened the statements articulating TCK it was felt safe to reduce this to three statements.

In total, 15 of 26 statements have been tweaked or changed to reduce ambiguity between closely aligned TPACK subdomains. Given the difficulties in articulating subdomains precisely, the importance of assessing each via multiple statements is evident.

Subdomain	No. of statements in original tool	No. of statements in revised tool
TK	3	3
TCK	4	3
CK	3	3
PCK	5	5
PK	3	3
TPK	4	4
TPACK	4	5

Table 9: Balance of questions relating to subdomains in assessment tool

The revised statements were used with the subsequent cohort (T3) of 34 trainees in the third cycle of activity both prior to and following a TPACK-related course activity, with analysis demonstrating a significantly improved ability for the assessment instrument to allow students to more easily distinguish between the subdomains especially in the particularly problematic areas of CK, PK and TCK as seen in the pilot. Outcomes from the pilot activity compared with cohort T3's first use of the revised tool are shown in Figure 10.

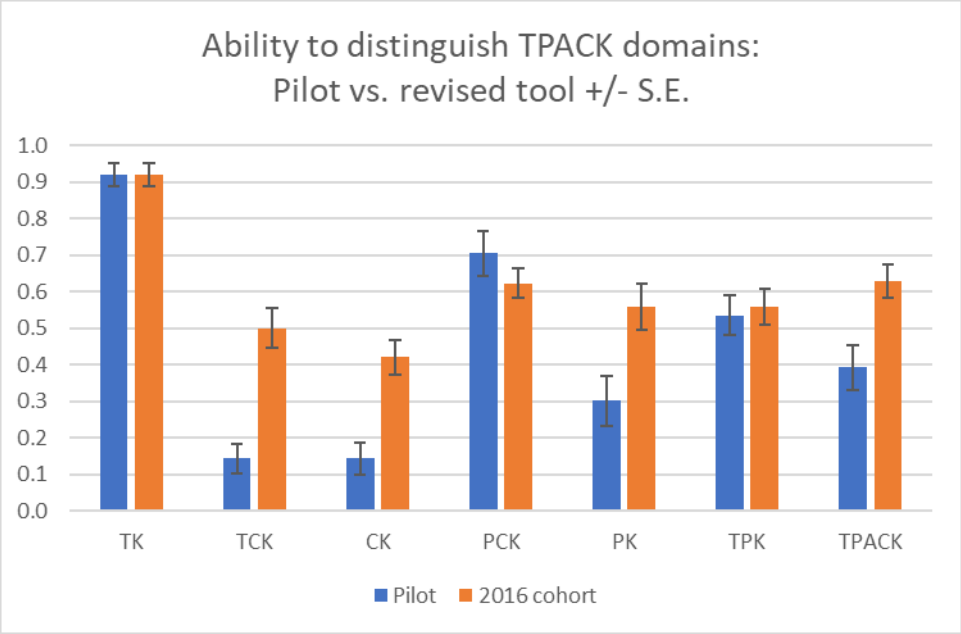


Figure 10: Effect of revision of assessment tool

Significant improvements are evident in the areas of greatest concern (TCK, CK, PK). The revision of statements and addition of an extra question to articulate TPACK have seen commensurate improvement in this central domain.

The capacity for the tool to be used to both gauge participants' confidence against each statement and also to attempt to locate the question within one of the TPACK subdomains affords a highly useful form of methodological triangulation to help assess validity and which has supported useful development of the assessment tool. This helps address an accusation in the literature that many studies attempting to measure aspects of TPACK have struggled to disambiguate the separate domains within TPACK and that a majority of studies have neglected to attempt to undertake measures of validity or reliability (Drummond & Sweeney, 2017).

3.3.2.1.3 Validity of the assessment tool

Given the difficulties associated with ensuring that statements accurately articulate the intended domains, the impact of the revisions made is clearly seen in terms of its ability to allow users to distinguish domains. This might be attributed to the effect of revising the statements but may, however, also be coloured by the effect of greater experience on my part training successive cohorts in their theoretical understanding of TPACK.

To assess the impact of the changes made to the statements in the assessment tool, a more reliable indication can be obtained by assessing the validity of the tool before and after modification. Construct validity is used to assess how closely items in a questionnaire relate to theoretical constructs they are designed to measure. This differs from other measures of validity such as 'criterion-related' validity or 'face' validity which depend on external reviewers or comparative use of a second assessment instrument and, as such, may be open to subjective interpretation. Construct validity is an internal measure of consistency which is described as being the 'most valuable' although 'hardest to measure' (Bolarinwa, 2015, p.197).

Construct validity can be assessed using a variety of evidence including self-report (convergent validity), observation or comparison with results from another group already known to score highly for the factor under investigation (known-group validity). In this study, however, the form of assessment of construct validity most closely aligned to the questionnaire in use, and most suitable to overcome the accusation that assessment of validity in TPACK studies is often found lacking, is that of factorial validity. This investigates whether items measuring the same domain are more closely related than items measuring different domains. Since, in my assessment tool, each subdomain within the TPACK model is addressed by several statements, the ability to compare clusters of questions affords useful opportunity to assess validity and the effects of any changes made.

Factorial validity is very closely aligned to the notion of 'internal consistency reliability' which explores the extent to which items in a questionnaire measure the same idea and negates the need for test-retest comparisons. Bryman (2008) supports this notion in relation to longitudinal studies such as mine since the very purpose of the study is to identify social change and therefore different results are to be anticipated if questionnaires are used both at the start and end of an intervention activity.

Internal consistency reliability was assessed using Cronbach's Alpha which compares the similarities between items designed as related in a questionnaire which makes use of semantic differentials with those that are unrelated, and 'demonstrates whether the test designer was correct in expecting a certain collection of items to yield interpretable statements about individual differences' (Cronbach, 1951, p.297).

Cronbach's alpha is calculated as: a = n/(n − 1)[1 − Sum Var (Yi)/Var (X)]
Where n = Number of items; Sum Var(Yi) = Sum of item variances; and Var(X) = Composite variance. To calculate these values, the dataset was imported into SPSS and subjected to analysis using the script:

```
RELIABILITY
/VARIABLES=A G Q
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Where in this example A, G and Q represent the three questions corresponding to the TK subdomain.

An important consideration in this was to acknowledge that the questionnaire and therefore the data it generates are, by design, multidimensional due to the different domains about which the questionnaire attempts to gain insight. Assuming the data are unidimensional appears to be a common problem in the use of Cronbach's Alpha (Tavakol & Dennick, 2011) so in this study, alpha has been calculated for items relating to each subdomain to afford information about internal consistency reliability in each case. An overall value for alpha can be calculated by taking an average of values of alpha for the subdomains (Bryman, 2008). A reliability score of 0.6 may be considered 'good' (Bryman, 2008) but 0.7 or greater is considered optimal (Bolarinwa, 2015).

Following its pilot with the group of 21 trainee teachers in the first cycle to assess potential of emergent tools to yield meaningful results, the first questionnaire was used, with minor modification as described earlier with cohort T2 of trainees (n=33) in the second cycle. The revised questionnaire was then used in the third cycle with cohort T3 (n=34).

The size of the sample exerts an effect on the value of alpha (Tavakol & Dennick, 2011), so it is of considerable help being able to assess the impact of amending both some of the descriptors and the number of statements representing each domain using data from similar sized cohorts from the second and third cycles. A comparison of values obtained for alpha is shown in Table 10.

Domain	Original assessment tool (T2)		Revised assessment tool (T3)	
	Number of questions	Cronbach's alpha	Number of questions	Cronbach's alpha
TK	3	0.891	3	0.859
TCK	4	0.763	3	0.743
CK	3	0.594	3	0.602
PCK	5	0.607	5	0.726
PK	3	0.668	3	0.793
TPK	4	0.585	4	0.641
TPACK	4	0.701	5	0.842
Overall (average across domains)		**0.687**	**Overall**	**0.744**

Table 10: Internal consistency reliability of original and revised assessment tools

Given that the relatively small number of questions reflecting each domain will naturally depress scores for alpha, the effect of modification of the statements within the assessment tool is highly encouraging. That the score for TCK drops very slightly in validity is of little concern given that the number of statements corresponding to this domain was reduced from four to three. CK remains problematic but this may well be for the reasons raised previously that teachers will naturally attempt to place content in the context of teaching. The slight increase in alpha for this domain is, however, a positive sign.

The increase in the overall (averaged) value for alpha following revision of the tool both validates the changes made and lifts the overall value above the 0.7 threshold defined above as being considered optimal.

The capacity for the tool to be used to both gauge participants' confidence against each statement and also to attempt to locate the question within one of the TPACK subdomains has yielded a highly useful form of methodological triangulation to help assess validity, and which has supported the development of an assessment tool which can be considered fit for purpose. Perceptions of the use of the assessment tool in practice and the experience of users are explored in chapter 4.

One further modification made in response to feedback from early users was the inclusion of the diagrammatic representation of TPACK on the assessment tool for users to reference while attempting to identify the domains to which each statement corresponds. The latest version of the assessment tool as used in the third cycle of activity is presented in appendix 1.

3.3.2.2 Introducing T-CoRes

The use of content representations ('CoRes'), as developed by Mulhall et al (2003), to scaffold thinking relating to Pedagogical Content Knowledge (PCK) is well documented and has been the subject of a small research project in which I was previously involved (Simpson et al, 2012). Their collaborative use by teachers has been shown to improve consideration of alternative pedagogies in planning for teaching (Williams et al, 2012).

To foster the consideration of the role of technology in relation to both pedagogical and content knowledge, a similar tool was developed to scaffold appropriate thinking in relation to the core domains and new subdomains introduced as technology was incorporated into the PCK framework to create TPACK. Although tools do exist to retrospectively explore how technology is used in the planning and delivery of lessons (e.g. Alsofyani & bin Aris, 2011), it was felt that a more useful tool for the purposes of this study and for the professional development of teachers would stimulate teachers' consideration of all aspects of the TPACK model, thereby scaffolding thinking during short and medium-term planning.

Positive experience using content representations to explore and develop PCK convinced me of the potential of a similar approach to allow teachers to articulate and record thinking about all seven of the subdomains inherent in TPACK. Permission was sought and received to adapt Mullhall et al's CoRes for this purpose (see appendix 2).

To stimulate thinking about domains already articulated in the PCK model, a number of Mulhall's original questions were retained. Additional questions used during previous work described in Simpson et al (2012) relating to assessment opportunities and aspects of the then current Science National Curriculum relating to 'How Science Works' have also been retained. New questions were introduced to stimulate thinking in relation to the subdomains introduced by the addition of technology to create the

TPACK model. The resultant content representation, including technological aspects and now covering all seven subdomains was named a Technology Content Representation or 'T-CoRe'.

The trigger statements included in the T-CoRe can be seen in Table 11.

CK	Why is it important that students know this? (e.g. skills, curriculum links)
CK	What do you know that you do not intend students to know yet?
PCK	Difficulties associated with teaching this idea
PCK	Likely misconceptions or student difficulties
PCK	How will you know students have achieved this Intended Learning Outcome?
PCK	Other factors influencing your teaching of this idea
PCK	Opportunities for 'Working Scientifically'
PCK	Opportunities for assessment activities (formative/summative)
PK	Proposed teaching strategy (and reasons for using them to engage with this idea)
TPK	Forms of technology that may be useful to develop students' ideas about this
TCK	How your knowledge of the technology may affect its use in class
TPACK	What forms of technology best suit the learning needs of your students for these ideas?
TPACK	Why is your chosen tool, particularly suitable for achieving this ILO with your students?
TK	What do you need to do to become confident using this technology?

Table 11: Trigger statements in the T-CoRe

These statements were provided in a grid containing columns for the consideration of up to three intended learning outcomes. The grid could either be printed onto A3 sized paper and used collaboratively as a 'table top' activity or supplied electronically so that it could be edited or resized to accommodate text as required.

The formatted T-CoRe as provided to participants is shown in appendix 3 and examples of completed T-CoRes can be seen in appendices 11-14.

A description of how the T-CoRe was used in the intervention activities offered to pre-service and experienced teachers is given in the next section.

3.3.3 The intervention

In this section, the activities undertaken by the different groups of participants are described, including how the resources outlined so far (the TPACK assessment tool and the T-CoRe) were used. Before this, consideration is given to additional resources produced to support the professional development activity.

3.3.3.1 Additional resources

As part of the toolkit of resources to support professional development activity, and in preparation for the intervention activities, an activity was developed which requires participants to consider how subject content might affect their pedagogical choices and selection of technology. This was based on the premise behind an online game devised by, and hosted on the website of, TPACK originator Matt Koehler (http://www.matt-koehler.com/the-tpack-game/). It is worthy of note that Microsoft's Teacher Education Initiative did something similar as part of an online course in Technology Enriched Instruction largely based around Microsoft applications, focusing on a range of generic learning skills and designed as an individual activity as part of the online learning experience. Although aspects of their game are evidenced in the presentation available at https://education.microsoft.com/GetTrained/Technology-Enriched-Instruction, the resource no longer appears to be available.

A new version of a similar game was therefore created with permission from Matt Koehler (see appendix 2) with the following novel features:

1. The game was designed as a collaborative activity to foster discussion between colleagues
2. A wider range of technological affordances were included
3. Specific aspects of subject content knowledge are included focused on the science curriculum with which my participants were familiar

The cards can be seen in appendix 4 and can be seen in use in Figure 11.

Figure 11: TPACK game in action

The 'toolkit' of resources to support professional development relating to TPACK offered in this project therefore comprises:

1. The TPACK assessment instrument
2. The T-CoRe
3. The TPACK game (here contextualised for Science)

3.3.3.2 Pre-service teachers

During the course of this study, three cycles of activity using the resources were performed with successive cohorts of trainee science teachers. By definition, these were non-random purposive samples which afforded me the opportunity to obtain a significant quantity of data to support the assessment of tool validity and to gauge the efficacy of the toolkit in use. Cohort characteristics were broadly similar in terms of the mix of age, gender and prior experience. The first group (n=21) were recruited to help pilot the assessment tool and the T-CoRe. The second group received a taught session on TPACK including completion of the assessment tool and were asked to integrate the use of the T-CoRe into a course task in which they were asked to reflect

on their planned use of ICT in their teaching. The third cohort undertook a planned intervention comprising a similar taught session and a new formal course directed task in which the T-CoRe was used in the planning and delivery of teaching episodes. Groups 2 and 3 were similar in size (n=33) offering useful potential for comparison where appropriate.

Introductory sessions included consideration of the affordances of technology in education, exploration of some of the barriers to technology integration, an introduction to TPACK including demonstration of activities considered good examples of TPACK in action, use of the TPACK game and introduction to, and exemplification of, the use of a T-CoRe.

Towards the end of their course and following their use of the T-CoRe in school, students in the second and third cycles were asked to complete the assessment tool a second time and were engaged in whole-group and small-group discussions which were recorded for later transcription and analysis to support ongoing resource development.

The T-CoRes generated were submitted as part of the requirements of the course directed task and retained where students' consent was given for further analysis as part of this or subsequent research activity. Finally, select students were engaged in small-group discussion about their use of the T-CoRes, selection being based on attendance on both occasions the assessment tool was completed and evidence of considered use being made of the T-CoRe document. These discussions were also recorded for later transcription.

The evidence collected from activity with pre-service teachers therefore comprised:

- A completed initial TPACK assessment tool from each student
- Recorded discussion relating to the use of the assessment tool
- Recorded discussion relating to the introductory use of the T-CoRe
- T-CoRes submitted by students as part of their course directed task
- Post-activity completion of a second TPACK assessment tool
- Recordings of small group discussions about the results derived from both assessment tools, their use of the T-CoRe and its impact on activity in school

3.3.3.3 Experienced teachers

During the third cycle of research activity, a small group of serving teachers were recruited to participate in an extended professional development experience based on the emergent toolkit. Of the invitations extended, six teachers expressed an interest in joining the research group.

Prior to the start of the project, one of the six obtained a position in another part of the country. There was some consideration given to whether he might be able to participate at a distance and, to this end, the first session's presentation was narrated and posted online. This participant subsequently found the challenge of starting a new post limited his potential for engagement and withdrew from the project.

A second member obtained a post overseas. Again, there was some question about distance participation, but this participant was unable to provide signed consent from the headteacher and was therefore not able to participate.

Four teachers remained and were able to participate throughout the project. Details regarding consent are given in section 3.6.

Other than that the participants were known to me before the project, they were self-selecting and no particular pattern was evident. To this end, they form a purposive sample but turned out to have a helpful variety of characteristics that might have potential to afford some useful insight.

The characteristics of the group are shown in Table 12. The 'technology adoption' judgement was based on self-report and aligned to the hierarchy described by Rogers and Twidle (2013).

Participant	Gender	Number of years teaching experience	Level of prior technology adoption
A	F	2	Adopter
B	M	10	Adopter
C	M	4	Innovator
D	M	20	Non-user/ adopter

Table 12: Members of teacher research group+

At the start of the teacher professional development activity, two of the participants (A and D) worked in the same school. Both then moved to different schools at the start of the subsequent academic year and completed the project in their new schools.

The project consisted of three two-hour twilight sessions and associated practitioner research by participants linked to their daily practice in their schools.

The resultant programme was formed as follows:

Session 1 – 24/3/2016

Participants discussed what they saw as the affordances of technology to support teaching. PCK was redefined and participants explored what they believed this meant in practice. The challenge of technology integration was introduced and PCK extended into the theoretical framework offered by TPACK. Participants then completed the TPACK assessment tool for the first time. An overview of the practical element of the project was then given.

Session 2 – 7/7/16

The theory underpinning TPACK was revisited and participants allowed to discuss. Their first use of the assessment tool was reviewed and an indication given regarding how TPACK might be visualised and the results interpreted. The TPACK game was introduced and several rounds played. This activity and subsequent discussion was recorded for subsequent analysis. T-CoRes were introduced, and an example shared and discussed. An opportunity then existed to collectively explore how the T-CoRe document might be used and completed. Participants were tasked with making use of the T-CoRe in planning and delivering an activity using appropriate technology before the next session. It was suggested that the T-CoRe be completed prior to teaching activity and then revisited and annotated so that any change in thinking could be recorded and presented in session 3.

Session 3 – 17/1/17

Collective and individual results from the first assessment exercise were shared and discussed. Participants were then asked to complete the assessment tool for a second time. The bulk of the remainder of this session was dedicated to participants sharing

and discussing their activities and use of the T-CoRe in the intervening period. Again, presentations and associated discussion were recorded for analysis later. Finally, a challenge was issued to engage in a second cycle of planning, use and evaluation.

Ideally a fourth group session would have been included to afford similar discussion and sharing of activity, but this proved difficult to timetable. The potential benefits of doing so on future occasions will be considered in due course.

All participants took part in an individual semi-structured interview at the end of the project. Completed T-CoRes were used to support stimulated recall and to allow participants to exemplify issues raised during their evaluation. The interview schedule used can be seen in appendix 5.

The evidence collected from activity with the teacher research group therefore comprises:

- A completed initial TPACK assessment tool from each participant
- Recorded discussion during the use of the TPACK game
- T-CoRes submitted by participants following the first cycle of use in school
- Recorded discussion about the use of T-CoRes in school
- A second TPACK assessment tool completed after first-cycle research in school
- T-CoRes submitted by participants following the second cycle of use in school
- Recorded individual interviews with participants about their experience during the professional development activity, their results and their use of the tools provided

3.3.4 Timeline of research

An indication of how the components of the research activity were enacted can be seen in Figure 12.

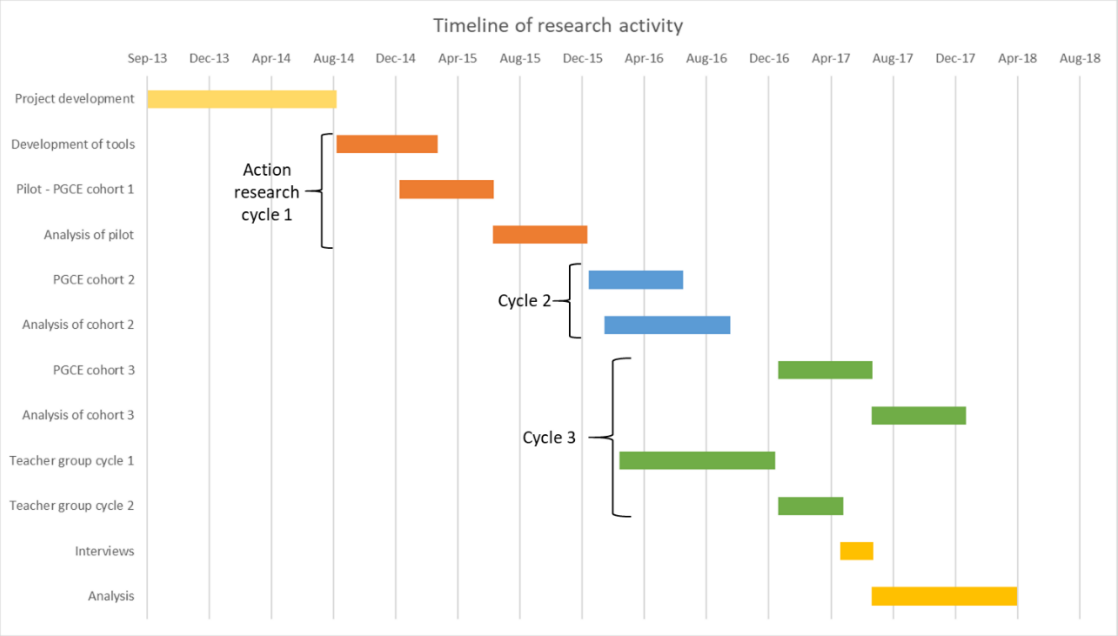


Figure 12: Timeline of research

A flowchart of the research process from conceptualisation to completion can be seen in appendix 6.

3.4 Quality assurance

An objective for any researcher is ensuring that data, and therefore the conclusions that can be drawn from it, are trustworthy. Each type of data being collected and used brings with it particular challenges including that of reliability (the consistency of results and the degree to which processes might be used by other researchers to the same effect) and, for quantitative data, validity (whether the methods used do what was intended in an accurate and reproducible manner). Bolarinwa (2015) suggests that these are ideas that are often omitted or dealt with very passively in research reports.

3.4.1 Validity

Given the accusation that many TPACK studies have paid insufficient attention to ensuring validity through appropriate measures (Drummond & Sweeney, 2017), the validity of the TPACK assessment instrument is discussed as an integral part of the development of the tool in section 3.3. It is demonstrated that the triangulation

afforded by obtaining data relating to both confidence and ability to distinguish domains has afforded diagnostic capacity to identify problematic areas and to demonstrate the positive effect of associated changes.

3.4.2 Reliability

A significant aspect of securing reliability is that of managing bias. As well as the potential for researchers to have pre-determined expectations or hopes, a wide range of factors may influence findings. These include the selection of participants. In this study, participants form purposive samples and care must be taken when attempting to generalise findings as participant activity may be heavily dependent on context and experience. The sample size is also of significance; the teacher development activity is based on a small number of participants and care must be taken with inferences made about the wider population.

The researcher's ability to remain impartial may be a challenge. Findings might be coloured by the extent to which we can interpret qualitative data derived from the words of others since we must, as Bryman (2008) suggests, 'participate in the mind of another human being' (p.385). The use of mixed-methods for data collection helps overcome some of these difficulties by affording opportunities for triangulation. Two notable forms of triangulation are included:

Methodological triangulation

- The assessment of the validity of the assessment tool was supported by two measures: the ability to distinguish domains; and the measures of internal consistency afforded by the use of Cronbach's alpha.
- The mixture of both quantitative and qualitative approaches to determine the effect of the intervention activity.

Perspective triangulation

- The use of serving teachers at a variety of career stages and with different levels of experience incorporating technology into teaching
- The use of cohorts of pre-service teachers in addition to the teacher research group

3.4.3 Generalisation

Generalisation was considered in section 3.1.2 and the caution that needs to be exercised was identified. The notion of 'fuzzy generalisation' (Bassey, 2001) promotes awareness of the extent to which findings are bounded by context. As a result, we may be able to make 'theoretical inferences' at best (Williams, 2000, p.218) to offer insight and ideas for others to weigh and explore more widely. From this work, it may be possible to make moderatum generalisations regarding the use of the tools by a wider audience and about the efficacy of the professional development activities employed.

3.5 Analysis and presentation of results

The methods used yielded a variety of data which required appropriate forms of analysis. An overview is shown in Table 13, before approaches to analysis are considered in more detail.

Data collected		Analysis
TPACK assessment tool	QUAN	Measures of internal consistency via SPSS.
Confidence data		Collated by individual and group for comparison. Variance considered in relation to sample size.
Ability to distinguish domains		Collated by individual and group for comparison. Variance considered in relation to sample size.
Discussion activities and interviews	QUAL	Transcription of recordings imported into NVIVO and subjected to thematic, emergent and magnitude coding.

Table 13: Forms of data analysis

3.5.1 TPACK assessment tool

Data from each participant were entered into a spreadsheet to record their confidence score against each statement and the domain to which they thought the statement most closely referred. Each domain response was coded as either '1' or '0' depending on whether it matched the domain expected.

Average scores were calculated for statements relating to similar domains to yield a confidence index and a measure of ability to identify that domain. An example of the analysis for a single participant is shown in Figure 14.

Across each group, averages were taken of confidence indices and identification indices. Where a visual representation of data relating to identification of subdomains was required, bar charts were created. To afford visual comparison of means and whether differences are significant, standard errors were calculated and included for each subdomain. The benefit of this is shown in the comparison of the pilot and a later version of the assessment tool in Figure 10 in section 3.3.2.

Confidence data could also be presented in a bar chart so that similar inference about significance of identified change could be made. For illustration, the collated data for the final PGCE cohort (T3) are shown in Figure 13.

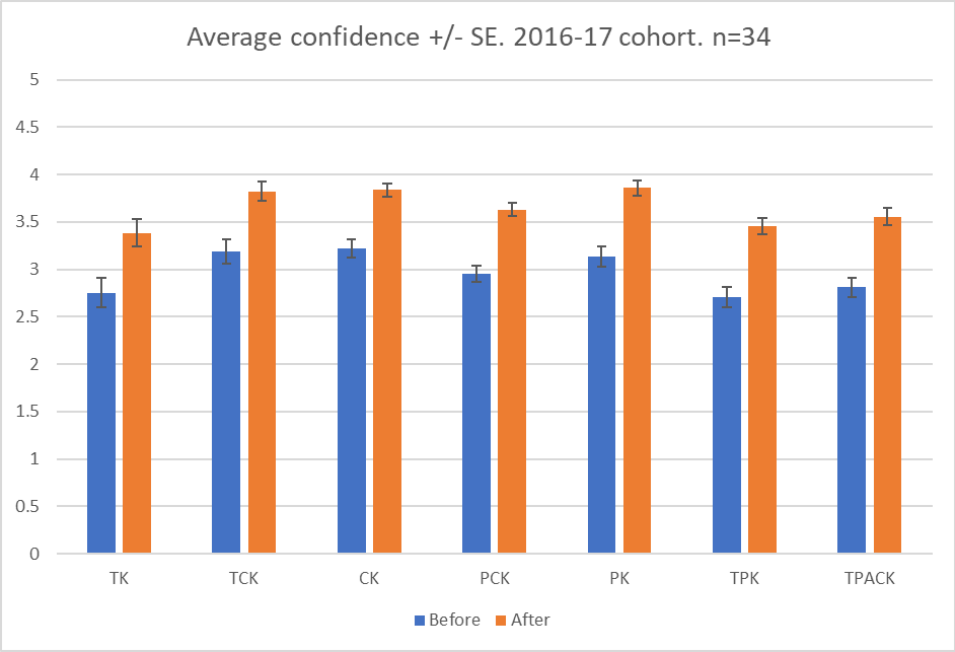


Figure 13: Sample comparison of confidence data

			Participant #		
Statement	Expected response		Confidence	Identified domain	Right/ wrong
			4		
A	TK		**2**	TK	1
B	CK		**3**	CK	1
C	PK		**3**	PK	1
D	CK		**4**	PK	0
E	TPACK		**3**	TCK	0
F	PCK		**2**	TPACK	0
G	TK		**2**	TK	1
H	TPK		**3**	TPK	1
I	PCK		**4**	PCK	1
J	PK		**3**	PCK	0
K	TPACK		**3**	TPACK	1
L	TPK		**3**	TCK	0
M	CK		**3**	PCK	0
N	TPK		**3**	TK	0
O	TCK		**3**	TPACK	0
P	TPK		**3**	TK	0
Q	TK		**2**	TK	1
R	PK		**3**	PK	1
S	PCK		**3**	PCK	1
T	TPACK		**4**	TCK	0
U	PCK		**2**	PCK	1
V	TCK		**2**	TCK	1
W	TPACK		**4**	TPACK	1
X	TPACK		**3**	TPACK	1
Y	PCK		**4**	PCK	1
Z	TCK		**3**	TCK	1
Sum	TK		9		3
Sum	TCK		8		2
Sum	CK		9		1
Sum	PCK		14		3
Sum	PK		10		2
Sum	TPK		12		2
Sum	TPACK		14		3
	Total				**16**
#of qus			**Av confidence for domain**		**Ability to interpret domain**
3	TK		**2.00**		**1.00**
3	TCK		**2.67**		**0.67**
3	CK		**3.33**		**0.33**
5	PCK		**3.00**		**0.80**
3	PK		**3.00**		**0.67**
4	TPK		**3.00**		**0.25**
5	TPACK		**3.40**		**0.60**
Av of subdomains			**2.91**		
TPACK			**3.40**		

Figure 14: Sample data for TPACK assessment tool

Another representation that affords potential discussion and a different perspective from which to explore the data about TPACK is a radar diagram as suggested by Colvin & Tomayko (2015). The same data can be presented in a manner that affords a view of related areas in accordance with their position on the now classic TPACK diagram.

This can be based on data at either the individual or group level. An example using the same data as Figure 13 is shown in Figure 15.

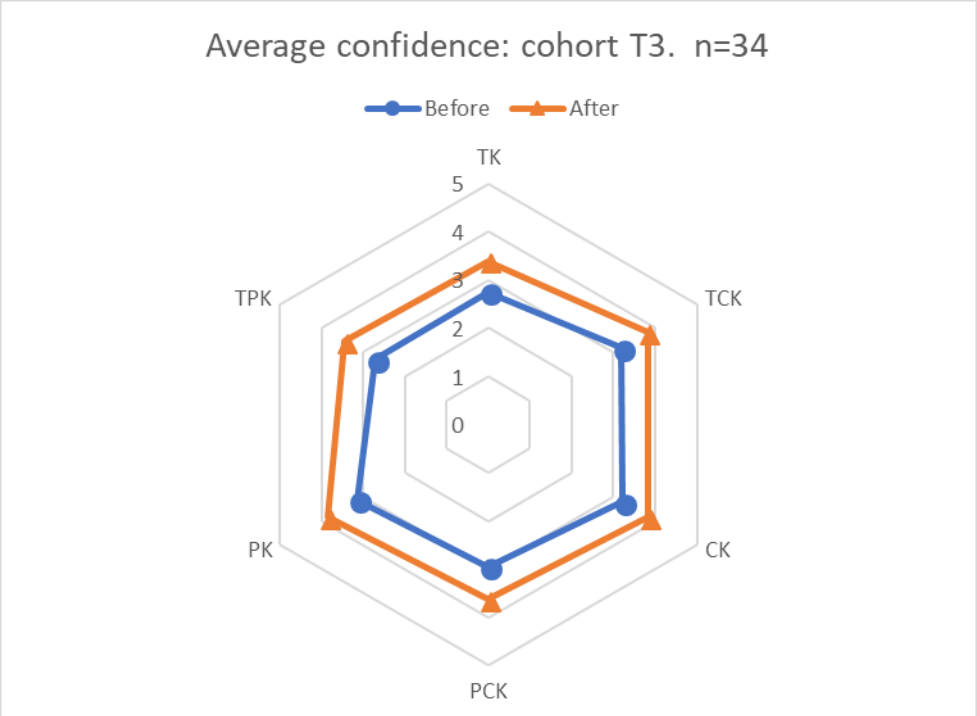


Figure 15: Radar diagram representation

To attempt to mirror the location of subdomains on the TPACK diagram, the central TPACK subdomain has been omitted and can be presented separately. A question worthy of consideration later is whether the overall pattern of the other subdomains is related to or representative of TPACK. To consider this, data were compared for TPACK and an average of the other subdomains for each individual within the same cohort (T3) as that represented in Figure 13 and Figure 15. The distribution (and the change in practice) can be seen in Figure 16.

The broadly linear relationship between the two variables would suggest that the omission of TPACK in the radar diagram may not limit the picture of practice it affords, and that the composite picture painted by the other domains is a good indicator of TPACK. The potential for radar diagrams to demonstrate changes in aspects of TPACK is evident and will be developed as findings are discussed in later chapters.

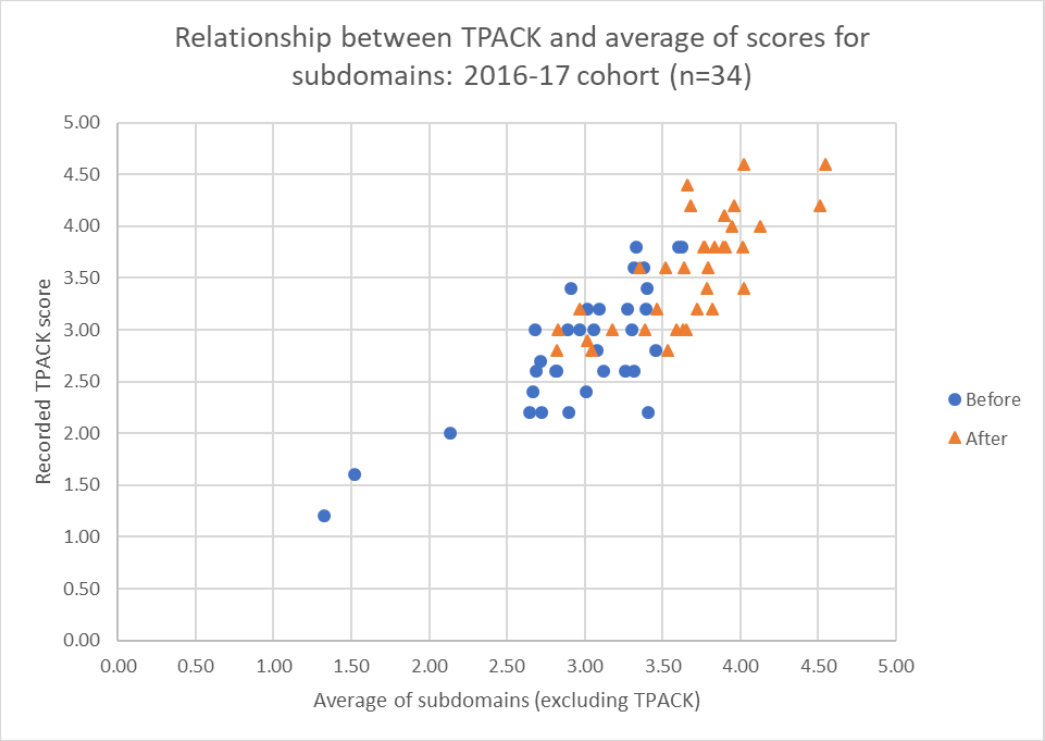


Figure 16: Comparing TPACK and other domains

One potential downside of the radar diagram and a potential reason why the bar chart may, at times, be a more useful representation is that, in typical spreadsheet software (in this case, Microsoft Excel), it does not appear possible to include error bars in radar diagrams to assign visual representation of significance. This, however, only has relevance when attempting to interpret group, rather than individual, results.

3.5.2 Discussion and interview data

Transcriptions of discussion and interview recordings were explored using NVIVO software. A first cycle of descriptive coding was made using pre-determined nested codes based on different aspects of the study: the TPACK assessment tool; the T-CoRe; the professional development (intervention) experience; the TPACK framework; and other codes likely to cut across categories. These pre-determined codes were based on intended outcomes defined in my research questions and reflection on an element of 'pre-coding' made during transcription of interview recordings in which aspects that were seen as potentially 'codable' were highlighted and analytic memos made.

In addition to the ability to identify themes to support analytical narrative, the ability to 'quantitize' qualitative data adds useful potential for methodological triangulation (Saldaña, 2016). Saldaña calls this 'paradigmatic corroboration' (p.26) suggesting that it affords a reality check and provides an additional lens through which to explore qualitative data. Although not contributing to a quantitative sense of validity, paradigmatic corroboration will hopefully support the trustworthiness of the data and its interpretation. Since my research questions intend to elucidate information relating to the ease of use and usefulness of the tools employed, simple magnitude coding was applied within each of the top-level nodes. This was based on 4 levels: NEG – negative statements; 0 – ambivalent statements; 1 – positive statements; 2 – strongly positive statements. Additionally, REC codes were assigned where any recommendations were offered by participants in relation to any aspect of the study.

Alongside this, during first-cycle coding, emergent coding was employed to maintain coding flexibility and allow the capture of additional significant ideas. Initially this was supported by an element of code landscaping involving the creation of word clouds from transcribed interviews and recordings of discussions. Individual discussions may warrant comparison later but there were some similar patterns which are neatly illustrated in a single word cloud generated from collation of all transcribed data as shown in Figure 17.

To illustrate the value of this activity, during first-cycle coding it became clear that much opinion was being offered and the phrase 'I think' was exerting a significant effect on the representation of the word stem 'think' in the word cloud. The word cloud in Figure 17 therefore represents the collated data in which all instances of the specific phrase 'I think' were removed. 'Think' as a word stem is still one shown as being used frequently therefore indicating that it warrants a coding node of its own.

Figure 17: Code landscaping

A second cycle of coding revisited emergent codes and provided the opportunity for pattern coding to 'meta code' similar ideas or offer comparative analysis between participants and resources.

In addition to attempting to capture the essence of participants' contributions, some in-vivo coding (as 'QUOTES') was made, as recommended by Cresswell (2015) to allow retrieval of key ideas best expressed in the words of the participants themselves.

Whilst discourse analysis was not seen as appropriate to support analysis in relation to the research questions under consideration, an element of coding was included to identify particular statements made by interviewees that were easily mapped against the TPACK framework. If not contributing directly to the findings of this study, there may be merit in doing this to explore whether the use of pre- and post-intervention activity/interview has the potential to measure differences in participants' TPACK. As such, this may be a useful outcome with potential to inform future work in this topic area.

The combination of the coding strategies selected offers, it is hoped, good scope for analysis and the selection is reassured by Saldaña's notion of 'pragmatic eclecticism' (p.70) which suggests that there is no single 'right' approach and that tools be selected

with regard to the Research Questions and therefore a sense of potential units of analysis in mind. The use of emergent coding techniques supports the recursive nature of abductive research and the synergy between method and analysis.

The final coding tree can be seen in Figure 18. The relationship between codes and the research questions, together with inclusion criteria can be seen in appendix 7.

Throughout this process, I have attempted not to fall foul of the warning sounded by Bryman (2008) that fragmenting the data by coding may result in the loss of the big picture by losing the voice of the participants. The researcher, warns Wolcott (1994), can get in the way of what he refers to as 'immaculate perception', as any analysis of data will be 'filtered by their own perceptions' (p13). He later argues that there is no such thing as immaculate perception and that 'purposiveness' is something about which researchers should be up front, whilst guarding against the tendency to take a 'dump truck' approach to the use of data in resultant narratives and indulging in an 'excess of descriptive reportage' (p14). For this reason, analysis and discussion will be treated thematically before a holistic view is taken.

Advice regarding what constitutes significance in the analysis of qualitative data appears mixed. Harding (2013) suggests that a quarter of respondents might share a node to merit consideration in analysis and three-quarters for commonality to be established. Whilst this may be appropriate for my student teacher cohorts, with the smaller group of teacher participants, these rules offer little that is helpful. Saldaña (2013), however, seems to take solace in Wolcott's propensity for rules of three offering reassurance that 'three of anything seems an elegant quantity for reporting qualitative work' (p.25).

Analysis of coding will therefore include a search for patterns and frequencies of codes to support identification of themes worthy of discussion.

Name	Sources	References
CPD	0	0
CPD-0	0	0
CPD-1	7	13
CPD-2	5	7
CPD-CARDGAME	5	10
CPD-NEG	0	0
CPD-problems	1	4
CPD-QUOTE	8	25
CPD-REC	5	20
x-A background info	1	6
x-B background info	1	5
x-C background -info	1	1
x-D background info	1	3
Domain	0	0
CK	0	0
PCK	1	1
PK	0	0
TCK	1	3
TK	2	4
TPACK	8	26
TPK	2	3
UNDERSTANDING TPACK	3	4
X-CONTEXT	4	5
X-DATA	5	8
X-FUZZY	5	6
X-TPACK INERTIA	5	9
Questionnaire tool	0	0
Q-0	0	0
Q-1	3	4
Q-2	0	0
Q-INTERPRETATION	4	6
Q-NEG	1	1
Q-QUOTE	2	5
Q-REC	0	0
T-CoRe	0	0
TCORE-0	0	0
TCORE-1	7	22
TCORE-2	9	14
TCORE-COLLAB	6	9
TCORE-DIFFICULTIES	1	1
TCORE-INTERPRETATION	8	18
TCORE-NEG	1	1
TCORE-ORDER	3	5
TCORE-POTENTIAL	2	2
TCORE-PROCESSvsPRODUCT	3	6
TCORE-QUOTE	11	25
TCORE-REC	9	25
TCORE-REFLECT	4	8
TCORE-TIME	5	6
TCORE-USE AGAIN	7	12
TCORE-USEFULNESS	5	19

General themes	0	0
Name	Sources	References
AFFORDANCES (not diff or engagement)	4	10
AfL	5	11
ALTERNATIVES	4	6
BARRIERS	10	44
BARRIERS OVERCOMING	10	28
BENEFITS-PARTICIPATION	5	14
BENEFITS-STUDENTS	6	30
CHALLENGE (between participants)	1	1
CHAMPION	7	19
CHOICE	2	3
COLLAB	10	37
CONTINGENCY	5	7
DEVELOP CONFIDENCE	3	7
DEVELOP PRACTICE	7	26
DIFFERENTIATION	4	7
DIG-LIT	4	9
ENGAGE	7	18
FEEDBACK (between particpants)	1	7
FUSION	1	1
IMPACT cf DEV PRAC	7	17
ITERATIVE	1	1
LEARNING	7	17
MOTIVATION	7	22
NEXT STEPS	7	15
OTHER QUOTE	11	32
OWNERSHIP	6	11
PLAY	3	6
PREP	5	11
QUESTIONS	6	10
RELEVANCE	2	3
RISKS of using tech	2	4
SPECULATION	2	2
SUCCESS	5	7
THINK	11	54
USEFULNESS	8	15

Figure 18: Coding tree

For ease of reference, a hierarchy chart can be presented for each top-level node to represent the coding density of constituent nodes. For example, a chart of the nodes contained within the 'General themes' node can be seen in Figure 19.

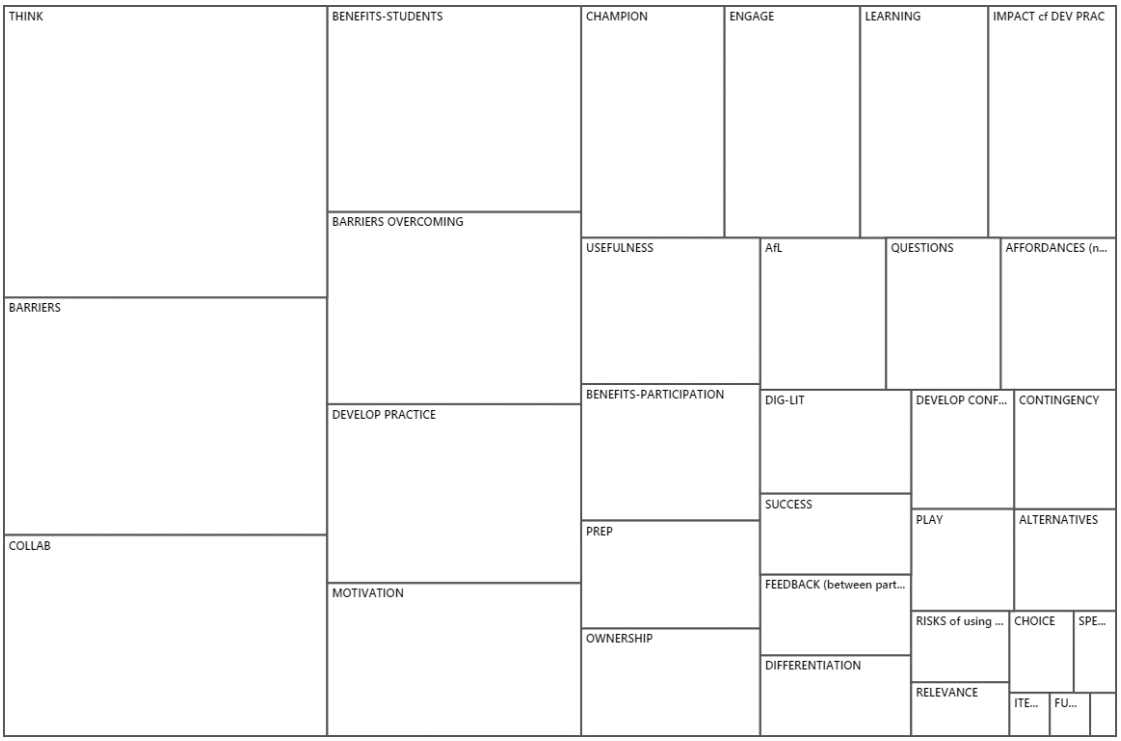


Figure 19: Hierarchy chart for general themes

The area of the blocks reflects the frequency of coding against constituent nodes. In this case, issues relating to thinking, barriers to the use of technology and ideas about collaboration seem to have generated significant discussion and can be prioritised for analysis.

3.5.3 T-CoRes

Teaching artefacts (T-CoRes) were retained where permission was obtained, explored for any significant or recurrent themes arising from their use and also used for stimulated recall during interviews. In this way, the T-CoRes might be used to verify suggestions about their use made by individuals in discussion.

For each T-CoRe produced, the topic, level and suggested use of technology was also recorded and encoded in NVIVO. Sections left blank were noted and reasoning offered for pedagogical choices recorded. Consideration of TPK was noted in terms of issues raised and suggestions for the mitigation of identified problems. Additional notes were recorded to capture interesting features and an arbitrary judgement made on a scale of 1 to 5 to afford comparison of the extent to which technology appeared to be integrated into the thinking evidenced by the T-CoRe. This is considered further in section 4.2.2.

3.6 Ethical issues

Research was planned and carried out in accordance with the ethical guidelines laid down in the University of Leicester's code of practice and by BERA (2011) which states that research should 'be conducted within an ethic of respect for the person, knowledge, democratic values, the quality of educational research and academic freedom' (p4).

All doctoral research in the School of Education at the University of Leicester at the time of application required ethical approval by the University Ethics Sub-Committee for Sociology; Politics and IR; Lifelong Learning; Criminology; Economics and the School of Education. Application was made, and approval received (see appendix 8).

For the professional development activities, participants were assured of the right to anonymity and that artefacts collated during the course of research would be destroyed once their research value had expired. Participants were also aware that they had the right of non-participation or withdrawal from the project at any time.

For school-based activities, all work would take part within the normal working practice of the teacher/trainee teacher. All participants had been previously subject to relevant formal safeguarding checks without the need for additional consideration for the purposes of this project and were subject to the requirements for professional conduct inherent in the UK Teachers' Standards (DfE, 2011).

Participants had both given their own informed consent and obtained consent from the headteacher of their schools for the research activity to be carried out with their pupils. The consent form can be seen in appendix 9.

3.6.1 Academic integrity

The work outlined here is, to the best of my knowledge, an original development of ideas gained from academic literature surrounding both technology and professional development.

Three resources developing directly from the work of others have been approved by the authors concerned (see appendix 2), these being:

a) The TPACK assessment tool after Archambault & Crippen (2009) and with consent from Leanna Archambault, Arizona State University
b) The T-CoRe, based on content representations by Mulhall et al (2003) with approval from Pam Mulhall and colleagues at Monash University, Melbourne, Australia
c) The TPACK card game adapted with permission from Matt Koehler, Michigan State University

Participants were selected as described in section 3.3.3. Trainee teachers undertook course level tasks using the tools, but small-group discussions involved voluntary participation. Serving teachers were invited and volunteered to participate based on their understanding of the project outlined to them.

It is important to recognise that these groups form non-random purposive samples that may not be representative of the general population of teachers or trainee teachers and that only guarded 'fuzzy generalisations' may be made as described by Bassey (2001). Their individual narratives, however, can hopefully provide insight regarding how the tools provided were used, how they might be developed further and how effective this approach is as a piece of professional development that fosters sustained impact.

3.6.2 Conflicts of interest

A conflict of interest is almost inevitable in any interventionist research and great care must be taken to avoid unintentional bias in the interpretation of results as a result of the vested interest the researcher has in what might be seen as positive outcomes. This might pose a greater problem where ongoing research funding is contingent upon early results or where researchers are acting as 'agents for a political agenda' (Gorard, 2013, p.190). Research design therefore needs to take into account the need for avoiding bias and for honesty and integrity in the interpretation of results.

In this study, I am seeking to develop effective professional development practice and therefore negative and formative comments from participants are as useful as, if not more useful than, positive comments. During the analysis of artefacts and interview recordings, 'magnitude' and 'rec' coding will be used in addition to emergent coding to support identification of significant and useful themes. The use of magnitude codes adds 'adjectival or statistical texture to qualitative data' (Saldaña, 2016, p.82) and will hopefully help provide a more nuanced analysis and therefore reduced likelihood of blunt interpretations that might be open to accusations of bias or loss of integrity.

As researcher I am integral to the intervention activities yet a little more remote from the participant practitioner research element which is self-guided. There are benefits and disadvantages to both positions. 'Outsiders' may be more objective but miss contextual subtleties; 'insiders', whilst familiar with context, may have only a limited perspective (Thomson & Gunter, 2011). In a similar manner to the challenge posed earlier to the binary philosophical positions that might be taken, Thomson & Gunter challenge this insider/outsider binary and advocate methodological consideration in the light of how 'messily blurred' things can become (p.26). They advocate the helpful but risky perspective afforded by the notion of 'liquid identities' (ibid.). This is a useful reminder to retain a perspective on the big picture of the research and retain sight of the research questions I have established throughout the various aspects of the research despite being very close to the research activity being undertaken.

This chapter has outlined the philosophical underpinnings of the research which have led me to take a pragmatic abductive stance which validates an action research approach to this project. The paradigmatic corroboration afforded by multiple perspectives and the use of both qualitative and quantitative methods helps ensure a robust approach is taken with attention to both validity and reliability. The tools and activities used are described and ethical consideration given.

In the next chapter, findings are described and presented in relation to the different elements of the project.

4 Chapter 4: Findings and analysis

In this chapter, the operationalisation of each of the tools will be considered in turn before looking more closely at the experience of each of the groups of teachers engaged in professional development activity.

The development of the toolkit of resources across the three cycles of action research has been considered in section 3.3. With the improvements shown in validity, the tools were deemed fit for the purposes of supporting research activity in the final cycle. The utility of the tools now comes under scrutiny as their use in the planned professional development activities is considered. These activities developed across cycles two and three of research activity.

Given the significant development of the toolkit, in particular regarding overcoming the challenges inherent in optimising the assessment tool for the third cycle of activity, reflection on and evaluation of its utility therefore centres largely on the experience of the teachers and trainee teachers in the third cycle although relevant findings are also drawn from trainee teachers engaged in cycle two. Rather than being presented chronologically, findings are therefore analysed thematically, firstly in relation to the utility of the individual components of the toolkit and then in relation to the professional development activities the participant groups experienced and the outcomes identified.

4.1 Referencing contributions

In discussion, the four experienced teachers are referred to as teacher A, B, C and D as described in section 3.3.3 and summarised below.

Participant	Gender	Number of years teaching experience	Level of prior technology adoption
A	F	2	Adopter
B	M	10	Adopter
C	M	4	Innovator
D	M	20	Non-user/ adopter

Table 14: Referencing teacher participants

Trainee teachers, in group discussions, are referred to firstly by group (T1, T2, T3), referring to the three cohorts (2014-15 (pilot), 2015-16 and 2016-17 respectively) and then by order of use in Roman numerals. Where possible, the same contributor will be denoted by the same number in each case. For example, T1.iii refers to the first cohort and the third contributor from that cohort.

T-CoRes produced by trainees are similarly referred to by cohort and then instance of use. First use (in pairs) is referenced 'a' and then alphabetically in order of coding since individuals are not identified (e.g. T2a.D) to show the second cohort, first use, fourth example coded). Second use, by individual trainees, is referenced 'b' and then 'n' where n is the reference number assigned each trainee. Where the assessment instrument was identified by name, the same number is used consistently for the same individual. For example, T3b.6 therefore represents the third cohort, and second (individual) use by the trainee identified as number 6.

4.2 Efficacy of the toolkit

4.2.1 The assessment tool

The development of the assessment tool is described in section 3.5.1 where consideration is given to the measures successfully taken to improve the validity of the tool. Its ability to identify measures of both confidence in each domain and ability to identify domains within the TPACK model has been demonstrated. The findings from use with both the trainee and serving teacher groups will be explored in section 4.3.

The analytical process described in section 3.5.1 allows measures of confidence and competence to be made and therefore, through pre- and post-intervention comparison, change to be identified.

In use, the four teacher participants made six positive statements about the use of the assessment tool compared to one negative. The negative statement (teacher B) suggested that this participant did not like having to identify the domain to which each statement referred, suggesting that he felt that 'at the end of the day it's all pedagogy'.

In future use, it may well be prudent to remove this aspect of the assessment tool and focus on confidence, but it was important at this stage in the development of the toolkit to evaluate its potential and relevance. As discussed in section 3.5.1, the availability of the domain identification data was of particular use in supporting development of the tool to its current state, evidenced by improvements in participants' ability to identify domains from the statements and corroborated by triangulation with the demonstration of enhanced validity of the tool via the use of Cronbach's alpha on confidence data.

Positive statements about the use of the tool by the same participant included reference to the tacit coding of statements against which to assign a measure of confidence: 'that is much easier and it's much better' suggesting recognition of the fuzzy nature of the subdomains in practice. Another participant, when asked whether there were statements in the assessment tool that were potentially confusing, suggested:

> 'No – because, even with the ones that I thought were tricky, it just made me think about it more' (Teacher C)

Teacher C was the most proficient and innovative user of technology and took very quickly to the theoretical dimension afforded by TPACK. Giving consideration to the use of the assessment tool, he suggested:

> 'I felt the questions covered a lot… covered everything that was mentioned in that Venn diagram'

This offers helpful feedback in terms of validating the choice of items included in the questionnaire and further useful qualitative, anecdotal corroboration of the quantitative perspective afforded by analysis of the numerical data.

Trainee teachers admittedly had less preparation prior to use of the assessment tool and several did not at first appreciate that the confidence results presented to them were generated by pre-determined coding of statements against subdomains and not affected by their subsequent attempt to identify the subdomain:

> ‘I’d probably got more confidence [the second time] in actually understanding what the question was asking… when we did the first one, I…found it quite difficult to answer it because I really wasn’t sure…what I was looking at… I mean, was it in that segment or that bit there…so I don’t think I was very confident in answering the questions’. (T2.ii)

On reminding him that the confidence ratings assigned were independent of his ability to identify the domain, T2.ii was able to look at his results in a more enlightened way: ‘so this is just a confidence…oh…right’.

Other trainee teachers expressed a limited sense of understanding the language of TPACK at the beginning, validating the use of tacit coding but also hinting at the potential value of spending time with a theoretical model such as TPACK:

> ‘The first time, I was like, oh…do I really know what…pedagogical content knowledge is, do I really know… I think cos we were being introduced to it quite early on… I think there was not a huge amount of knowledge about it at the start for me but I kind of followed and went ‘ok – yeah… I don’t understand that’. After I’d done this I was like ‘oh yeah – content knowledge is that’ you know and I know what that is and specifically knowing the difference between TPACK and TPK so actually, you know you’ve got your TK – how is the technology related to how you’re teaching and also the content - rather than how could the technology help the content. I found that distinction a lot easier after having done this’ (T3.i)

Findings relating to individual and group performance as gauged by the assessment tool will be considered in section 4.3. However, the efficacy of the tool has been demonstrated as well as insight gained relating to the apparent relationship between the level of a teacher’s TPACK and the average of scores obtained for the other domains.

4.2.2 The T-CoRe

In this section, the use of the T-CoRe document to scaffold thinking relating to aspects of TPACK is considered. Examples of annotated T-CoRes are provided and findings are drawn from these artefacts produced by participants and from discussion and interview data.

4.2.2.1 The T-CoRe in use

Once introduced to T-CoRes, cohorts of trainees and the teacher group were invited to 'have a go' collaboratively, using a topic of their choice. This afforded the opportunity to discuss the trigger statements to allow their interpretation.

4.2.2.1.1 Interpretation

The level of introduction provided made a significant difference to the use of the T-CoRe. During first use with the first cohort for whom an intervention activity was provided (T2a) trainees left a significant number of sections blank whilst working through the document. In the 25 columns analysed (each column representing an intended learning outcome defined for exploration), these centred around statements relating to Technological Knowledge (5x TK), Technological Pedagogical Knowledge (5x TPK) and Pedagogical Content Knowledge (5x PCK). An additional 3 statements were left blank corresponding to TPACK and 2 to Content Knowledge (CK).

This may have been through a desire to rush through the document but there were some signs that this was linked to a lack of understanding of the trigger question:

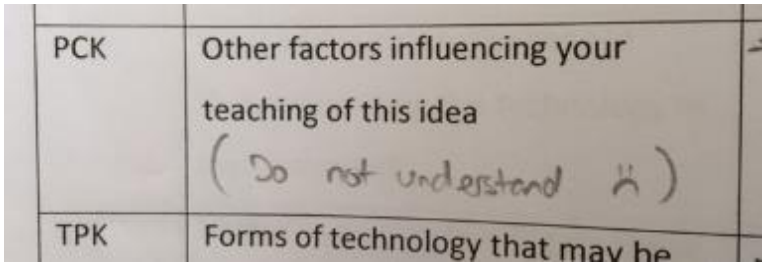


Figure 20: Evidencing lack of understanding

(T2a.B)

In the subsequent discussion with this group, trainees acknowledged some of these difficulties:

> 'I think everything I wanted to say, I said, it's just I'm not sure if they're in the right boxes or not' (T2a.i)

> 'I think I'm not entirely sure on - I mean I put stuff in all of them but I wasn't sure if they were in exactly the right place so I kind of just guessed a little bit with that one' (T2a.ii)

Following discussion and in subsequent individual use, of the 35 columns submitted for analysis by 19 trainees in the same cohort, only 3 contained blanks showing a much more considered interpretation of the trigger questions on the T-CoRe. The importance of adequate preparation and introduction to the use of the T-CoRe is therefore clear. Student feedback made it clear that some exemplification of statements would help support understanding:

> 'Would it be acceptable to put, behind it, in brackets: 'for example…' just to show what you mean by the question?' (T2a.iii)

> 'It would be useful if there was one example, like the one you gave with the CoRe [in previous work on PCK] then you had expected answers or what it could look like and you could actually follow it with what we are doing so you know well this is what you're expecting – something specific which guides us' (T2a.iv)

To this end, completed examples were used in discussion prior to the use of the T-CoRe with the following year's cohort (T3), and trainees were talked through the T-CoRe in more detail before they made exploratory use. In the eight groups undertaking the task, only two left blanks: one because they spent a considerable amount of time discussing the first half of the document and did not complete in the time available, and one group who left a single blank relating to one of the trigger statements concerning TPK. In individual use in the subsequent planning/teaching task, only one trainee of the seventeen who gave consent for copies of their T-CoRes to be retained left a single blank.

The teacher CPD group ran concurrently with cohort T3 and preparation allowed all teacher participants to complete all sections of the T-CoRe.

4.2.2.1.2 Focus

Initial use by groups tended to be less focused than the more detailed responses required in subsequent individual use, but this was not surprising since participants needed time to explore the materials to get a sense of the big picture. Initial use often tended to involve reflection on past teaching episodes to which all members of each group could relate. In this sense, the T-CoRe was used to deconstruct teaching rather than as part of the planning process, but this too was seen as valuable as participants were actively linking ideas from the T-CoRe to the context of the classroom.

During initial use with the first cohort with whom T-CoRes were used in this way (T2a), there was a tendency towards the general rather than the specific, with reference to non-specific resources such as 'interactive' or 'animation'. Similarly, there were superficial responses by some in initial use to the question about how identified problems might be mitigated. The T-CoRes were able to evidence some discussion regarding the need to plan for such eventualities but, of 24 T-CoRe columns analysed for T2a, 12 did not identify the need for anticipating the need to mitigate potential problems, 6 recognised a generic need for a 'backup plan' or 'plan B' and only 6 identified specific solutions to identified issues.

The same cohort, during individual use in relation to a directed task in school, showed that a slightly higher proportion had anticipated the need to mitigate problems in their planning (34 columns received of which 13 ventured specific responses, 5 acknowledged the need for a backup plan and 16 considered no mitigation).

A similar pattern was exhibited by the following cohort (T3), reflecting either an unwillingness to go into sufficient depth at the time of their introduction to the use of the T-CoRe or an inability to think of means by which potential problems might be mitigated by additional planning.

All the experienced teachers taking part, were able to anticipate and plan for such eventualities when preparing T-CoRes showing a more highly developed ability to anticipate and mitigate logistical problems in the classroom.

4.2.2.1.3 Affordance

Of interest in the use of the T-CoRe was the range of pedagogical affordances of technology about which it stimulated thought by participants.

Uses included: animation; specific apps; augmented reality; presentation; quizzes; research; simulation; video clips; video recording; time-lapse recording; and virtual learning spaces. The pedagogical justification given for these included demonstration of abstract concepts; Assessment for Learning; engagement; assisting memorisation; fostering independent learning; interactivity; simplicity; visualisation; and providing alternatives to difficult or controversial teaching strategies such as dissection.

This is extremely encouraging, particularly given the tendency of trainee teachers to talk about presentational uses of technology on first discussion rather than approaching technology from a more pedagogical perspective.

Thought given to the mitigation of difficulties centred largely on technical issues such as internet access and hardware/software problems but also included thinking relating to: issues of behaviour management whilst using new teaching methods; the need to evaluate resources before use; the need to practice before classroom use; the level of operational skills possessed by students; the availability of resources; and the need to provide clear success criteria to ensure that students had a sense of purpose using novel resources.

The range of technological affordances considered reflects a welcome breadth of independent thinking on the part of participants and validates thinking that, given the opportunity, teachers can contextualise their thinking about technology in their own working context.

4.2.2.1.4 Exemplification

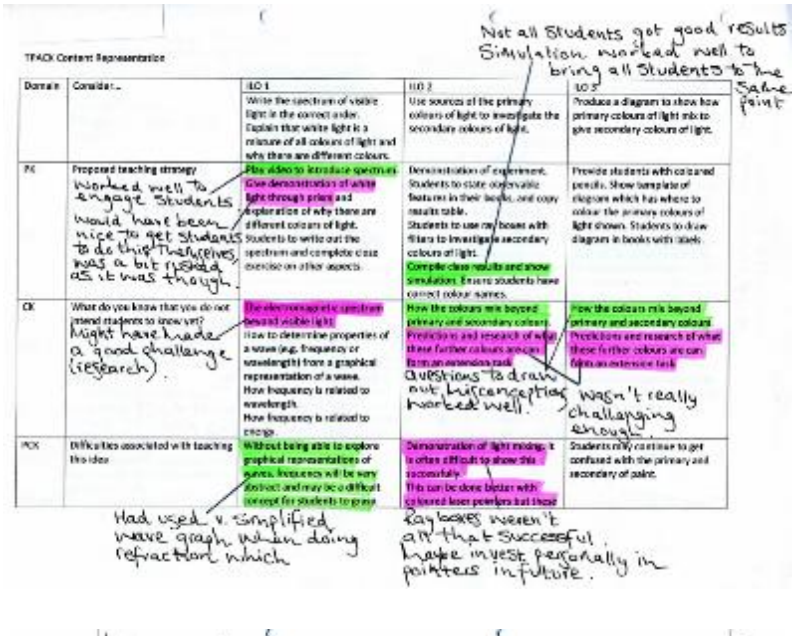
Several examples are drawn from trainees from the second cohort (T3) who made both determined use of the T-CoRe and opted to identify themselves on both uses of the assessment tool. In this way they can be cross-referenced if required. These participants were also invited to form part of the discussion groups held at the end of the process.

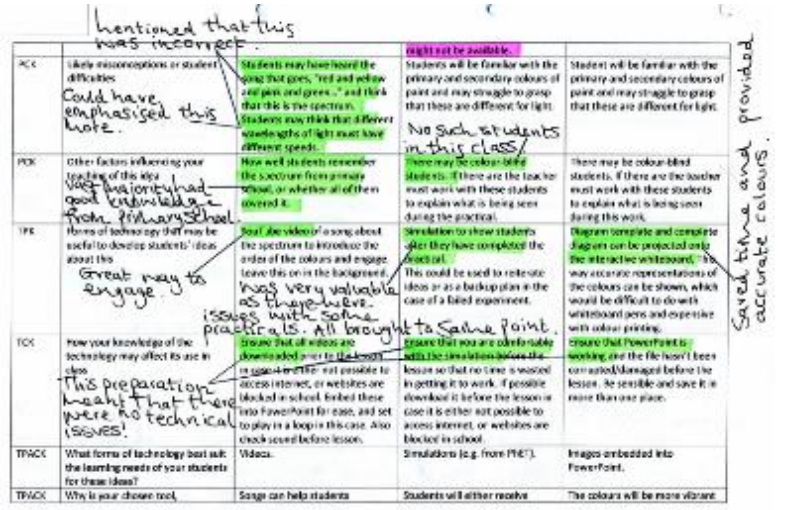
With admittedly less effective preparation than that subsequently developed for cohort T3, one example from T2 is offered in Figure 21 as exemplification of the good extent to which some users were still able to offer evaluative annotation. This example is reproduced full-size in appendix 11.

In this T-CoRe, the trainee (identified as T2b.15) reflects helpfully on the pedagogical justification for the choices made and the value of planning the inclusion of technology into this teaching episode.

Two further examples, corresponding to trainees whose data are discussed in more detail in later sections are also included. Appendix 12 shows the T-CoRe for the trainee identified as T3.i in relation to analysis of discussion, and appendix 13 shows that for trainee T3.ii.

Instead of extensive annotation, the group of experienced teachers offered oral evaluation whilst presenting at two of the face-to-face sessions, although one of the participants (Teacher B) added helpful annotations to the T-CoRe shown in appendix 14.





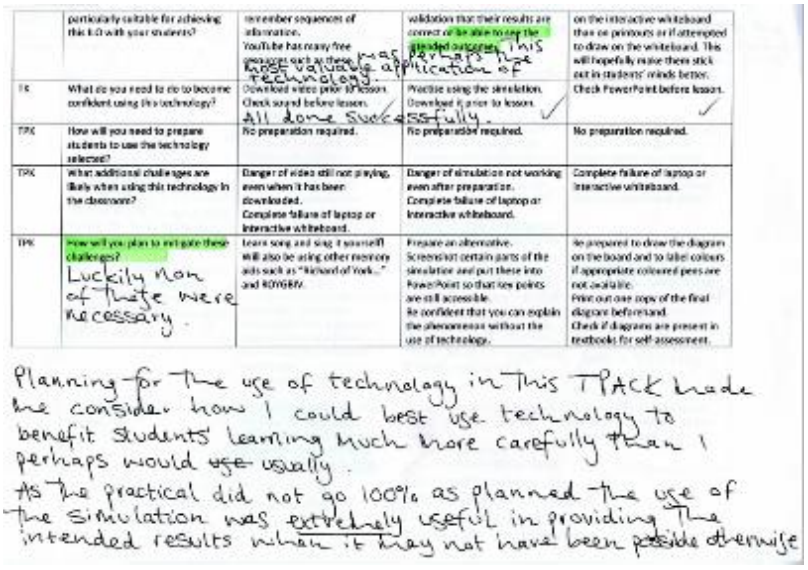


Figure 21: Example of an annotated T-CoRe

4.2.2.2 The T-CoRe in review

4.2.2.2.1 Support

The concept of the T-CoRe document was well received by both trainees and teachers. In discussion groups and interviews thirty-six supportive statements were recorded compared to one negative. The negative comment related to the time taken to complete the document and is a factor that warrants discussion later in this section when combined with recommendations made by participants.

Supportive statements, when asked how useful the document and associated process were, ranged from the concise to more expansive consideration:

> 'I thought it was brilliant' (Teacher A)
>
> 'I like a framework where you need to answer questions' (Teacher B)
>
> 'Actually, just doing that T-CoRe was really effective because…I could talk about the things that actually mattered' (Teacher C)
>
> 'I found that really useful and I sort of used this to think… was this the right way or could there have been another way? So I thought that was really useful.' (T2a.i)
>
> 'It was actually quite useful – when I first saw it I thought wow that's a lot to write – that's a lot of boxes – but it actually was very useful.' (T2.v)
>
> 'I thought the way the questions were worded got me to really think about just being a bit more innovative with some of the different technologies and things which I wouldn't have thought about otherwise – because of the way some of the questions were worded, I was like 'ooh' maybe I could do this and things like that – it was useful.' (T2.vi)

Users therefore appeared to appreciate the structure of the T-CoRe which scaffolded a logical sequence of thinking about the incorporation of technology into teaching.

4.2.2.2.2 Identification of themes

Deeper exploration following thematic coding of discussion and interview data suggests a number of areas are worthy of more detailed consideration as shown in the hierarchy chart below:

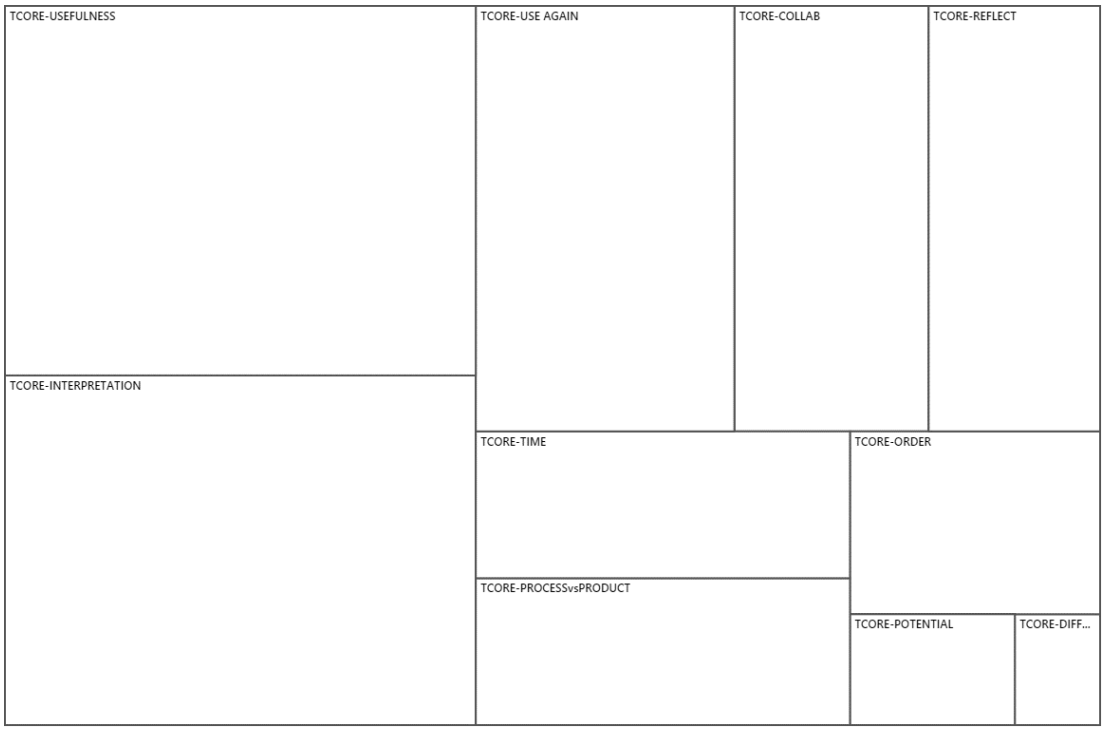


Figure 22: T-CoRe identification of themes

Thoughts about metacoding suggested that significant aspects of evaluation fall into three broad areas. Firstly, there are notions of usefulness and potential including the nodes USEFULNESS (19 references), COLLABORATIVE USE (9) and POTENTIAL (2). Secondly, participants' evaluation of use of the T-CoRe is worthy of consideration including the nodes INTERPRETATION (18 references), TIME (6), ORDER (5) and DIFFICULTIES (1).

Consideration of the value of the T-CoRe itself versus the process of completing it was also raised six times and is something that, in both recorded and informal discussion, has increased in the 'luminosity' alluded to by Tavory and Timmermans (2014) in chapter 3 and feels worthy of discussion. These, together with recommendations made regarding further use of the T-CoRe will be considered in the following sections.

4.2.2.2.3 Usefulness and potential

The capacity for the T-CoRe to promote pedagogical thinking in relation to technology came across strongly during discussion and interviews:

> 'I'd never thought about it in so much detail in all the aspects and it also makes you think 'actually yeah it does help with this and it does help with that' rather than just seeing technology as something nice to use in the classroom.' (Teacher A interview)

> 'So it's made a big – a really big difference… Without picking it apart on here, I don't think I'd have thought about it as much.' (Teacher D interview)

> 'What I find useful is that the questions really force you to think about every aspect' (Teacher B interview)

Teachers recognised the value of the retention of statements relating to PCK from Mulhall et al's (2003) original CoRes but also the merit of additional statements with a specific focus on technology. For example:

> 'I want people to plan with questions like this anyway, whether you use technology or not… all these questions are important but, ok, 'how will you prepare students to use the technology selected' is maybe a specific question to do with technology… and I think that for me those questions are very important because I will think more about how to incorporate technology more in my lessons' (Teacher B group discussion)

When questioned about how likely they were to choose to explore their thinking using the scaffold provided by the T-CoRe in future during their planning, some teachers were very positive reflecting on their capacity to teach unfamiliar topics:

> 'doing this [T-CoRe] for [new topic] would be really helpful. So yes, I think it will be useful – I think I will use it.' (Teacher D interview)

Others, although wary about the time implications, reflected on the potential benefits of CPD for others:

> 'I think there would be for professional development for others because I think the best thing about it, I think, is that with it being big, with it being visual and clear, that collaborative work lends itself really well to it.' (Teacher A interview)

Teachers also began to reflect on strategies for future use with others:

> 'you could even have that, if you work in threes, that one really works on one or two questions and another works on some other questions and you discuss that with each other so that, together, you get a nice framework – and the next time you swap the questions so that you work on all the questions but you don't do it all in one go.' (Teacher B interview)

> 'we are starting to plan as a department now, moving forward and creating our own schemes of work – and I'm thinking, if the time does come up when we are struggling to teach an idea, whether it might be useful to do something like that in like a teaching pair.' (Teacher C interview)

Building on the potential for collaborative use, the same teacher speculated about use of the T-CoRe to support school strategy for meeting perceived teaching challenges:

> 'with our CPD now, SLT are talking more and more about collaborative planning - when you're doing medium and long term plans, we should be collaborating and thinking about how to tackle these challenges together as a department or within groups within a department, so yeah, I think it's something that I would want to sort of have in my back pocket and, when we come across a problem, say 'oh – you know this will take 5 minutes guys – why not let's have a go at this and see what ideas we come up with?'' (Teacher C interview)

Two of the teachers undertook their first cycle of practitioner research together whilst working at the same school. It was clear that they valued the opportunity to focus together on an aspect of problematic teaching as illustrated in the following exchange during a group discussion after they had both moved to new schools:

> Teacher D: 'You get so much more from planning with someone'
>
> Teacher A: 'I definitely miss having you there to plan with'

Student teachers were perhaps less receptive to the idea of making voluntary use of the T-CoRe in future but did appear to recognise the potential value of collaborative use:

> 'I wouldn't use it all the time but equally… if you're doing a scheme, it's quite useful cos it's just in a different format that you can collate those things together and say 'right – this is probably the way we want to approach it' – but I wouldn't use it on a day to day basis' (T2.ii)
>
> 'You know these would be really useful when everyone's sitting down at the end of a piece of work, just thinking about what technology you've got available – you could do it as a department' (T2 whole cohort discussion)

They did seem to recognise the value of the implicit thinking the T-CoRe fostered and that they might now enact this same thinking during routine planning processes:

> 'I don't think I'd do another one of these again but I do think the processes go through my head when I'm doing lesson… [planning]. I think I'd go 'is that going to help them with this context?' and I think is something I'm going to take on every time I use technology, I think it's really useful. (T3.ii)

It was interesting that one teacher considered, without prompting, the use of the T-CoRe by trainee teachers:

> 'I certainly think for training, as in student teachers, it would be invaluable because it gets them to think because they won't necessarily have any idea of misconceptions yet… it might actually get them to think about technology and what technology they could use. And if they were thinking of it, they might actually think 'actually, no, there is a better…' so I think it would be really useful, thought provoking and certainly, if I was a trainee, I'd find it useful.' (Teacher D)

Following its use by both teachers and trainee teachers, it is pleasing to note the feedback offered regarding the potential of the T-CoRe to promote and scaffold thinking. Analysis extended into operational use of the T-CoRe and useful evaluation was similarly offered by participants as discussed in the next section.

4.2.2.2.4 Evaluation of use

Initially, both teachers and trainees were cautious about completing the T-CoRe, with some worried that they might respond to sections in the 'wrong' way as alluded to in section 4.2.2.1, and others possibly doubting their ability to differentiate between statements. One trainee suggested problems interpreting the statement relating to difficulties associated with teaching an idea and the statement relating to identification of likely misconceptions: 'I just found them quite similar when I first did it… and I think I was beating myself sometimes in that one' (T2.iv). This participant did go on to complete the T-CoRe suggesting that some guesswork was involved. One peer in the same discussion ventured that interpretation might be influenced by their subject specialism and familiarity with reflective writing: 'It might be because we're Science… English would have been like 'right – yeah'' (T2.v).

Another trainee, clearly more comfortable with reflection than some, suggested that statements that were too explicit might hinder quality of response: 'I quite like the questions quite open-ended cos it means they're quite open to interpretation' (T2.vi).

A trainee from the subsequent cohort, responding to whether the statements on the T-CoRe were easy to respond to, suggested that the act of completing aspects of the T-CoRe provoked deeper thinking which offers some validation of the intended purpose: 'I wouldn't say hard but it took a bit of extra thinking than what the rest did' (T3.ii).

In designing the T-CoRe, statements corresponding to those on Mulhall et al's (2003) PCK CoRes were placed first, before statements arising from the addition of technology. Thinking about general factors such as misconceptions and possible pedagogical strategies was felt important so that subsequent selection of appropriate technology, if appropriate, had a pedagogical basis. This helps overcome the temptation to use technology for technology's sake and becoming guilty of letting the technology 'dazzle' as warned by BESA (2015) and find use without appropriate thought to the potential advantages it might bring to learning situations. It has already become apparent that some participants valued the clear structure and progressive thinking fostered by the T-CoRe. For others, the thinking was clearly important but the order less so.

> '…some of the ordering, I don't know, I should have written it down as I did it, I should have said what order I filled the boxes in – I didn't fill it out in order' (T3.iii)

> 'I sort of jumped around and more formulated what my lessons were going to look like as I went along with this' (T3.i)

The statements above, from trainees, might be open to accusation that limited experience hindered their ability to make judgement calls on aspects of PCK but teachers too commented on how they had completed some aspects first and then taken the thinking involved and subsequently applied it to sections initially left blank:

> 'In the beginning it made me think of, if I'm doing something it needs to be useful, so I knew some of these questions and I started working on this already half way through before filling things in, and then, when I had a better idea of what I was doing, I started to fill more in' (Teacher B group discussion)

At times, participants were not aware of specific next steps; for example, relating to the statement 'what do you need to do to become confident using the technology'. When raised, this was by the teacher participants who were working together. Despite suggesting 'it's the area we were least confident on… I think we found that quite tricky… as I wasn't au fait enough with the technology to know' (Teacher D interview), there was recognition of general solutions: 'So it would be quite a generic 'I need to practice using it' or something', but also reflection that, after attempting to use the new form of technology in teaching, a more detailed response might be offered, 'at the end it might be 'well I had to master the use of whatever it was about it' – and you'd be more specific then'.

This supports the value of considering the notion of the T-CoRe as a process rather than a product but, before considering this, one other significant piece of evaluation remains pertinent to this section – that of time.

Participants clearly recognised the time commitment that completion of the T-CoRe entails which did not always sit easily with the demands of their day-to-day reality. Statements in discussion groups about the time it took to complete the T-CoRe were, in each case, tempered by subsequent discussion about the inherent value of doing so, as can be seen in the following exchanges:

Firstly, by trainee teachers:

> T2.ii: Whether I'd do a full sheet
>
> T2.iii: a bit time-consuming
>
> T2.ii: Yeah, it was but I think as well its… if you were going to do sort of a suite of subjects
>
> T2.iii: It is a good planning
>
> T2:ii: Yeah – but it does make… does challenge you to make sure that am I actually using this method for the right reason. Do you know what I mean? Am I doing a practical for the right reason? Is this the best way? Is there anything else I could be doing? It just makes you pause and think about should I be doing it this way or is there another way I could do it?

Secondly by teachers:

> Teacher B: So I think it's very useful. The issue is always time. And having to fill this all in is a chore
>
> Teacher A: It's almost like sometimes you could just have these questions to look at and think in your head rather than having to write it all
>
> Teacher B: I think just having the questions is enough because, when you fill it in, you know what you're going to fill in… but it's nice to have a few of these because you can compare and contrast and you can decide for something else 'do I want to write something like this or do I just go with what I know'… I want to write a few of these so that I have that for myself and for other people to use
>
> Teacher A: That's another thing, the more you answer these kind of questions and you're working on it, the more it gets in your head and becomes a part of your system and I think all these question are incredibly important

One of the teachers made several references to time as a recommending factor for working with the T-CoRe as part of the professional development experience, exemplified in the following extracts:

> 'I think what it does actually, is it slows you down – you know, something like meiosis which is hideous for kids, it slows you down and it gets you to look at it… it stops you doing everything as you've always done it I think. So, it slows you down and gets you to look at what you're doing. Makes you rethink and go about, maybe if necessary, adapting what you've done…
>
> Without picking it apart on here, I don't think I'd have thought about it as much…
>
> You might not need to go into the detail every time but, if it gets you to think about it, it means that… again it's slowing you down'
>
> (Teacher D interview)

Time was clearly an important commodity to this teacher who expressed a real sense of gratitude for a process that provided time and structure for quality reflection on his teaching even after 20 years of classroom experience.

The tension between time investment and the opportunity for reflection, gives rise to a question about whether it is the process of engaging with the T-CoRe or the end-product that is of greatest value. The cautiousness alluded to at the beginning of this section similarly lends support to consideration of whether there is a right way and a wrong way to use the T-CoRe for benefit to be gained from the thinking it fosters.

4.2.2.2.5 Process vs. product

There seemed to be unanimity in endorsement of the T-CoRe as a vehicle for promoting thinking whereas only moderate support for informal use of the document during the day-to-day reality of teaching. The value of using the T-CoRe appears to be in professional development activity as a way of structuring and modelling some of the thinking upon which developing TPACK is contingent. This is evident in some of the statements made by participants:

> 'it's the process because… the whole way through… I was like 'why is it [the technology] important?'' (T3.ii)

> 'The main thing I took from it though is, like certain questions and the way that I think about it… but it's more the thinking that I've taken from it that's been most useful. But it was good initially to have it all set out like this cos it made you think and actually write it down.' (Teacher A interview)

> 'It's the process cos, if I did one of these, I would then go away and actually write my notes up for my lesson and perhaps wouldn't come back to this… it's the process of talking and thinking that informs our decisions and then our decisions end up being what we teach in lessons… it was good food for thought'. (Teacher C interview)

Participants talked favourably about the process and there emerges strong suggestion that it is the thinking it stimulates that is of greatest benefit rather than the artefacts produced:

> 'The main thing I took from it though is, like certain questions and the way that I think about it. I think realistically in teachers' time, to have this sort of plan every time you use technology… I don't know… I guess maybe for a new piece of technology, you could even have it set out like this - but it's more the thinking that I've taken from it that's been most useful. But it was good initially to have it all set out like this cos it made you think and actually write it down.' (Teacher A interview)
>
> I don't like having to write it all up but, in a way, that is also quite therapeutic to do that because you need to think really hard about what you did and why you did that. So I don't mind to do that… it's working *with* it that's powerful' (Teacher B interview)
>
> 'It just makes you pause and think about should I be doing it this way or is there another way I could do it?' (T2.ii)
>
> 'the effort you put into thinking through this process makes you ask questions you wouldn't normally' (T3.iii)
>
> 'I think that's what it's for isn't it – it's for… you're actually thinking in detail' (T2.iv)

Some participants were able to reflect on the impact they felt working with the T-CoRe had, for example:

> 'I'd thought so much in detail cos of doing this, I found the lesson went really quite successfully and it maybe made me change my mind about other lessons and think ok how could I have adapted that using these ideas and maybe bringing technology in or doing things slightly differently' (T2.v)

Although the T-CoRes produced by participants yielded some helpful information about the way in which they had used them as discussed in section 4.2.2.1, it was good that they were seen as dynamic documents and that participants eventually felt able to take a degree of ownership, using them in the way they felt best served their needs and applying focus to areas they felt of greatest importance under a particular set of circumstances. Individual cases will be considered in a later section where the degree to which the T-CoRes produced were subject to subsequent evaluation and annotation will be explored. In this way, they perhaps sit more deservingly in the toolkit of professional development resources as a working document and not a product in their own right. That there may not be a right or wrong way to use them is therefore not considered a disadvantage.

The idea that the thinking the T-CoRes help foster is the most important outcome is significant and leads me towards a notion that very much ties in with the goal of seeking to operationalise the TPACK framework – a notion upon which other aspects of the study converge and which I will subsequently term '**TPACK thinking**'.

4.2.2.2.6 Further use and suggested improvements

Having acknowledged the time investment required to make use of the T-CoRe, the teacher participants were positive about future use, particularly under the following circumstances:

- Professional development for others
- Collaborative use
- Departmental development and review work
- Exploring novel approaches for teaching troublesome topics

Trainee teachers were able to hint at some of these but were limited by experience, preferring instead to think about their individual use of the T-CoRe.

A number of recommendations emerged from the data regarding improvements to the T-CoRe or to its use. These included:

1. Reducing the number of columns on the blank T-CoRe to remove the perceived expectation that users will identify three intended learning outcomes to work with. On first use, T-CoRes had generally been presented in hard copy, enlarged to A3 size so they could be discussed in small groups and annotated by hand. On second use, users were subsequently reassured that they were welcome to edit the document to remove or add columns as they wish.

2. Giving license to use the T-CoRe to scaffold thinking without necessarily writing everything down. It was felt important to structure activity during professional development activity and this was reinforced by participants when considering the potential future uses above. In their own subsequent lesson planning and curriculum development activity, it has become clear that the thinking involved is the greatest product of use rather than the artefacts generated – except when these might be returned to in curriculum review and subsequent development. That participants are keen to continue enacting TPACK thinking beyond the project is seen as a positive outcome.

3. Extending point 2, two teacher participants asked whether ongoing thinking, making use of the theoretical idea of TPACK that was inherent in the use of the T-CoRe, could be summarised as an aide-memoire in the form of e.g. a bookmark.
   'I was just wondering, if you were to do it again, it might be quite nice to have a little bookmark or something just so that… cos I like the model but just having something as a quick reminder of it.' (Teacher A interview)
   'actually just a little checklist. You don't necessarily have to write it out but… just a little checklist with 'oh yeah yeah' – it might just slow you down a bit cos, you know, people dive in don't they?' (Teacher D interview)
   Teacher D was perhaps the most critical of the time it took to complete thoroughly but did, on reflection, place much significance on the value of the structure provided by the T-CoRe and inherent TPACK thinking in that it provided a welcome incentive to slow down the usually hectic thinking that takes place around lesson design.

4. The availability of good examples of completed T-CoRes. An example was made available for the teacher group and trainee cohort T3. As more have been created over the duration of this project, better and better examples have emerged which demonstrate depth of thinking as well as how the T-CoRe can be annotated in evaluation of the teaching episode based on the thinking they inspired. Through exemplification of evaluation and reflection on practice, the potential value of the document as an item that might be retained and revisited becomes clearer.

5. Identification of the domain identifier before each statement on the T-Core was felt unnecessary by Teacher D although no other participants commented on this. This was prompted by this teacher's suggestion that the document could be further streamlined by focusing on the pedagogical aspects ('once there's a TPACK question or a PCK question, that's where it becomes interesting for me' - Teacher D, group discussion) or having up to four compulsory questions and making the rest optional. Whilst this was not echoed by others, it does support ideas surrounding license to make flexible use of the document depending on the situation in which it finds use. As a CPD tool, teacher C was keen to retain structure but suggested that such flexibility would be welcome:
'I think if I was doing it with someone I was working with, I'd kind of like it as it is – but perhaps, if I was doing one on my own, I would want to think well how can I actually shorten the process down a bit? How could I streamline it so I could go through one quicker...?' (Teacher C interview).

6. Inclusion of contextual information or exemplification behind each statement on the T-CoRe. This suggestion, made by a trainee, resonates with ideas raised about interpretation of the statements in the previous section. There is a danger that this might clutter the document when there was a general desire for simplicity but might be overcome if good exemplar T-CoRes are presented for reference during introduction to the document.

As a result of the ideas and recommendations made, it was not felt necessary to adapt the T-CoRe document for ongoing use. On introduction, however, in recent use the document has been presented in association with exemplar T-CoRes such as those in appendices 11-14. On first use, participants are encouraged to attempt to complete as much as they can to stimulate the underlying thinking. In future use, participants beyond the scope of this project will be allowed to take a degree of license with recording responses whilst enacting the thinking the statements elicit. There is nothing inherently wrong with leaving a section blank – particularly if users can reflect on this in discussion.

4.2.2.3 T-CoRe summary

The methodological triangulation afforded by both exploring the T-CoRe artefacts produced by participants and through analysis of discussion and interview data has provided a helpful picture of the T-CoRe as both a document and a process. It seems that the process is ultimately where the inherent value lies, although the documents themselves may find particular uses in which they are kept and revisited. The notion of the T-CoRe as process and a vehicle by which 'TPACK thinking' can be fostered will be revisited in section 4.3 where an overview of the professional development activity will be taken and then viewed from the perspective of both teachers and trainee teachers.

4.2.3 The TPACK game

As a means of fostering TPACK thinking and to encourage discussions using the language of TPACK, the card game was met with wide approval. For some it was the level of focus it provided:

> 'I really liked that… we have all these TeachMeet things…and there's always these wonderful ideas and you think 'oh I'm going to do that' but then it doesn't happen necessarily. But then again you meet in a smaller group and you actually do an activity like a card sort – it stimulates you much more' (Teacher B interview)

For a less-experienced teacher and self-confessed less confident user of technology, the collaborative element was highly significant when working with more experienced colleagues:

> 'I found it most useful because we were doing it together and I got a lot from [the others]. I think had I sort of done it on my own, which I probably wouldn't anyway, or in a pair with another less experienced teacher, I don't think I'd have found it as useful. But listening and discussing it with them I found really useful' (Teacher A interview)

This teacher had also suggested in group discussion that the game was useful in that it provided a starting point for discussion when ideas were not forthcoming:

> 'I liked being able to split it into technology, pedagogy and the content because, although you think about the three things, I couldn't think of specific examples that leads to that extent as well so that was good.'

Another teacher (very much a 'power user' of technology in teaching) suggested that the collaboration was particularly effective because of the opportunity to explore differences of opinion:

> 'I think it was quite good actually... it did start to foster those discussions. It did get people to give their opinions and their thoughts on what that scenario was relating to - and, if there were differences of opinion, it was quite productive to be able to talk about those things. And, if any of us were… you know, have to point out that we were misinformed or mistaken about what one of the cards was really representing – yeah I think it was quite good'. (Teacher C interview)

This teacher went on to suggest that if 'all your teachers and you had sets of cards and they were all talking and all having those discussions, it's doing it an incredible amount of good there', so recognising the professional development potential for wider use.

As an example of the quality of discussion generated with no intervention on my part, a recorded extract from the use of the card game by three of the teachers in the group is transcribed and shown unedited in appendix 10. In this extract, a content card is selected identifying the content as 'Explain how blood flow is one directional in veins'.

The teachers explore a variety of ideas and representations before starting to talk about the needs and misconceptions of the students, evaluating how effective various solutions might be, identifying a pedagogical problem and then considering how technology can help overcome it.

What is gratifying about this is that all three voices present are represented in the discussion despite significantly varying teaching experience and levels of experience using technology in their teaching and that, where there is disagreement, genuine dialogue ensues.

As a means of developing understanding of the concept of TPACK, of fostering TPACK thinking and generating discussion using the language of TPACK, there is therefore strong recommendation for the inclusion of this activity as part of the toolkit of resources offered for ongoing professional development.

4.2.4 Summary

In this section, the efficacy of the various components of the proposed toolkit of resources has been considered and the value of each as a standalone tool demonstrated. It is, however as a suite of activities that the most significant value appears to emerge. Firstly, participants can explore the nature of their own TPACK using the assessment tool. The card game serves to reinforce understanding of the relationship between the three core domains of the TPACK framework and the T-CoRe helps scaffold thinking about this new understanding as users attempt to enact it in their own planning.

Although providing useful diagnostic and evaluative information, the greatest value reported from the toolkit in use is the TPACK thinking participants describe. This appears significant to all groups with whom I have used the resources to date. This is perhaps summarised best in the words of the participants themselves:

> ‘the effort you put into thinking through this process makes you ask questions you wouldn’t normally’ (T3.iii)

'what I find useful is that the questions really force you to think about every aspect' (Teacher B group discussion)

I'd thought so much in detail cos of doing this, I found the lesson went really quite successfully and it maybe made me change my mind about other lessons and think ok how could I have adapted that using these ideas' (T2.v)

In the next section, a broader view of the professional development experience is taken before looking for patterns and themes arising in terms of outcomes both by groups of trainee teachers and for the teachers engaged in the extended professional development activity at the heart of this project.

4.3 Professional development activity

4.3.1 Thematic analysis

Analysis of magnitude coding in relation to statements made in discussion or interview regarding the professional development received reveals that twenty positive statements were made and no neutral or negative statements. The strengths of the process as reported by participants fell into several categories:

- Thinking – a new perspective afforded by TPACK
  e.g. 'I'd never thought about technology in such a deep way for teaching and learning' (Teacher A interview)
- Time – to reflect in the light of understanding of TPACK
  e.g. 'what I have used, I think has been really useful… really, really useful in the teaching and I think it has made me just, like I said, take my time and think' (Teacher D interview)
- Support for future use as professional development with colleagues
  e.g. the idea of wider engagement of colleagues in reflection on their own practice 'in a decent, not forcing, way' (Teacher C interview)

- Confidence to try new ideas and seek appropriate support
  e.g. 'if we hadn't had the support of those sort of sessions, I probably wouldn't have been willing to go to the IT department and say 'I've got this really good idea for a teaching tool' (T3.i)
  'And I'm not very confident… and actually this is reinvigorating' (Teacher D, group discussion)

A variety of themes of importance to participants emerged from thematic and emergent coding of discussion and interview data, a number of which are worthy of consideration before exploring specific aspects of use with the different groups of participants. Prioritising items for consideration is based on representation within the hierarchy chart shown in Figure 23.

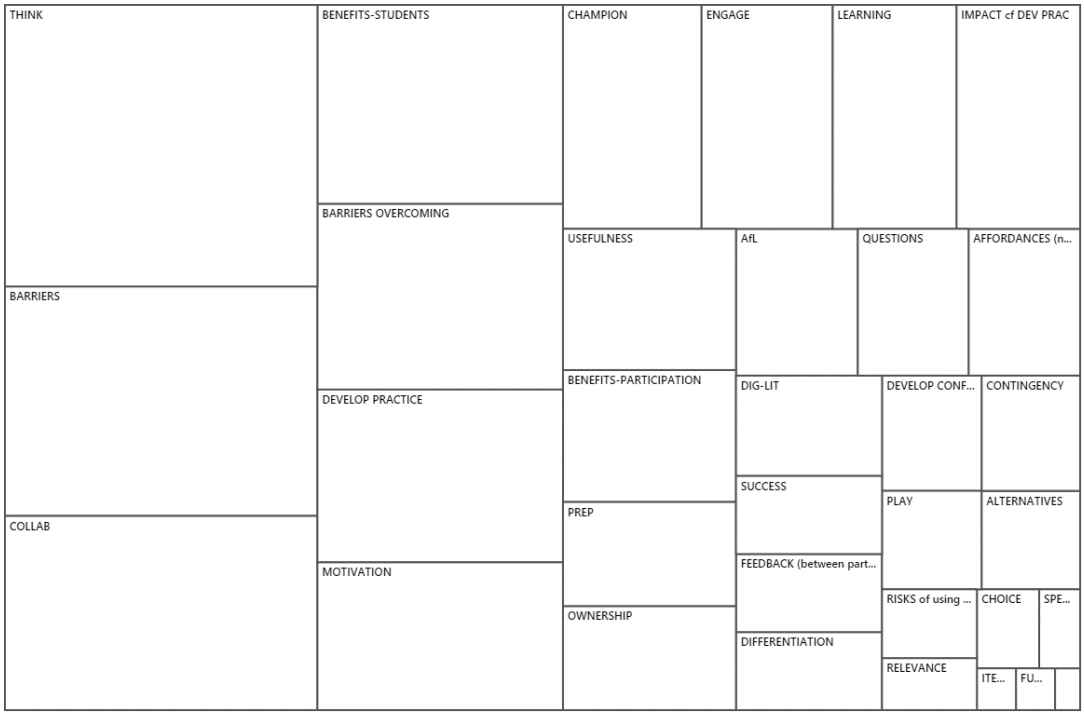


Figure 23: Hierarchy chart for general themes

Thinking again emerges as a highly significant feature of participants' engagement in this process. Whilst demonstration of understanding of the barriers associated with the use of technology in the classroom is expected, it is worthy of note that reference to how those barriers might be overcome (BARRIERS OVERCOMING) is also strongly represented in the hierarchy shown and perhaps indicative of aspects of TPACK thinking in action.

Participants exhibit reflection on collaborative aspects of the process (COLLAB) as well as considering impact on their practice and on student outcomes (BENEFITS-STUDENTS, DEVELOP PRACTICE, MOTIVATION, CHAMPION, BENEFITS-PARTICIPATION).

Ownership has been a significant theme in the literature review so will be considered separately in this section.

4.3.1.1 Thinking

References to thinking were the most commonly coded item with over twice as many references as most other items coded. Participants reflected in depth about the way in which the process challenged their thinking:

> 'It definitely made me realise that I have a bit of a fixed mindset… I'd never thought about it in so much detail in all the aspects and it also makes you think 'actually yeah it does help with this and it does help with that' rather than just seeing it as technology as something nice to use in the classroom.' (Teacher A interview)

> 'it trains your thought processes rather than just 'I'll do that using that' or, you know, so I actually do think more carefully about which route to take' (Teacher D interview)

> 'it makes me really think about pedagogy. It makes me really think about what and how need the students learn. And how can I provide the best possible way to make that happen' (Teacher B interview)

> 'I mean realistically it did get you thinking outside the box about other ways' (T2.i)

> 'I think that's what it's for isn't it – it's for thinking because – originally you think I'm going to do a lesson on this… it's going to be amazing – and then you ask yourself all these questions that you might not normally ask about… so it does make you think more deeply about it, you're not just sort of going 'I'm going to do this lesson, it's going to be great', you're actually thinking in detail before it happens what could go wrong or what could be good' (T2.iv)

> ‘the effort you put into thinking through this process makes you ask questions you wouldn’t normally’ (T3.iii)

It was pleasing to see these teachers reflect on their practice in this way and also about the way in which a more pedagogical perspective of technology appeared to be promoted:

> ‘it made me think actually what is the value of using this technology here?’ (T3.ii)

In doing so, teachers and trainees were very aware of the barriers to using technology. The literature reviewed suggested that this may be an attitudinal factor in which teachers cite external factors as barriers to their willingness to engage (Becta, 2003; Groff & Mouza, 2008). In this sense, teachers’ beliefs or preconceptions may need challenging by demonstration of effective TPACK in action before they can be persuaded to reflect and explore their practice more deeply. It may subsequently be useful to think of this in terms of ‘TPACK inertia’, an idea that will be revisited in chapter 5.

In section 2.1, a range of barriers were identified from the literature, that fell into what could be considered intrinsic (teacher awareness, beliefs and confidence) or extrinsic (resource issues, technological issues, political factors, school factors and student factors). These are very much echoed by participants who cited:

Intrinsic issues: Awareness of resources (4 coded references); Beliefs (1); Confidence (2); as well as adding issues relating to time and perceived complexity (7 references).

Extrinsic issues: Resources (4); technological issues (14); political factors such as curriculum (2), school factors such as policy or levels of support (4) and student factors including behaviour, attitudes and levels of digital literacy (4).

The ratio of extrinsic to intrinsic issues raised (28:14) suggests that there is good awareness of external hindrances but that there is also some innate resistance on the part of teachers to the use of technology in their teaching deriving from prior experiences. In discussion and interview more solutions to the barriers encountered related to extrinsic factors (18:4).

Solutions to intrinsic issues included commitment to preparation, commitment to investment of time and making use of students' digital literacy to help overcome their own identified shortcomings. There was recognition that confidence has an important role to play in developing momentum, e.g. 'if I feel more confident, I'm sure I teach it better' (Teacher B interview).

A wide range of solutions to the extrinsic issues was offered including training for students, provision of success criteria to support classroom management, and evaluation of alternatives (e.g. computer rooms vs. use of laptops). Some professed commitment to learning how to troubleshoot common issues. Others suggested applying pedagogical evaluation to gain maximum benefit by careful episodic use of technology within a lesson instead of extended and unstructured use thereby reclaiming the pedagogical choice rather than risk letting this be dictated by the technology.

Particular frustration was evident when there was tension between school policy regarding the use of mobile devices and the affordance they offered. It was recognised that availability of resources commonly interfered with progress and that mobile devices include simple affordances such as timers, calculators and video cameras that can be exploited to good effect in the classroom, reducing the dependence on functioning sets of these devices. Under such circumstances, some professed a willingness to break with school policy, as evident in this exchange between trainee teachers:

> T2.iv: Or even timers because getting those was sometimes an issue so it was like, 'kids get your phone out'. 'Really?' 'Sure - just get them out'
>
> T2.v: yeah… cos there's never enough timers
>
> T2.vi: All the stopwatches were broken…

The teachers and trainees involved in the project were therefore able to reflect in some depth about the challenges they routinely face but were also able to give good consideration to overcoming some of the barriers that might have limited their use of appropriate technology.

There is therefore some indication that using TPACK to lend a framework and common language to the discussion of technology in the classroom can support the requisite thinking to overcome the TPACK inertia postulated.

4.3.1.2 Collaboration

Working with others was seen as a great advantage and an important part of the professional development offered.

> 'I love… if I can work together, I would always jump at the opportunity. It always baffles me why people don't share and don't work together' (Teacher A interview)

As well as the opportunity the professional development activity provides to work with others, the time and space to work in this way was highlighted as important:

> 'I think it's incredibly important to work with other people. The problem is you never have the time to do so. And for teachers, it's very difficult to find time to do stuff unless they are being given the time' (Teacher B interview)

In section 2.2 a challenge was raised that teaching can be an isolating profession (Hargreaves & Fullan, 2012; Levine & Marcus, 2010; Rosenholtz, 1989), a feature that was picked up by Teacher C who suggested that he missed the opportunity to work with others as he moved from being a trainee to becoming an independent teacher:

> 'I think it [collaboration] is crucial. I mean, I would love the opportunity to actually talk to other teachers about these kind of things, like we are stuck in our own sort of planning process… when we were doing our teacher training – we would do these kind of activities as a group but, when you get into your teaching practice, there's that idea that it's your own planning. You've got to get on with your own planning as everyone has their own jobs to do but I think it's so important. It makes the job easier – but then everyone else benefits from it as well' (Teacher C interview)

This teacher valued the opportunity to discuss when differences of opinion became apparent and was very positive about making use of ideas such as the T-CoRe with colleagues as part of curriculum development but also as a way of supporting the development of his colleagues.

Teachers A and D worked together in the first cycle of school-based research activity, both appearing to relish the opportunity to focus together on a problematic aspect of practice.

> 'It's just that sharing of ideas and you develop it so much more don't you… the collaboration aided the development and actually then aided the delivery and the outcomes because we refined it really as we went through' (Teacher D interview)

One trainee teacher, although working independently on the directed activity using the T-CoRe during a school placement, suggested that they applied some of the thinking to a topic they were sharing with another trainee, referring to the benefits of 'bouncing ideas off each other' (T2.v).

All participants were positive about the discussion afforded by collaborative professional development activities such as the card game not just for the sharing of ideas but also for the encouragement and stimulus they provide:

> 'one of the biggest values I've taken away is the countless pages of notes… of other people's ideas. You know, that you don't have yourself because you need a prompt to get that out and actually have those discussions' (T3.iii).

Collaboration then is seen as an important part of the professional development experience since it affords the opportunity to share ideas, benefit from the experience of others, challenge and be challenged, and can provide the impetus to create the time and space needed for reflection and personal and professional development rather than operating in isolation and experiencing professional estrangement with the associated risk of stagnation of practice.

4.3.1.3 Impact

Participants reported a range of impact resulting from involvement in the project relating to outcomes for their students and to changes in their own practice.

4.3.1.3.1 Impact on student learning.

Teachers A and D developed resources to teach problematic aspects of cell division in Biology. 'The point of the technology bit was trying to reinforce it and get it up there… it's made a big – a really big difference... without picking it apart on here, I don't think I'd have thought about it as much.' (Teacher D interview).

In his second cycle of independent activity, Teacher D reflected on how many times he had tried to teach abstract concepts as part of Science curriculum ('out-there concepts that they can't apply'), again reinforcing the value of this process in affording time to stop and think about the best ways to approach teaching for understanding. He admitted frustration trying to find new ways to explain concepts to a particular group:

> 'And it was out of desperation really, rather than fore-planning, it was like 'what on earth can I do to try explain this' because they weren't getting it on paper, they weren't getting it from me looking silly at the front and I then searched for the technology really. And I think what it's done is it's built their confidence because they could see what was going on.'

In terms of outcome, having developed his thinking about teaching one group, he reported:

> 'By the end of it they were all able to start giving me the answers. And it was one of those moments when you think 'thank goodness for that' cos I didn't know how to do this otherwise so it was extremely useful… They're a fairly mixed class, you know, I do feel that their understanding is a lot deeper.' (Teacher D, group discussion).

Teacher C also considered the benefit of the technological approach he took to supporting his students' scientific literacy, suggesting that the activities he developed whilst using the T-CoRe enhanced his ability to engage in Assessment for Learning and to modify his teaching input in subsequent lessons to the benefit of his students.

4.3.1.3.2 Impact on teacher practice

Teachers were able to identify changes in their practice without the need for drawing on the quantitative data generated from the professional development activity (which will be considered in the next section), highlighting a renewed focus on pedagogy and choice:

> 'I think it's helped my planning most and thinking about not just 'oh – what shall we put in this lesson' more 'what are they getting out of this thing we're going to do? Is that the best thing to use?'' (Teacher A interview)

This teacher admitted a degree of inertia initially but felt that, as confidence and understanding developed, so too did her motivation to engage with new forms of technology in her classroom 'which was based on having thought about it and how much it can add to teaching and learning' (Teacher A interview). She reflected on the way the TPACK model had supported her thinking and tied this in with current reading she had been doing about Carol Dweck's notions of fixed and growth mindsets:

> 'I think, sometimes with technology, you can be a bit fixed on one rather than… and I think… even if it's just made me think right, 3 things come together – 'how is this best?'. I think it's done the job.' (Teacher A interview).

A developing awareness of the pedagogical affordance of different forms of technology was something trainees also reflected upon. For example:

> 'I've shifted in understanding that there is stuff out there – and, if I don't think there's stuff out there, it's definitely worth going and having a look because the chances are, by now, there is.' (T2.ii).

This perhaps reflects an increased confidence in, and motivation to explore, technology as a tool to support learning. This sentiment is echoed by another trainee who considered what an ideal technological solution would look like to a problem identified in trying to make digital worksheets accessible to students and then reported the confidence to seek support to develop the solution:

> 'I knew that's what I wanted them to do but I had to find out a way to do that, so I spoke to IT' (T3.i).

Participants were also quick to encourage each other when good ideas were proposed. On reflecting on the progress made, one trainee spoke of whether the time investment in creating a complex animation to serve a particular purpose was worth it. His peers were highly supportive:

> T3.ii: 'I thought I'm actually going to do this, I'm not going to just do it just to show off – this is going to be really useful. And I think I've moved on a lot. I came out the end of that lesson thinking – yeah – I can't think of many better ways to discuss that with them'
>
> T3.iii: 'That's a sell on TES job for sure' [the TES website being a vehicle through which teachers can share and monetise resources]

Trainee T3.ii, although very competent, admitted apprehension about exploiting technology in the classroom for the first time. He reflected on the benefits seen from engaging with the tasks set using the toolkit:

> 'My opinion really changed… from being quite scared about using technology in the classroom for fear of… not knowing what to do with it. It's sort of taken me out of my comfort zone… so, yeah, it massively changed the way I considered using technology.'

This trainee was notable since he asked for a copy of the set of cards used in the card game for future reference when ideas dried up. His outcomes will be considered in terms of the quantitative data he generated in section 4.3.2.

Confidence was a key theme emerging as a benefit of participation both by teachers and trainees.

> 'I think that I'm a bit more confident with trying things out that I've been putting off that I've wanted to do' (Teacher B interview)

Even the most tech-savvy participant, Teacher C, reflected on confidence as an outcome:

> 'I think, if anything, it's perhaps maybe reinforced my confidence in how I perceive I can use technology in my teaching practice and how I can use it to support how I want to deliver learning outcomes and objectives to different cohorts of students… It makes me feel confident in my ideas and, because it makes me feel more confident in my ideas, it makes me feel more confident and willing to share those ideas and actually collaborate with other members of staff.'

A consequence of developing confidence appears then not only to foster impact in terms of student and teacher outcomes but also to develop local ambassadors or 'champions' who are willing to share ideas and are capable of supporting colleagues.

4.3.1.3.3 Developing technology champions

In the literature review (section 2.1) I reflect on the notion of the 'champion' and it is gratifying to see evidence of emergent thinking about participants' roles in their post-project teaching.

As a self-confessed weaker user of technology, Teacher A, reflecting after engaging in the project, highlighted a willingness to share ideas and activities developed or trialled with colleagues: 'if they want to know how to use it, I'll go through it with them. I think that would be really good.' (Teacher A interview)

Teacher B thought about disseminating some of this activity as part of the project group to his colleagues:

> 'I think you need to also see it like something you can present in school after you've finished this because if you have extra material that is attached to it, you can use it to run a CPD session in school – or at least to get them interested and then you can be a pioneer in school to get TPACK going and you could be the person who leads that.' (Teacher B, group discussion)

Teacher C (the 'power user' of the group) also recognised the importance of the champion:

> 'it raises the standards of everyone so you're sharing the skills of the more tech-savvy individuals, you're bringing up the skills of those people who aren't so confident with technology and it's kind of encouraging them to be a little bit braver with it because they can see the benefit… because it works for me, it's going to work for other teachers' (Teacher C interview)

Trainees too, despite acknowledging their relative inexperience within the departments to which they had been recruited after their training, saw a way in which they could contribute to developing colleagues:

> 'I think… adding your contribution to the engaging curriculum – is quite challenging when you're relatively new… but it could be an interesting one for you to table at a department meeting and, I think, drop a line to the Head of Department, you know, 'is there a chance for one of the meetings, why don't we spend half an hour discussing how we exploit technology in one or two of our topics… I think we could use that to bring value. (T3.iii)

Developing new champions is a significant by-product of the professional development experience and offers testimony to the enduring impact of the form of professional development offered. The impact, particularly on Science departments, of not having (or losing) a technology champion may very much be to the detriment of the variety of pedagogical styles in evidence in classrooms. Reflection on how pedagogy and technology can be aligned with respect to content and context appears to play a valuable role in this area of departmental practice.

4.3.1.4 Ownership

The concept of ownership of professional development emerged from the literature as being an important contributory factor in developing professional capital. To this end, the activities in the professional development experience included opportunities to apply the TPACK thinking elicited to aspects of participants' own work in the classroom.

Teacher B reflected on approaches to CPD taken in his school and identified the importance of being able to apply ideas to his and colleagues' own practice.

> 'CPD…needs to feel, for the teachers, it needs to feel that they get something out of it – that they're not wasting their time and I definitely didn't feel that I wasted my time here at all.' (Teacher B interview)

This built upon his earlier thinking, evidenced in group discussion:

> 'it's like how you need to enthuse the children to learn, you need to be able to enthuse yourself to learn because this is learning for us as teachers isn't it? So we need to be enthused to actually take that on because otherwise we'll never put the energy in that is needed for it' (Teacher B, group discussion)

Teacher C asserted that, in this respect, TPACK was a useful vehicle for CPD, suggesting:

> 'I think it's one of the few theories that actually has a very strong practical element to it. It has this notion that, this is what you can use to overcome your challenge and the pupils' challenges when they're learning – whereas with lots of other theories, it just talks about, well, this is how people learn, go figure out the rest for yourself' (Teacher C interview)

Trainees discussed the effect of working with a mentor on the school-based element of the experience, questioning whether this might rob them of the chance to enact their own independent thinking. For example:

> 'I think, if I'd done it with them, it would have been less my reflections… I think I wanted it to be my reflections on the topic rather than their thoughts as well' (T2.iv)

Building on his earlier statement, Teacher C went on to validate this sense of ownership quite neatly:

> 'this is one of the few things I've looked at where I've actually solved problems as a result of it. And those problems being things that crop up in my teaching practice.'

In the next section, outcomes for some of the individual participants and groups involved in the project will be considered in the light of the quantitative data generated by the assessment tool and qualitative data from accounts of personal experience.

4.3.2 Outcomes

Outcomes will first be considered for pre-service (trainee) teachers both at cohort level and then exploring data for some of the key individuals engaged in interviews and for whom the T-CoRes have been retained and analysed. In the subsequent section, data for the teacher research group will be subjected to similar analysis.

4.3.2.1 Pre-service teachers

After developing resources with the pilot group (T1), activities were used with two successive cohorts of trainee Science teachers (T2 and T3). The pilot group demonstrated that the assessment tool was a useful instrument in principle but early analysis of data from cohort T2, as described in section 3.3, revealed some issues in internal consistency of the assessment tool. The data collected were far from useless, however, in that they afforded excellent opportunity to explore ways to analyse and visualise the quantitative data generated. Across cohort T2, with the selective use of data described earlier relating to omission of items deemed ambiguous from the analysis, the effect of the intervention appears to be minimal, but I make no suggestion that the omission of select data was valid and that apparent outcomes (as seen in Figure 24) can be assigned significance.

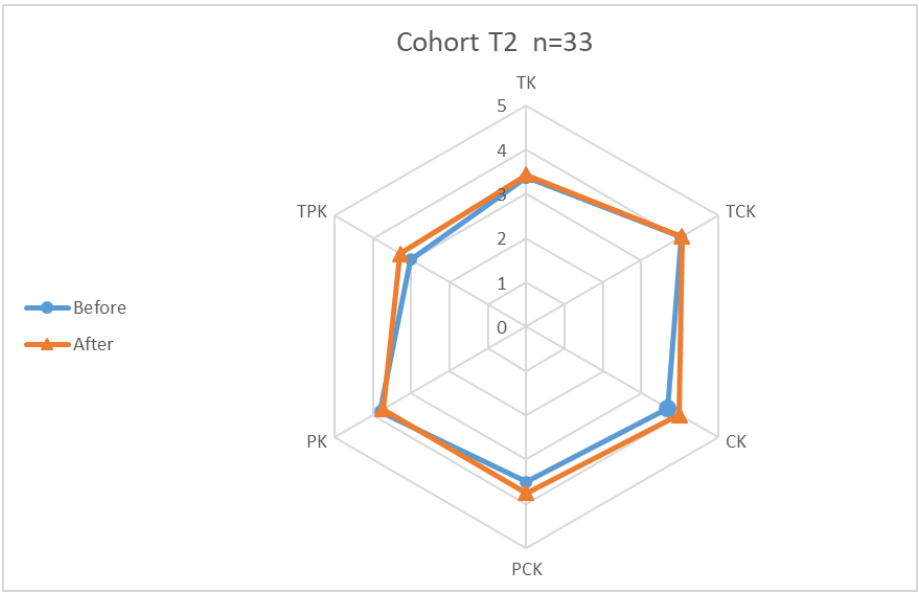


Figure 24: Averaged confidence outcomes across cohort T2

I suggested earlier, following review of the T-CoRes generated by this cohort that better preparation of trainees and exemplification of the tools made a significant difference to outcomes for the next cohort (T3). This, together with the demonstrated enhanced validity of the revised assessment tool used with cohort T3, renders the set of data obtained from this later cohort of much greater interest and provides a much more solid foundation upon which to base any subsequent attempt to infer meaning or generalise.

The revised assessment tool used with cohort T3 has already been shown to have improved participants' ability to distinguish between the domains within the TPACK model (see Figure 10 in section 3.3.2).

As with the previous cohort, the trainees were asked to complete the assessment instrument twice over an interval of six months. During the intervening period, a course directed task was set involving the use of the T-CoRe to support planning and evaluation of an aspect of a topic taught during their practicum in schools.

From the collated data for individuals and cohorts, an analysis was performed as follows, here exemplified for cohort T3:

Cohort n=34					
Domain	Before	(Area)		After	(Area)
TK	2.75	3.80093		3.39	5.61
TCK	3.19	4.44344		3.82	6.35
CK	3.22	4.11804		3.84	6.04
PCK	2.95	4.01149		3.63	6.07
PK	3.14	3.67586		3.86	5.77
TPK	2.71	3.29105		3.46	5.32
=TK as ref	2.75			3.39	
	Area=SUM	23.3408			35.16
TPACK	2.81			3.55	
Av of domains	2.99			3.67	
Area/TPACK		8.31			9.89
Av/TPACK		1.07			1.03

Figure 25: Analysis of confidence data (cohort T3)

This drew together average values for each domain before and after the intervention as well as affording the opportunity to assess whether there was mileage in exploring sector areas on the radar chart or simple averages of peripheral domains for a relationship with the TPACK scores identified. There was little advantage going to the complexity of calculating areas and a broadly linear relationship between the average of peripheral domains and TPACK was evident in earlier discussion (see Figure 16 in section 3.5.1).

Across this cohort, an average of confidence scores for each subdomain taken both before and after the intervention reveals change in all domains as shown in Figure 26.

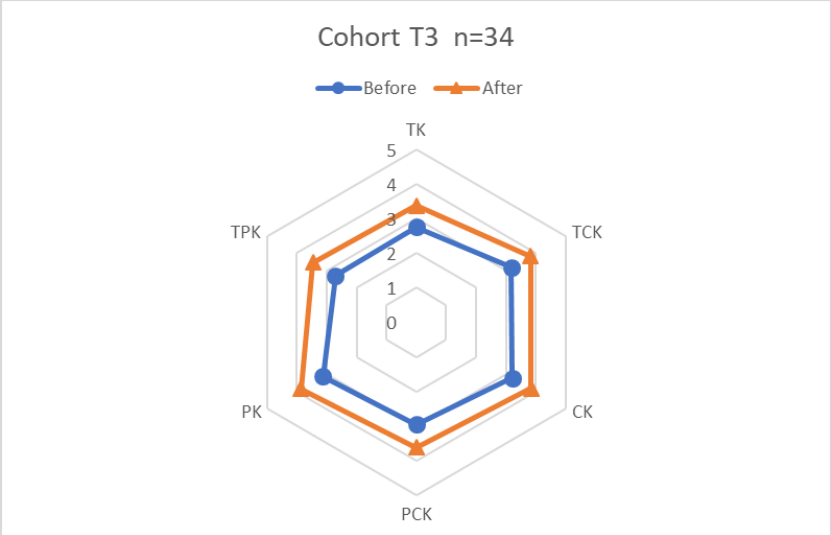


Figure 26: Averaged confidence outcomes across cohort T3

Whilst a helpful visual representation of the peripheral subdomains, it is hard to assign significance using the radar chart. Significance can, however, be inferred from a different representation of the same data:

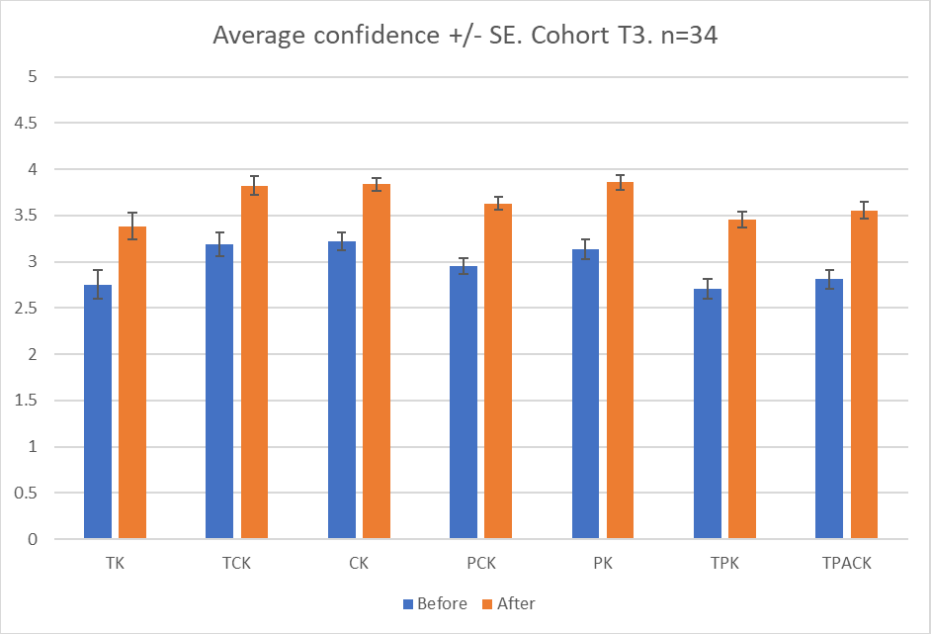


Figure 27: Assigning significance to confidence ratings for cohort T3

Changes, as postulated earlier, may be due to a number of factors including a genuine increase in confidence against the factors that were tacitly coded against each subdomain. Alternatively, it may reflect increased confidence in interpreting the statements based on their contextualisation in a school setting. To explore this, data need exploring at participant level so that it can be aligned with qualitative data derived from discussions. With the trainees, these discussions were held in groups of three but did afford some helpful insight.

Individual cases from this cohort were selected, based on their level of engagement with the range of activities and whether they had identified themselves on both their first and second use of the assessment tool.

For each case, a radar chart is presented as well as a simple indication of change in the TPACK score generated.

Trainee T3.i

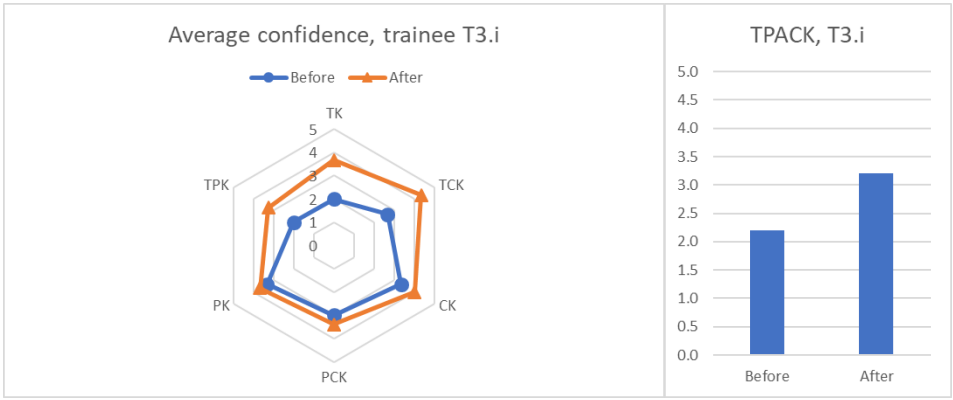


Figure 28: Trainee T3.i outcomes

Trainee T3.ii

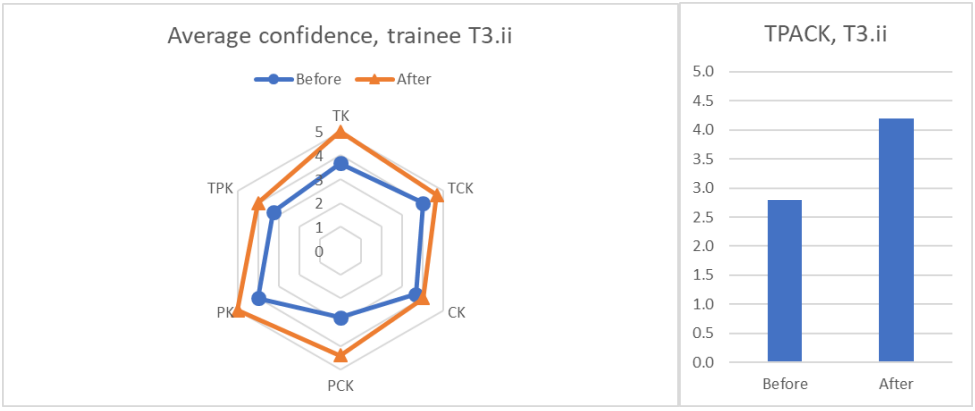


Figure 29: Trainee T3.ii outcomes

Trainee T3.iii

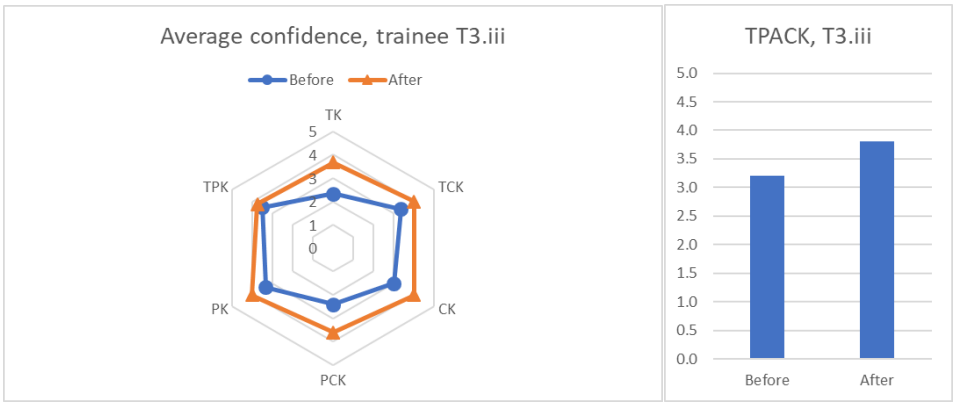


Figure 30: Trainee T3.iii outcomes

In each case, these trainees rated themselves higher against statements relating to each of the seven domains in the TPACK model at the end of the process than at the beginning. In the majority of cases the increases evident in TPACK as compared to the other peripheral domains were proportional (most within ten percentage points).

A similarity between each of these is the increased area enclosed by the outer (post-intervention) line in the top half of the diagram which represents the technological subdomains. A concomitant increase in PCK for two of the three is not unexpected given that technology presents new pedagogical opportunities and the suggestion both from literature and discussion between participants that TPACK is a special form of PCK and that TPACK tends towards PCK with familiarity. I had warned against this as a simplification given that technology as a pedagogical resource is, and will continue to, evolve and cannot be considered a static component.

If judged by confidence, it can be argued therefore that the professional development activity using the toolkit of resources developed has had a positive impact on trainees. All three of these participants had clearly invested time in thinking about and preparing their T-CoRes, two of which can be seen in appendices 12 and 13. The question remains regarding whether the change is real or perceived.

Trainee T3.ii suggested that the change evident in his results may well have been, in part, due to his developing understanding of the theoretical ideas inherent in the activities:

> 'I felt when I did it, I absolutely whizzed the second... The first time, I was like, oh… do I really know what pedagogy… pedagogical content knowledge is, do I really know…? I think cos we were being introduced to it quite early on… I think there was not a huge amount of knowledge about it at the start for me but I kind of followed and went 'ok – yeah… I don't understand that' – after I'd done this I was like 'oh yeah – content knowledge is that' you know and I know what that is and specifically knowing the difference between TPACK and TPK so actually, you know you've got your TK – how is the technology related to how you're teaching and also the content - rather than how could the technology help the content. I found that distinction a lot easier after having done this'

Discussion then speculated about the possibility of a reverse scenario in which ability may be over-estimated early on and judgements then tempered in the light of experience. Another trainee ventured:

> 'I thought I was doing that but it's interesting actually how my results have gone up… because when I was filling it out I was thinking oh actually am I just realising how little I know?' (T3.i).

Experience seemed to be a significant factor in speculation about their results:

> 'I think if I was being asked how confident I am at using technology in the classroom, there's no way I could have gone 'yeah – really good' at that point because I'd have used it a little bit but then actually doing this process, it was like I'm really going to consider this now' (T3.ii)

It is clear the whole process challenged trainees' perceptions and did influence the way they thought about the use of technology in their teaching but the reasons behind the increases are still unclear. Consideration of the results of the experienced teachers may help shed light on this.

4.3.2.2 Teacher Continuing Professional Development

The experience of the teachers involved in the project appears entirely different in terms of quantitative outcomes and do not appear to mirror the significant overall gains evident in the trainees in any of the domains.

One of the participants, teacher D, was only able to complete one of the assessment tools and therefore cannot be considered in terms of quantitative change.

4.3.2.2.1 Teacher A

Teacher A showed minor variation in CK and PK but little change overall in the peripheral domains. A minor but barely significant change in TPACK was apparent.

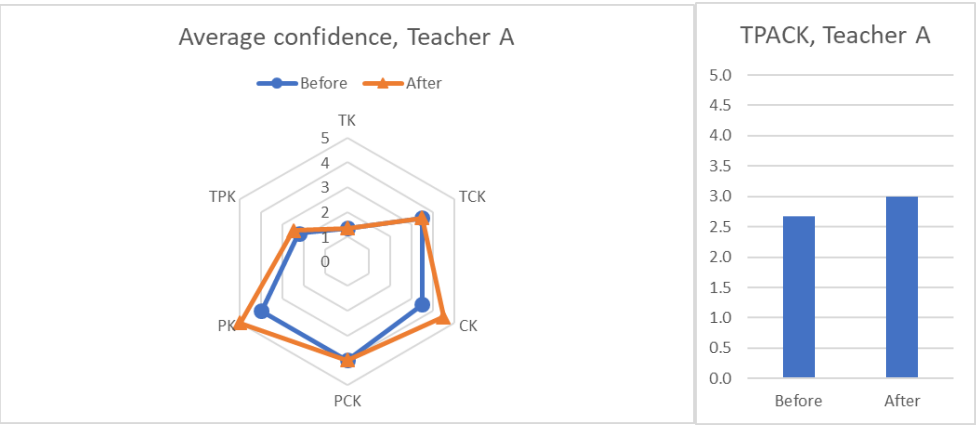


Figure 31: Teacher A outcomes

Given the depth of reflection offered on how she felt she had exhibited a 'fixed mindset' towards technology in the classroom and subsequently felt that her understanding of and thinking about TPACK had developed, Teacher A was surprised that this was not reflected in these results:

> 'I would honestly think, if I'd have looked at that, that I would have increased.'

She went on to reflect on the timescale of the activity and her increased engagement with only a narrow range of technology:

> 'I think, probably with more time, that that would have increased. Because I'd have had more time to sit down and look at technology better.'

Reflecting on the slight increase evident in reported TPACK she suggested that she would 'like to think it could have made a difference' but did elsewhere, in qualitative aspects, provide copious evidence of developing thinking about this aspect of her practice.

4.3.2.2.2 Teacher B

Teacher B also showed little apparent change in the peripheral domains but showed a slight decrease in reported TPACK.

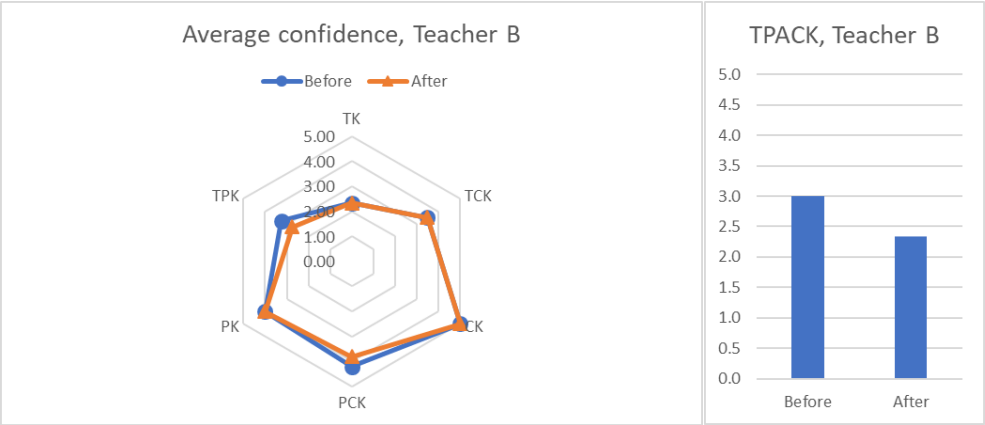


Figure 32: Teacher B outcomes

Reflecting on the slight decrease reported in PCK and TPK and the slightly larger, but still of questionable significance, decrease in TPACK, teacher B noted that this was not surprising:

> 'that's possible of course… but I think the time is too short for me to change my confidence a lot I think'

He reflected on the sorts of activities teachers were likely to seek to develop in school, suggesting that they would choose something 'reasonably safe' since, if choosing an aspect of technology with which there is very little initial confidence:

> '…the risk is too high that it's not leading to anything at all. You can't afford that because you need to teach kids at the same time and they need to get a proper education'

He also linked the notion of increasing confidence to take such risks to the opportunity to work with others 'so that you're still safe if you really don't know anything about it for instance'.

4.3.2.2.3 Teacher C

Teacher C showed equally little change in relation to peripheral domains but analysis reported a significant increase in TPACK.

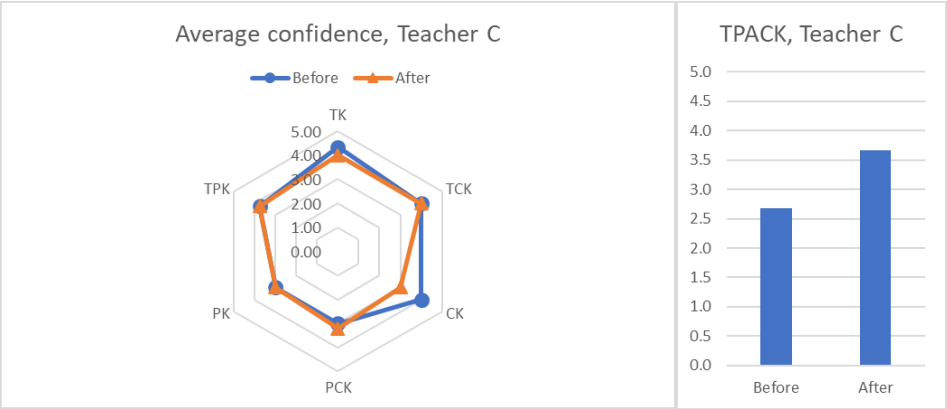


Figure 33: Teacher C outcomes

Like teacher A, teacher C was expecting to see a more of a difference given the anecdotal evidence offered in his reflections:

> 'I'm a bit surprised myself. I was hoping for like a shift… evidence of a shift in my thinking to show that oh actually I was misinformed about this'

He made clear reference to the synergy of the various ideas inherent in the peripheral subdomains to contribute to TPACK and suggested that the increase evident in this section was not surprising:

> 'I think, if anything, it's perhaps maybe reinforced my confidence in how I perceive I can use technology in my teaching practice and how I can use it to support how I want to deliver learning outcomes and objectives to different cohorts of students'

4.3.2.2.4 Summary

Little quantitative change in the peripheral domains is not entirely unexpected for this group as experienced teachers bring a wealth of experience established over a number of years and will therefore already have a more highly developed pedagogical content knowledge than their trainee counterparts. Given the established frame of reference from which they completed the assessment tool, consistent judgement could be thought of as expected, offering validation of the algorithm behind the analysis, and being less likely to be influenced by medium term intervention given that the assessment tool looks at general aspects of practice in each of the subdomains. To quantitatively capture changes in perceptions might perhaps require looking at very specific aspects of practice in relation to the subdomains and linked closely to the topic and technological ideas under consideration or taking a much longer-term view of their practice.

That Teacher C was the only one reporting a significant increase in TPACK is somewhat surprising since he was the 'power-user' of the group. It is of interest that he reported a lower TPACK score initially compared to Teacher B which perhaps reflected a more developed sense of 'conscious incompetence' as a result of his much greater prior engagement with technology than the other participants. This might also account for the decrease evident for Teacher B who had clearly made a connection between thinking about technology and pedagogy during the course of the project, having made him:

> 'really think about pedagogy. It makes me really think about what and how need the students learn. And how can I provide the best possible way to make that happen.'

The quantitative analysis afforded by the data generated through use of the assessment tool has demonstrated that some indication of confidence is possible. This is supported to an extent by the manner in which measures obtained from amalgamated scores for the peripheral domains correspond closely to the TPACK scores generated.

Differences in apparent outcomes for teachers and trainee teachers reflect differences in experience and differences must be treated with caution regarding whether they reflect actual changes in confidence/competence or are indicative of increasing familiarity for trainees with the component parts of TPACK and what these look like in practice. The notion of how conscious incompetence might colour teachers' perceptions has also been raised.

4.4 Synopsis

In this chapter, the TPACK assessment instrument has been assessed in operation and proven capable of generating results that afford useful analysis. Interpreting these results is not without problem in that different patterns appear to emerge depending on the experience of the participant. Given the consistency of findings within each of the two groups (trainees versus experienced teachers), early speculation is that this relates to the extent to which their awareness of the level of their pedagogical competence is conscious or unconscious.

The other components of the toolkit of resources, namely the T-CoRe and the card game have been shown to be capable of generating thinking by, and discussion between, participants that challenge their consideration of the pedagogical affordance of technology. The T-CoRe has been well-received, but its main benefit appears to have been in scaffolding a thinking process rather than for the summary document produced by its use. To this end, a recommendation emerges that licence be given for flexible use to allow focus to be applied where considered most appropriate. The card game was highly popular, reported as stimulating consideration of the link between pedagogy and various forms of technology and in making a strong contribution in terms of the collaboration fostered through its use. Ongoing use of both these resources in future professional development activity was considered by participants, suggesting that wider dissemination of practice is a potential additional benefit of such professional development activity.

The most significant theme by far to emerge from consideration of the findings is the ability of the combination of activities and resources to foster deeper consideration than many participants had previously reported of the interplay between technology and pedagogy. Since TPACK lies at the heart of this consideration, this notion has been assigned significance and given rise to the term 'TPACK thinking' as a concept worthy of ongoing consideration in the quest to operationalise TPACK.

The value of the methodological triangulation afforded by the use of quantitative and qualitative methods has been seen in that they each contribute to the understanding gained of the resources in use by participants as part of a professional development experience. Key themes arising from this analysis are considered and evaluated in the next chapter in the light of the conceptual understanding derived from the literature reviewed during planning of the research activity.

5 Chapter 5: Discussion

I opened my introduction with the following statement from a recent report on technology in teaching:

> Technology can amplify great teaching,
> but great technology cannot replace poor teaching.
>
> (OECD, 2015, p.4)

This throws down a challenge to give detailed consideration of teachers' choices regarding the use of technology in the classroom and whether they are hindering or supporting teaching and learning. A warning was sounded that technology might be used for technology's sake (BESA, 2015) and that it might even detract from personal interactions between teachers and pupils (OECD, 2015). The counter-argument in the statement alludes to the great potential benefits that technology can bring when carefully selected and used.

Both these ideas have been explored in detail in earlier chapters and the approaches and activities developed and used in this study were informed by key findings from the literature studied surrounding the three areas which converged to form the conceptual framework for the research, namely the seemingly inadequate use made by many teachers of technology to support teaching and learning, the problems identified with common modes of professional development, and the theoretical framework offered by TPACK. Having explored component aspects in the previous chapter, this chapter seeks to consolidate findings in the light of the theoretical perspectives derived from the literature.

The three strands of the conceptual framework will be considered in turn before taking a more holistic view through the lens of professional capital and turning towards evaluation.

5.1 Technological challenge

Key ideas drawn from the literature regarding the challenges inherent in teaching with technology can be broadly considered as those relating to teachers and those relating to teaching. New ideas that resonate with this thinking include a construct labelled 'Teaching in a Digital Environment' (TIDE) which comprises two dimensions: teachers' ICT skills and teachers' ability to apply pedagogical criteria to supporting students' work with technology (Claro et al, 2018, p.164). Although this is approached from the perspective of digital literacy in its broader sense, this is a term worthy of becoming familiar with as the digital landscape unfolds further within education.

5.1.1 Teachers

Teachers' beliefs, skills and experience all play a part in the level at which teachers are prepared to engage with technology (Vacirca, 2008; Koehler et al, 2011; BESA, 2015). Beliefs may be influenced by a range of intrinsic and extrinsic factors (Becta, 2003; Groff & Mouza, 2008). It is clear from participants in the study that they were well aware of a range of barriers to the use of technology but that, given the time and structure to consider these, they were able to offer mitigation for many, meaning that barriers could be overcome and therefore provide less of an obstacle to development of practice.

Intrinsic barriers were interpreted and considered by participants using terms with which they were familiar such as the notion of fixed and growth mindsets as described by Dweck (2007). The intervention offered in the professional development activity and the thinking it promotes appears to be able to overcome some causes of what I termed 'TPACK inertia'. Tondeur et al (2017) suggest that there is a reciprocal relationship between pedagogical beliefs and technology use. The tentative use of technology can, through its perceived advantages, support changes in teachers' beliefs; and the act of exploring the theoretical affordances of new technology can strengthen teachers' constructivist beliefs about the benefits of technology.

In practice, TPACK was seen to afford a lens through which to explore technology integration and purpose, providing the push needed for some to engage with new forms of technology in a planned manner which may have required additional learning before implementation. Other teachers were seen to engage with technological affordances in a more exploratory manner or, as one teacher reported, to be willing to be 'taken outside my comfort zone' (T3.ii). In all cases, the opportunity for collaborative discussion yielded rich dialogue and enhanced evaluation. Although hard to measure mindset, the attitudes reported in the findings suggest good capacity for such forms of professional development to provide the needed momentum to overcome intrinsic barriers.

Participants widely acknowledged that there may be the need to develop operational skills specific to forms of technology for which they see pedagogical value and that this requires an associated time commitment. Within the framework of professional development activity there appeared to be the motivation and willingness to do this. Some expressed a desire to explore the pedagogical affordance of new technology, and others to investigate how different forms of technology might meet identified needs. Curiosity-fuelled exploration is synonymous with what Koehler et al (2011) termed 'deep play' and it was clear that involvement in professional development activity was the push some participants needed to explore uses of technology they would not have had the time or inclination to engage with otherwise. Collaboration was seen as important to help raise awareness of suitable resources and to promote support, motivation and developing confidence.

At times there was a perceived conflict with school policy and the ability of, for example, pupils' own mobile devices to provide simple solutions to problems caused by a lack of resources. This raises a question on a much larger stage about the tension between schools' early approaches to restricting or controlling the use of such devices in classrooms as they became more common, and the real potential they offer as they become ubiquitous. This perhaps reinforces the digital divide to which literature points (Hramiak, 2012) and necessitates a rethink about how acceptable use can be negotiated with pupils to revise policy to the benefit of learning potential.

5.1.2 Teaching

It was seen in the literature review that teachers at different stages in their careers might approach the problem of linking technology and pedagogy from different perspectives; experienced teachers potentially having more highly developed PCK but limited digital literacy (Vacirca, 2008), and those with high levels of digital literacy, such as new entrants to teaching, possibly not having yet considered the pedagogical affordance or need to make evaluative decisions to support the best pedagogical choices relating to technology use (Rogers & Twidle, 2013). The differing quantitative outcomes for these two groups of participants in this study, suggests that these differences may exist in practice and that the intervention activity may foster a degree of pedagogical awakening for new teachers and possibly develop awareness of the level of conscious incompetence demonstrated by experienced teachers.

The significant gains made by trainees in all domains of the TPACK model appears to reflect increasing understanding of, and confidence with, the language of TPACK (conscious competence) although, when compared with experienced teachers, trainees may subsequently over-estimate their ability. On second use of the assessment tool, trainees were not reminded of their scores in the first attempt so were unlikely to be influenced by this and to attempt to show improvement to conform with what they might perceive as expectation, so a degree of confidence is expressed in this moderatum generalisation.

Experienced teachers, on considering their competence the second time, appeared to articulate a greater sense of being aware of the extent of what they might not yet know. This similarly might be argued to be indicative of the significant learning to which the qualitative data point. Whilst the attempted measurement of TPACK has fostered interesting conversation resulting from its interpretation with participants, it is perhaps this discussion which provides more meaningful insight than the numbers obtained from the assessment tool. The contrasting numerical outcomes from the trainee and experienced teachers, whilst consistency was evident within groups, does sound a warning for other TPACK researchers with regards to the interpretation of quantitative TPACK data and the need for careful evaluation.

Harris et al (2010) suggested that external performative judgements may be preferable to self-assessment due to the difficulty in distinguishing performance from confidence. Although the challenges associated with this have been discussed earlier, this may merit ongoing consideration.

In both cases, however, qualitative outcomes affirm that the pedagogical responsibility of the teacher can be challenged and developed in relation to the use of technology. The pedagogical integration of technology was seen to a greater degree in participants' planning using T-CoRes and in report during interviews. Scaffolding this process appears therefore to address the warnings sounded in the literature that rapid or unsupported introduction of technology in schools can lead to pedagogical poverty as teachers try to fit teaching around the technology rather than making their own informed choices (Becta, 2003; Jenkins, 2009).

In addition to its pedagogical affordances, technology was also seen by participants as a means of securing pupil engagement. There is a risk that this is simply due to novelty value and participants recognised the classroom management implications of this. Some elegant examples of highly appropriate thinking also centred on the capacity of technology to support differentiation and assessment which demonstrate that quality thinking can overcome the challenge identified in the literature that technology can inadvertently have a detrimental effect on the level of human engagement in evidence in the classroom (OECD, 2015).

The challenges of teaching in a digital environment as defined by Claro et al (2018) and requiring both operational skills and pedagogical skills neatly summarises the ideas used to articulate the technological challenge underpinning the first of the three aspects that converged to form the conceptual framework upon which this research is based. Teachers involved in this study have demonstrated that careful consideration of *why* technology is used rather than just *how* is needed if we are to realise the potential to which the OECD (2015) alluded by claiming that 'Technology can amplify great teaching' (p.4).

5.2 Professional development

The second question contributing to the conceptual framework is that of how effective pedagogical consideration of technology by teachers can be promoted through professional development. Professional development related to the use of technology was seen to be subject to much criticism in extant literature both with regards to its structure and relevance. Key elements of the arguments set out in the literature explored were used to guide the development of the professional development experience trialled in this study.

Structural criticisms of professional development were levelled at its technocentricity (Harris & Hofer, 2011) and brevity (Rogers & Twidle, 2013) which, in combination, can yield limited potential for impact (Sherwood, 1993). These ideas, coupled with a preference by teachers for face-to-face training over online delivery (Preston, 2004) and substantial evidence advocating collegial approaches (Koehler et al, 2011; Voogt et al, 2013), fuelled development of professional development activity that provided opportunities for extended interaction between participants. The collaborative elements were reported by participants as being very positive aspects of the professional development experience since they offered both challenge and support. The difficulties encountered engaging potential participants at a distance by narrating presentations would seem to lend support to the reported value of including a face to face component to the experience.

A desire for more practice-based training (Rodrigues et al, 2003) was accommodated, as was strong recommendation that training should relate to teachers' daily reality (Preston & Cuthell, 2007; Schön, 1983; Koehler et al, 2011). Developing participants' ownership of aspects of their training was seen as fostering personal investment, reducing resistance and increasing potential for sustained impact (van Driel et al, 2012). This resonates strongly with the need raised earlier to address teacher beliefs which 'act as a filter through which new knowledge and experiences are screened for meaning and relevance' (Tondeur et al, 2017, p.557). Establishing the relevance of both the training and the affordances of the technology with which teachers are presented is seen as important in fostering ownership and intrinsic motivation.

The professional development experience developed therefore focused on practice rather than skills, including a mixture of didactic, discursive and independent activity. Participants were able to apply and evaluate the thinking stimulated to their own teaching through cycles of practitioner research and collaborative review. There was clear evidence of the value to participants of being able to contextualise activity within their own practice as this was felt integral to their daily work and driven by problems that they had previously encountered. Strong and positive reflection was shared between participants regarding the impact of activity both on their practice and on pupil outcomes. There was a strong sense from participants that the thinking evoked through the structured activities provided may influence ongoing thinking regarding their use of technology in future.

The timely publication of the new Standard for Teachers' Professional Development (DfE, 2016) affords an additional lens through which to evaluate the professional development activity delivered. The Standard identifies five areas against which recommendations from my literature survey can be mapped – see Table 15.

Within this Standard, the DfE are clear to make a distinction between professional development *programmes* and professional development *activities*, reinforcing the notion earlier identified that 'one-shot' training approaches are likely to have limited impact, particularly when focused on operational skills (Rogers & Twidle, 2013; Sherwood, 1993; Hargreaves & Fullan, 2012).

In the activities developed and used with participants, a blended approach was taken including some face-to-face training and some independent work. Face-to-face activity allowed introduction to the theoretical dimension afforded by TPACK (Standard area 2) and afforded the opportunity for collaboration, focused discussion and peer-coaching (area 1). The TPACK card game was seen as particularly effective in supporting productive dialogue. Participants welcomed the opportunity to work together and support each other, and a level of challenge was also noted in the discussion that activities fostered.

DfE (2016a) PD guidance	Links to van Driel et al (2012)	Links to Angeli & Valanides (2008)	Links to other recommendations
1. Clear focus • Explicit reference to participants. • Designed around teacher experience, knowledge and needs • Relates to teachers' working context • Reflects intended pupil outcomes	Coherence with professional working context	Engagement in real-world authentic tasks	Meets needs of individuals (Preston, 2004) Focus on practice (Rodrigues et al, 2003)
2. Evidence informed • Links theory and practice • Links pedagogical knowledge with subject knowledge • Informed by research • Supported by expertise • Challenges teachers' beliefs and expectations	Focus on PCK	Awareness	
3. Collaboration • Includes peer support • Includes focused discussion • Challenges existing practice • Includes coaching to model and challenge	Collaborative	Collaboration Opportunities to discuss with an expert	Collegial (Koehler, 2011; Preston & Cuthell, 2004; Jimoyiannis, 2010a; Voogt et al, 2013) Peer coaching (Jang & Chen), 2010)
4. Sustained over time • Iterative • Includes opportunities for experimentation, reflection, feedback and evaluation	Sustained Includes inquiry-based learning		Sustained (Rogers & Twidle, 2013) Experimental (Twining et al, 2013)
5. Prioritised by school leadership • Leaders model and champion effective PD • Provides time and resources • Balances teachers' and school needs • Develops professional trust	Supported by school organisation so conducive to professional learning		

Table 15: Recommendations for professional development

The professional development programme involved three twilight sessions providing the opportunity for fostering ongoing motivation and the impetus to evaluate and share participants' interim activities (area 4). These interim activities centred around participants' individual use of the T-CoRe document to support planning for episodes of teaching which were subsequently evaluated. This very much allowed participants to use the project to help meet identified needs within their teaching or to explore aspects of technology they felt might offer something useful to their practice (area 1). The importance of this is summarised by Hine (2013) who ventured that by 'exercising their individual talents, experiences and creative ideas within the classroom, teachers are empowered to make changes related to teaching and learning' (p.153).

In the findings, participants were very positive about the opportunity to reflect on the aims of the project in the context of their own practice and the impact this had in their classrooms. They were similarly positive about the value of the collaborative activities (area 3), with one teacher making specific reference to the damaging effect of the sorts of professional isolation identified from the literature (Hargreaves & Fullan, 2012; Levine & Marcus, 2010; Rosenholtz, 1989) and evidence of peer-coaching emerging.

These findings lend weight to the benefits of four of the five areas of the DfE standard. The effect of grounding participants' experience within the theoretical construct of TPACK and making explicit links between content and pedagogy (area 2) is considered in the next section. Area 5 (a whole-school perspective) was beyond the design and scope of this project but there was evidence of participants' wider consideration of how their learning might be disseminated to colleagues. Ways of demonstrating value to senior leaders and securing the necessary commitment required to roll such a programme out in school might form part of ongoing study relating to this topic. The empowerment of teachers by these activities, however, may play an important role in helping them play an active part in planning for their own future professional development in line with some of the aims identified within area 5 and help them move towards becoming 'accomplished teachers' as highlighted by Loveless (2007, p.510) and teaching 'like a pro' (Hargreaves & Fullan, 2012, p.46) as identified earlier.

It is felt that the experience offered teachers through use of the toolkit of activity derived from this study addresses the recommendations inherent in the new Standard for Teachers' Professional Development (DfE, 2016) within the specific context of training relating to technology and that the outcomes described endorse these. The theoretical dimension alluded to by area 2 of the standard is considered in the next section.

5.3 Operationalising TPACK

Of a variety of approaches considered, TPACK was selected as a vehicle through which to facilitate theoretical and subsequent practical consideration of the interplay between pedagogy and technology. This potential was strongly advocated in the literature (Koehler et al, 2011) but practical application was considered under-developed (Jimoyiannis, 2010a). The third strand of the conceptual framework therefore derived from a more in-depth exploration of the literature surrounding TPACK.

The toolkit of resources developed during the project aimed to operationalise TPACK, firstly as a means of assessing practice and secondly as a theoretical lens through which to foster reflection on practice in a structured manner aligned to professional development activity. The tools created: the assessment tool; the T-CoRe; and the TPACK game were all found to have merit within professional development activity. The assessment tool was found, as a result of the iterative development described in chapter 3, to be able to produce valid results. This is very pleasing in the light of accusations that assessment instruments were previously under-developed (Voogt et al, 2013) and that assessment of validity was often overlooked (Drummond & Sweeney, 2017). The potential to present results in a variety of ways was explored and Colvin & Tomayko's (2015) suggestion that radar charts offer a useful and visually appealing representation confirmed in the context of individual results and found to be particularly suitable when discussing results with those from whom the data derived.

Although the differential findings between established teachers and trainees appear to be, in part, due to the level of reflection about pedagogy of which different groups of participants are capable, the ability to visualise TPACK in this manner may well prove of use as a diagnostic tool upon which targeted and personalised professional development might be constructed. This is certainly an area for further consideration about subsequent avenues for ongoing research.

For group results, the inability of radar charts to offer an indication of variance (such as standard error of means) when generated in common software was found to be limiting and therefore caution is offered together with a suggestion that representations be kept simple and fit for the intended purpose.

An unexpected but interesting finding was the ability, using the data obtained via the assessment tool, to explore the relationship between the index of TPACK obtained and the amalgamation of the other domains. This relationship appears directly proportional and therefore throws into question whether attempts to measure each domain within the theoretical construct, something which has always been reported difficult, is actually necessary for many purposes (other than as a diagnostic as intimated above). This too may be something worth pursuing as a potentially useful addition to the TPACK literature through future collection and investigation of a larger data set.

The T-CoRe has been shown to scaffold thinking that has led to development of practice as well as potentiating excellent reflective capacity about the various domains within the TPACK framework. The ability to tease out thinking relating to each domain as well as exploring classroom practice was seen as fundamental to the 'complex process' of examining teachers' TPACK (Polly & Brantley-Dias, 2009, p.46). This was reportedly supported well by the card game which generated reflective thinking and productive discussion within a community of practice, thereby allowing more confident members of the group to model good reflection to the benefit of those less confident.

The operationalisation of TPACK will be further considered in terms of its transformative potential, its potential to support collaborative professional development and the ongoing impact for teachers that its use might foster.

5.3.1 Transformative potential

A highly significant finding from this research is the capacity of a structured approach to professional development relating to technology to enrich teachers' thinking and reflection. The perspective offered by the use of TPACK as a theoretical lens has been seen to foster productive dialogue in which consideration of pedagogy is prominent.

This suggests a shift from previously documented allegations of professional development in relation to technology being biased towards operational skills (Harris & Hofer, 2011; Rogers & Twidle, 2013). I have attempted to encapsulate this shift in the term 'TPACK thinking' as a means of reflecting its capacity to lead to consideration of the strategies needed for the effective pedagogical integration of technology.

Through such TPACK thinking, the pedagogical value of different forms of technology appears to be recognised which, for a number of participants, has contributed to increased motivation to explore new possibilities to solve identified pedagogical problems, be they related to the teaching of abstract concepts, the challenge of meeting identified pupil needs or aiding in Assessment for Learning. Participants have reflected on a range of personal and pupil outcomes resulting from changes in their teaching enacted as a result of the TPACK thinking applied. The ability to use this thinking to overcome resistance to change has led me to see perceived barriers as contributing to 'TPACK inertia' and active consideration of TPACK as a vehicle by which momentum can be imparted.

Earlier this idea was related to the notion of Threshold Concepts, an idea worth revisiting to support evaluation. The key features of threshold concepts (Meyer & Land, 2003) were identified as being:

1. Transformative

   Impact in terms of thinking, confidence and pupil outcomes is reported. An important part of this is participants' improved ability to recognise concepts or factors that form the boundary wall of the liminal state they currently occupy. Teachers' beliefs about the use of technology have been seen to be important but evidence has been shown of participants' abilities to address identified barriers rather than conform to the borders they present.

2. Irreversible

   Mastery of new ideas has the potential to lead to sustained practice. Participants appeared to offer clear suggestion that TPACK thinking was something they would carry forward and apply to ongoing teaching. See section 5.3.3.

3. Integrative

   TPACK has proven a highly effective means of supporting consideration of the interplay between technology, content and pedagogy and is clearly able to move beyond the theoretical into the realm of practical application.

4. Bounded

   Although in their ongoing practice the tools provided such as the T-CoRe may fall into disuse, TPACK thinking appears to be something participants think will influence their ongoing practice. This has potential to support the motivation and problem-solving required to master future threshold concepts as new barriers are encountered.

Viewed through this lens, the transformative potential of TPACK is clear.

An important contribution, identified by participants, to the success of TPACK as a vehicle to drive transformation is the quality time afforded through professional development. Many participants noted the value of the time and space the deliberate focus on TPACK provided within the otherwise hectic reality of teaching. Whilst all professional development experiences offer time, the iterative nature of the training offered here allows for development and sharing of ideas within a structure that helpfully defined the space within which that thinking could occur.

The notion of a defined thinking space proved helpful to some. One trainee (T3.iii) suggested that scaffolding thinking in the manner afforded by TPACK helped prevent her getting lost 'down the rabbit hole' of ideas presented by less structured thinking about technology. This trainee eloquently suggested a previous tendency towards 'going blanket' - using technology beyond its pedagogical affordance, and thereby falling foul of the warning seen in the literature regarding letting technology dictate pedagogy or absolving teachers of the need to think about the extent and purpose to which technology is used (Becta, 2003).

The license to think afforded by the structured activities for both teachers and trainees was therefore seen to help meet the challenges identified earlier for both experienced and new teachers relating to the enhancement and integration of digital literacy and pedagogical skills. As such, the potential for TPACK to support development of what Cornu (1995) called 'integrated pedagogy' is clear and I venture that it has the potential to transform rather than merely enhance practice.

5.3.2 Collaborative working

The importance of collaboration as an approach with potential for 'strengthening ownership of change' (Jang & Chen, 2010, p.556) was seen in that teachers offered strong reflection on their own practice in dialogue with others about practical teaching. These ideas were carried forward in individual practitioner research activity but subsequently shared and discussed in group sessions.

Follow-up sessions were seen as important in relevant literature (van Driel et al, 2012) and were seen as supporting ongoing motivation by reducing the potential for professional isolation during the practitioner research elements of which Hargreaves & Fullan (2012) warned.

Participants reported the benefits of collaborative working both in terms of being able to gain from the experience of others and in the challenge and support offered during discussions. Increasing motivation, provision of support and reassurance of not being alone in their endeavours were seen as important outcomes of collaborative activity.

Coupled with the opportunity to discuss and report back on ideas relating to their individual activity, links between collaboration and ownership are perhaps evident.

Cviko et al (2014) found that using collaborative technology design activities fostered a useful degree of co-ownership. Although, in this study, the design element was an independent activity, the understanding that participants were to report back to each other on the independent activity undertaken between sessions can be seen as helping focus participants' actions, defining a time-frame for activity and adding a weight of expectation necessary to foster ownership and motivation.

Good evidence was identified in the literature for professional learning communities as vehicles for motivating and fostering innovative practice and no suggestion can be offered, in the light of this study, to the contrary. There was, however, good evidence of participants' thinking beyond the scope and timeframe of the study and the potential role they might play in future.

5.3.3 Tomorrow's champions

The successes identified by participants were, in many cases, reported with a degree of pride. This intrinsic endorsement of their activity and capabilities contributed to enhanced confidence. The impact of this on self-perception and ongoing or renewed teacher identity led to several participants reflecting on their capacity to support the professional development of their colleagues. For some this was manifested in a desire to share aspects of the training undertaken. For others it involved engaging directly with specified colleagues to share new ideas. Even for those less certain of their standing in the hierarchy of a new department, there was suggestion that they might seek to shape department meetings to include focus on shared technology and associated pedagogy. Each of these demonstrates the 'champion' effect to which I alluded in the introductory chapter.

This champion effect was seen not only in those identifying as tech-savvy who are willing to share skills but also by those who developed the confidence to be proactive in meeting their own needs by enlisting others as champions. The latter is perhaps a

good example of a key feature of Angeli & Valanides' (2008) thinking about knowledge construction in which tapping into the expert knowledge of others is advocated.

I warned of the risks associated with the loss of a champion from a department so am delighted to note participants acknowledging their potential as change-agents and seeking to play an increased role in fostering collaboration within their own workplaces. In most cases this was seen from a sense of altruism, but one experienced teacher reflected on the potential career benefit of being a champion:

> 'you can be a pioneer in school to get TPACK going and you could be the person who leads that. And nowadays it becomes more and more difficult to get TLRs – what can you do to stand out compared to your colleagues?'
> (Teacher B interview)

Whilst not wanting to externalise the motivation for being a champion, since there is a risk that this then results in professional development being done 'to' rather than 'with' colleagues, recognition of the value of sharing practice and the hope that this might, in turn, be recognised and valued by middle and senior leaders is, of course, welcome. Trainee teachers were similarly able to recognise the role they might play within their departments once qualified to foster their own ongoing development and that of their colleagues.

5.3.4 TPACK in summary

TPACK has therefore provided a theoretical basis for professional development and a shared understanding and language for collaborative activity. In reflecting on its affordance in terms of Wenger's four features of a community of practice (1998), it appears that TPACK offers something of value in each:

- Meaning: a shared understanding of the way the framework articulates the notion of integrated pedagogy – as fostered through a group introduction to the concept and collaborative use of the TPACK card game. Wenger's interpretation of meaning including learning as experience also resonates with the ability of participants to locate their activity within their own practice and workplace.

- Practice (learning as doing): collaborative exploration of use of the T-CoRe supported scaffolding of thinking in preparation for independent activity
- Identity (learning as becoming): Membership of a defined group of professionals who could challenge each other within a supportive environment
- Design: Wenger suggests that 'learning cannot be designed' (1998, p.225) but that we can design infrastructures that facilitate learning. Through shared rather than isolated activity, participants were able to help influence the nature of the project in terms of ongoing development of resources and in the independent activity undertaken between group sessions.

Among researchers who cling to TPACK as a purely theoretical construct, there are perceptions that it is too complex to operationalise. Younie & Leask cite Webb (2010) who suggests that the range of knowledge required to make sense of TPACK renders it 'unmanageable for individual teachers to achieve a sufficiently comprehensive knowledge set in this domain' (Younie & Leask, 2013, p.102). The ability to measure, the potential to use results to set targets and to empower participants to set their own agenda for professional development, the ability to scaffold TPACK thinking, and the ability to promote the application of a shared understanding in productive dialogue and subsequent independent action, leads me to venture in response that, in contrast, TPACK does indeed have practical application that can be realised.

5.4 Developing professional capital

The conceptual framework upon which this study was based developed from the three strands articulated above. In consideration of the convergence of these strands, it has proved helpful to consider these ideas further in terms of the contribution they could make to professional capital.

The toolkit of resources has been seen to be capable of influencing and supporting teachers' thinking and reflection, and thereby their ability to make pedagogical decisions about technology use. There is, as a result, strong evidence that these activities are capable of contributing to participants' decision capital. Similarly, the programme of professional development developed, trialled and evaluated has

embraced recommendations from the literature regarding the individual and group agency fostered by collaborative working over an extended timeframe, thereby ensuring that the process fosters social capital.

Through these, participants have been able to develop the confidence to explore new technological affordances and develop their understanding of how technology can be exploited to better effect in their teaching and in the learning of their pupils. Alongside this, adding the language of TPACK to their knowledge base also contributes to developing the human capital of participants.

A summary of the effect the activity described in this project appears to have had on all three dimensions of professional capital is shown in a development of the figure introduced as part of articulating the conceptual framework:

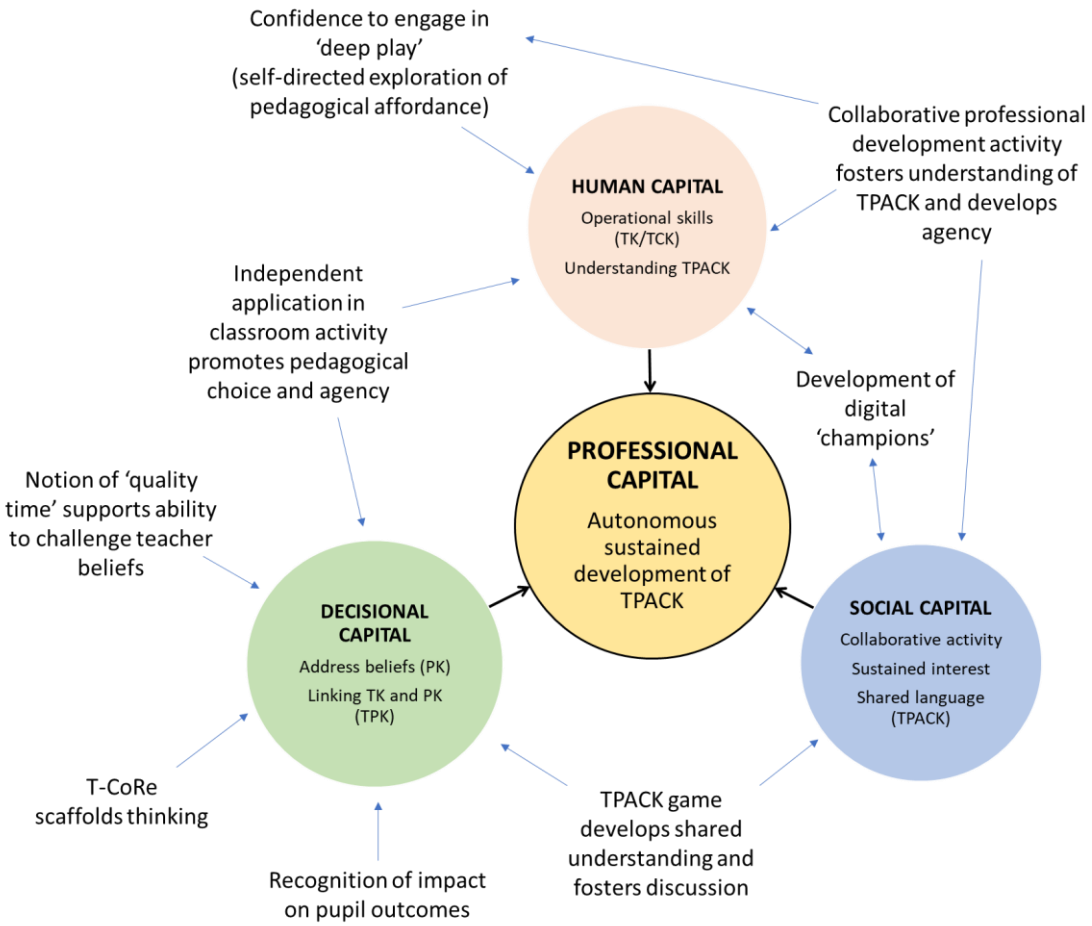


Figure 34: Effect on professional capital

In consideration of their model of professional capital, Hargreaves & Fullan (2012) emphasise that maximum efficiency is achieved by addressing all three components simultaneously by addressing them as components of the function PC = f(HC, SC, DC). They suggest that addressing professional capital in this way contributes to supporting colleagues to 'teach like a pro' (p.46) and it is hoped that the ideas, resources and outcomes derived from this study can continue to support colleagues to engage further in teaching like a pro as they seek to integrate and embed technology in their teaching.

5.5 Evaluation

Before moving towards conclusions, it is appropriate to evaluate various aspects of the study to allow determination of the weight that can be assigned to the generalisations that are offered. Methodological, analytical and ethical issues are considered here further to their consideration elsewhere in this thesis.

5.5.1 Research methods

The benefits of the abductive pragmatic stance taken in this research are seen in the iterative development of the toolkit of resources and the capacity to respond recursively to formative use of early resources with participants. Patterns of behaviour have emerged and the notion of probabilistic inference (Niiniluoto, 1999) allows tentative conclusions to be offered within the spirit of moderatum generalisation. Tavory & Timmermans' (2014) suggestion that meaning making within abductive analysis is a practical achievement 'occurring in action' (p.23) validates the use of Action Research as a suitable methodology which suited the developmental goals of the creation of a toolkit, the development of training activities, and the evaluation of resources with successive cohorts of trainee teachers leading to the training package delivered to the final cohort and the professional development experience offered to the group of experienced teachers. Action Research was seen as suitable for research in which change is a goal and not just an outcome, a feature which further resonates with the abductive notion that change is a perspective that can help gain a greater understanding of actuality.

Hine (2013) acknowledged that Action Research can facilitate the 'professional development of educators, increasing teacher empowerment and bridging the gap between research and practice' (p.152) which resonated strongly with Polly & Brantley-Dias' (2009) challenge to future TPACK researchers to adopt methodologies that allow the exploration of the interplay between theory and practice. It is hoped that this study achieves this to promising effect.

Action Research and an abductive stance commend methodological pluralism and mixed methods approaches were found to offer useful opportunity for methodological triangulation and paradigmatic corroboration. For example, the qualitative and quantitative aspects of the study offer insight into the different thinking employed by the two distinct groups of teachers leading to a distinction between conscious and unconscious incompetence underpinning their interpretation of the assessment task. Although qualitative methods may be seen as an 'attractive nuisance' by positivists (Miles, 1979), it has been seen to afford rich data which supports interpretation when quantitative methods tell a blurred story. The use of a single approach may have resulted in this being overlooked.

Methodological triangulation was also of importance in supporting the iterative development of the assessment tool. The combination of data derived relating to the ability of the tool to assess confidence as well as its ability to identify the ease with which participants could distinguish the subdomains of the TPACK model was fundamental in diagnosing and addressing issues limiting the validity of the instrument. As a result, confidence in the ability of this tool to yield useful and meaningful data was substantially enhanced.

Data were drawn from a variety of sources, both qualitative and quantitative, and subjected to analysis using a variety of tools. The capacity of the planned data collection to provide both methodological and perspective triangulation was a distinct advantage, contributing to the validity of findings. The ability to generate insight relating to the relationship between TPACK and its constituent subdomains was unexpected and leads to questions deserving of further study.

Quantitative analysis was performed using MS Excel, largely for reasons of familiarity but also for the ease with which large data sets can be subjected to simple arithmetical analysis and measures of variance obtained. More complex processes, such as the calculation of Cronbach's alpha, were entrusted to SPSS which required some learning on my part but provided an accessible user interface through which this more detailed analysis could be performed. Analysis of qualitative data similarly required gaining familiarity with NVIVO to a level that was fit for the intended analytical purpose. The use of thematic, emergent, magnitude and 'rec' coding all contributed to the picture described in the findings and, again, validate the structured yet flexible approach advocated by the abductive, pragmatic stance taken.

5.5.2 Generalisation

The notion of 'fuzzy generalisation' was raised in the methodology chapter and it is again acknowledged that findings are constrained by contextual factors including the nature of the participants and the length of the professional development activity undertaken. The perspective triangulation afforded by the use of two distinct groups of teachers, namely experienced teachers and beginning teachers has, however, shown that some benefits claimed as arising from the study are evident across the profession but that some interpretations appear to hold true only for some, for example, the interpretation of the apparent differences between changing confidence levels of both groups following the intervention activities. The abductive notion of inference to the best explanation has proven helpful in the consideration of explanations of these differential outcomes between groups of teachers, but it is recognised that many of the findings and interpretations offered here are stepping stones to ongoing study. As such, only moderatum generalisation is offered, with the implication that reliability is bounded by the context of the study although findings and questions are identified that might fuel further study or be subjected to evaluation in a broader context.

5.5.3 Integrity & ethics

The delivery of training at face-to-face sessions, as well as passing over ownership of responsibility for participant activity in school between sessions, required my moving between insider and outsider roles as researcher, retaining the 'liquid identity' defined by Thomson & Gunter (2011) seen as both risky and potentially helpful. Risks were evident in that the products of independent activity were very much down to the interpretation of tasks by participants. As such, T-CoRes were used inconsistently although a distinct benefit of this is that they did not limit the variety of activity planned by participants and do yield testimony to the importance of the level of ownership they perceived and demonstrated. This gave rise to identifying that T-CoRes are highly useful to scaffold thinking whilst the actual product was seen, outside training purposes, as temporal and of less importance. Having a more fluid identity as researcher was therefore seen as beneficial to the study and not at risk of reducing the integrity of the research particularly with regard to second-person action research.

Requirements for ethical research as outlined in section 3.6 were observed and there were no teacher withdrawals from involvement in the project once started. All materials have been anonymised and although, at the close of this project select participants will be asked if anonymised artefacts can be retained for use as exemplar materials for future groups using the toolkit of resources, all other artefacts and personal data associated with this research will be returned, deleted or destroyed.

6 Chapter 6: Conclusions and recommendations

The conceptual framework offered as the basis for this research represented the convergence of three distinct ideas and bodies of literature relating to: teachers' use of technology; modes of professional development relating to technology; and the theoretical framework offered by TPACK as a means of articulating the relationship between technology and pedagogy. The research questions derived from this consideration are considered in this section. New theoretical insights are identified, and consideration given to directions in which subsequent research might move.

6.1 Responding to research questions

Four research questions were identified under the umbrella of the over-arching question, 'How can teachers be encouraged to take ownership of professional development regarding their use of educational technology?'. The contribution made by this study towards answers to each will be considered in turn before taking a more holistic view relating to the question above.

RQ1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology?

TPACK was identified as a lens through which teachers' practice relating to the use of technology can be observed and, as such, is documented as having great theoretical appeal. Its practical application is something that has been explored to a much lesser degree (Jimoyiannis, 2010a). TPACK's potential for use in professional development activity is recognised (Schmidt et al, 2009; Akkoç et al, 2008) but largely through its potential to measure aspects of practice rather than to drive transformation of practice. Abbitt (2011a) suggested that, whilst developing our theoretical understanding of TPACK is a worthy and ongoing goal, work towards practical applications would be key to developing teachers' practice.

This study reveals that TPACK is able to provide an accessible vehicle through which teachers can explore the interplay between technology and pedagogy in the teaching

of their subject. The development of tools, notably the TPACK game (after Koehler, 2018) to foster dialogue and the T-CoRe (after Mulhall, 2003) to scaffold thinking, has allowed teachers to provide substantial evidence relating to their developing understanding of integrated pedagogy. These tools were well received and evaluated by participants.

The TPACK game was a developmental afterthought, developed to support the introduction of TPACK and to enact some of the scaffolding of thought developed further by T-CoRes. The collaborative nature of this activity fostered highly productive dialogue and evaluation of alternative approaches to teaching. Reflection is seen as a key part of developing TPACK as a result of pedagogical experimentation with technology (Voogt et al, 2016). The extent and depth of reflection evidenced and the significance of this to the transformative potential of TPACK has led me to suggest that 'TPACK thinking' is a key benefit of such professional development activity.

There is some suggestion in the literature that TPACK is a self-limiting construct which will reduce in prominence and tend towards PCK with increasing competence in technology integration (Cox & Graham, 2009; Paiva et al, 2016). Participants in this study offered some endorsement of this in terms of recognition that technology use simply adds to the armoury of pedagogical approaches from which they can select but I recommend treating this view with caution as new and developing forms of technology require careful pedagogical evaluation before adding to stock approaches. Teachers, in contrast, tended initially to share perceptions based on forms of technology already known to them. This reinforces the significance of extant teacher beliefs on entry to professional development experiences and the importance of presenting materials within a framework that can challenge these.

Despite TPACK's attendant theoretical complexities (Voogt et al, 2013), this study strongly suggests that TPACK is a potent vehicle for professional development activity, thereby having significant practical potential in addition to its theoretical appeal. The focus on integrated pedagogy through a shared understanding of TPACK during professional development is seen as a powerful means through which to challenge Kinchin's notion of 'technology-enhanced non-learning' (2012, p.46).

There has been recent debate based on different epistemological viewpoints represented in the literature regarding wither TPACK is a transformative or an integrative concept. Convincing argument based on extant studies relating to the application of TPACK suggests that TPACK must be conceptually transformative since general courses seeking to improve constituent parts in isolation do not necessarily lead to an enhanced ability to teach with technology, whereas a focus on TPACK as a unique type of knowledge embracing a holistic view of the constituent parts can lead to the development of integrated pedagogy (Angeli et al, 2016). This gestalt view of TPACK is supported by this study, suggesting that 'TPACK thinking' is a powerful product of the theoretical consideration fostered by the activities presented.

RQ2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development?

Theoretical interest in TPACK has led to a number of attempts to measure practice since its introduction, hampered by the now widely recognised notion of the constituent domains having 'fuzzy' boundaries (Jimoyiannis, 2010b). Despite several models for assessment via observation, examination of teaching artefacts and through self-report, there is little current consensus regarding the most promising ways to capture aspects of TPACK in action (Voogt et al, 2013).

Given reported ongoing potential for its adaptation and use (Koh & Chai, 2014), Archambault & Crippen's (2009) TPACK assessment instrument was selected, adapted and developed to produce findings which appeared to show reliability in use within each group of participants. Iterative development of the tool was shown to improve validity to a level considered fit for purpose and which pre-empted the challenge that many TPACK studies omit this step (Drummond & Sweeney, 2017). In combination with the use of radar charts as described by Colvin & Tomayko (2015), these results were easily visualised in a form that has potential to support demonstration and discussion of impact or potentially be used for diagnostic purposes in future work.

Whilst graphically satisfying and capable of producing valid results, the emergent tool's ability to indicate changes in practice over time requires further exploration.

As a self-report tool, it appears to highlight differences in self-perception between experienced and beginning teachers that has required the use of additional qualitative data to start to understand. It is possible that other studies in which quantitative approaches are used to identify aspects of TPACK are limited for similar reasons.

This question has been addressed in terms of how practice can be assessed but it is clear that the question relating to determination of impact also requires what Saldaña (2016) terms 'paradigmatic corroboration' (p.26) through the additional use of qualitative data to support interpretation. Whether the assessment tool can be developed further to address issues of interpretation by users at different stages in their careers might be worthy of further work but perhaps to the detriment of the richness of findings afforded by drawing from participant narratives. I would strongly recommend that results from further use of any quantitative instrument be subject to corroboration by qualitative data. The assessment tool does, however, allow visualisation and therefore easy identification of areas worthy of discussion in interview so clearly offers important potential for further studies relating to transformation of practice.

RQ3. To what extent is a community of practice important in securing sustained impact of professional development?

Wenger (1998) advocates a social theory of learning, and the notion of professional learning taking place within a community of practice is addressed repeatedly in the literature surrounding professional development (Preston and Cuthell, 2007; Loveless, 2007; Voogt et al, 2013; Twining et al, 2013). This refers not just to collective training events but to training programmes in which collaborative activity is fostered to allow colleagues to 'co-construct learning' (Gu et al, 2012, p.22). The Department for Education incorporate collaboration and expert challenge in the recent Standard for Teachers' Professional Development (DfE, 2016) but there is also recognition that the participants may usefully challenge each other, and that peer coaching may ensue (Jang & Chen, 2010).

Collaboration was seen as an important aspect of the professional development work undertaken by participants involved in this study, affirming suggestions from the literature and its inclusion in the DfE Standard. Participants similarly confirmed ideas (Levine & Marcus, 2010) that day-to-day teaching could be professionally isolating so welcomed the time and opportunity for working with others during planned professional development activity. Working within a community of practice was reported to be of benefit in terms of the support and encouragement offered by colleagues which were noted as contributing to motivation for sustained engagement.

Sustained impact is harder to gauge within the timeframe of the study, but an indication of potential is given through exploration by participants of the ongoing contribution they might make as 'champions' in their departments and schools to develop the practice of their colleagues and to avoid the risk of professional estrangement.

RQ4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination of practice?

Studies and metastudies explored in the literature reveal a number of goals for professional development relating to ensuring relevance to daily practice to foster ownership, operating over an extended period with opportunities for follow-up activities, focusing on pedagogy rather than operational skills and providing the opportunity for collaboration. Whilst these cannot be tested in isolation to assess the individual contribution each might make to the development of TPACK, these all contributed to the development of an approach to professional development that was received positively. The effect of combination suggests significant advantages over the poor examples of professional development against which accusations are levelled and the recommendations offered in the literature are made. Engagement was good with the professional development provided in this study, fostered through a coherent structure and tools that have been positively evaluated. Longevity would be harder to determine given the scope of the study but there is reason for hope relating to the TPACK thinking participants take forward into their ongoing practice.

Wider dissemination is also something for which clear intent was demonstrated by participants as alluded to by the champion effect alluded to above.

These four research questions were developed to render an over-arching question researchable: 'How can teachers be encouraged to take ownership of professional development regarding their use of educational technology?'

From the study, it is clear that participants were able to personalise their professional development experience during the practitioner research elements as these enabled them to place focus on aspects of their own classroom practice and either explore their curiosity or address identified needs. It is also noted that the collaborative element was important as a means of tackling the sense of professional isolation to which literature points. Although counter-intuitive, collaboration was seen to offer peer support and motivation that were seen as important by participants as elements fostering ownership. That they were able to contextualise collaborative activities and the discussion afforded within their own practice resonates strongly with Jang & Chen's (2010) assertion that collaboration can 'strengthen the ownership of change' (p.556).

The framework provided by TPACK helped provide structure and a shared perspective upon which effective reflection was based. Ownership is perhaps seen as being related to decision capital which is recognised as one of three aspects of professional capital required for transformation of practice. With the potential of TPACK to promote changes in human, social and decision capital through its use in the activities described in this project, the use of 'ownership' as the initial focus in this over-arching question was perhaps short-sighted in the early days of the project but retained for the purposes of academic honesty since these research questions formed the basis of the project for which ethical approval was given. With hindsight, this over-arching question might have been rephrased in terms of professional capital and perhaps better expressed as:

> How can teachers' professional capital be developed through professional development relating to their use of education technology?

This is something offered for consideration for ongoing research into this area. However, the combination of TPACK and the professional development approaches taken are seen as offering great potential for further study and development of teachers' practice in the integration of technology and pedagogy.

6.2 Implications for policy and practice

The DfE Standard for Teachers' Professional Development (DfE, 2016) appears to represent a timely and effective encapsulation of the key features of professional development activity suggested by the literature with which this study has engaged. Implementation of the ideas contained within the Standard represents a departure from what can be considered 'traditional' modes of teacher professional development. This shift in focus appears particularly helpful when applied to developing teachers' understanding of the learning affordances of technology.

The professional implications of the findings described in this study can be considered at four discrete levels, relating to: policy; schools; teacher professional development activity; and the preparation of new entrants to the teaching profession.

6.2.1 Policy

In the formative years of educational technology, beginning in the 1980s, there was not the benefit of research upon which to draw to inform practice. Instead, policymakers 'jumped on the technology image and offered it to the electorate as a talisman' or emblem of the bright future consistent with political aspirations (Somekh, 2007, p.93). Early policy making both in the UK and abroad was typified by the 'launch and relaunch of often indistinguishable national education technology policies' (Selwyn, 2011, p.56). These were seen as flawed as a result of limited planning for evaluation (Somekh, 2007) in that they depended on teachers who were prone to resisting change for their success (Cuban, 2018) and that, with a lack of appropriate training, teachers merely attempted to use technology to 'replicate traditional learning activities' (Dwyer et al, 1991, p.13).

Teachers are the most important component in enacting educational change (Fullan, 1989) but Younie and Leask (2013) assert that policy is enacted at micro (teachers and schools), meso (school trusts and local authorities) and macro (government) levels. These 'multiple ecologies', they argue (ibid. p.26), make change complex to achieve. The involvement of multiple departments and agencies at the macro level has been seen to complicate the messages received by schools (McLean, 2007). At the meso level or within school leadership, a lack of understanding or proficiency risks limiting personal investment by stakeholders at the micro level. Given the relative independence of academies and free schools, and the demise of local education authorities in recent years, the challenge for consistency in the way new government policy or initiatives are implemented is clear. As Cuban (2018) puts it, 'there is no Mission Control for school reform' (p.63). Similarly, the integration of technology in lessons is heavily influenced by the subject taught (Selwyn, 1999). Younie & Leask (2013) make a distinction between political initiatives and policy in that initiatives do not necessarily compel schools to act. Initiatives such as NGfL and NOF (see section 2.1.1) saw widespread engagement, but lasting impact was harder to define.

Where early policy largely related to resourcing schools, Cuban (2018) suggests that new policy needs to embrace the notion that 'it's not about the technology, it's about the learning' (p.57). He notes that the provision of examples of how technology is used is not the same as providing examples of 'success' in student learning. Webb & Cox (2004) confirm that it is not enough to simply know *about* emergent technology but that teachers need to be helped to consider its potential contribution to learning. They do acknowledge, however, that 'enabling teachers to adapt their pedagogical reasoning and practices in response to learning opportunities provided by technology is likely to be a very difficult and complex process' (Webb & Cox, 2004, p.278). Cuban (2018), however, asserts that the goal of technology integration is to make it 'routine and transparent' (ibid. p.194) as it supports learning goals, a sentiment reminiscent of the Stevenson report in which technology was likened to electricity in the way that it might become 'no longer a talking point but taken for granted' (Stevenson, 1997, p.4).

The goal of future policy should be to create a culture of competent and considered use, gauged by evaluation of concomitant improvement in pupil outcomes. In additional to performative measures, it is important that responsible technology use promotes safeguarding and information security. Watson (2001) suggests that 'a vocational and pedagogic agenda could co-exist and complement each other, but only with an overt and comprehensive policy that recognises the validity of both and resources schools accordingly' (p.261). Technology, she argues, is not a catalyst for change, but remains a tool; a sentiment that requires ongoing commitment by policy makers to intervention 'with educational ideas, not simply technological ones' (p.264).

Future policy, despite inevitably being shaped by government priorities, funding, international trends and lobby groups (Starkey, 2012), should allow those who enact it at the meso and micro levels to assume ownership of change and pedagogical responsibility rather than dictating how technology is used in schools. This study has demonstrated that consideration of technology at the pedagogical level supports transformation of practice, and it is suggested that, while the government continues to support development of infrastructure and encourage innovative practice, school leaders and teachers be empowered to bridge the gap between policy and practice at a local level both in subject teaching and broader student experience.

6.2.2 Schools and professional development

Lawson & Comber (1999) identify three types of school:

- Integrative – in which ICT is integrated into programmes of study with planned implementation. Senior leadership are supportive, with a forward-looking ICT policy
- Adjunct – in which ICT is seen as an addition to curriculum, driven by limited number of enthusiasts with unsustained support from SLT and a reactive ICT policy
- Opportunistic – in which indifference by teachers leads to minimal technology use. There is limited support by leadership with little planning for whole-school ICT

The importance of headteachers who can promote an ethos that embraces technological change is therefore seen as central to success. Where headteachers do not profess to be experts, effective use of distributed modes of leadership are seen as powerful (Younie & Leask, 2013).

Key requirements identified by Younie & Leask relating to effectively led technology integration include:

- Change is more effective when all teachers are involved
- Shared vision and recognition of potential barriers to implementation
- Effective modelling of practice
- Formation of communities of practice
- Commitment to developing and maintaining effective infrastructure with clear responsibilities and support

Cuban (2018) recognises the importance of engaging all stakeholders in embedding practice, suggesting that 'achieving policy aims requires leadership, political support, resources, technical assistance, staff development, and cooperation between administrators and teachers' (p.5). Key to success is addressing the 'barrier of fixed assumptions and settled tradition' (Somekh, 2002, p.108). Selwyn (2013) notes that engaging with and integrating educational technology is a messy process, but Starkey (2012) reinforces the importance of the individual agency of teachers within the broader goals of schools as they enact policy. She asserts that learning occurs best 'on the edge of chaos' (p.5), a sentiment that echoes the importance of validating the 'deep play' advocated by Koehler et al (2011) in earlier consideration of developing teachers' TPACK.

The features of effective practice bulleted above, can be fostered through the sort of professional development developed in this study which seeks to engage, situate and share new knowledge and practice, suggesting that a significant contribution to effective technology integration at school level will be fostered by commitment to professional development. These goals and current reality are, however, somewhat at odds.

In 2017, the Teacher Development Trust (TDT) reported that over 20,000 teachers worked in schools with no budget for professional development of staff (Weston, 2017). UK secondary schools are reported as spending an average of 0.37% of their annual budget on CPD (ibid.) compared to 10% in what are argued as high performing school systems such as Canada (Clay, 2013). The TDT assert that spending on CPD contributes to pupil achievement as well as recruitment and retention of quality staff but recognises that such spending is often first in line when budget cuts are called for.

Cuts to CPD budgets at times of austerity have been described as 'counterproductive, short-sighted and evidence-averse' (Weston, 2017). At the same time, the DfE suggested that school funding was at the highest recorded level and implied that the blame regarding apportioning budgets lies squarely with headteachers (Coughlan, 2017).

With such tension between intention and budgetary constraints, new models of professional development are required that move away from the traditional notion of teachers 'going on a course' in addition to the statutory expectation of whole-school 'training days' to fulfil perceived requirements for in-service training (INSET). Some schools have addressed the need for ongoing training through menus of twilight activities or bite-sized 'TeachMeets' argued, respectively, as being inefficient and 'happy go lucky' (McGill, 2017). There is an ongoing need for teachers to have more professional conversations over a longer period of time than existing modes of CPD offer, and a responsibility for school leadership to facilitate such opportunities (Cordingley et al, 2015).

The design of the professional development activity inherent in this study aligns with the recommendations contained within the DfE Standard for Teachers' Professional Development (DfE, 2016) and findings suggest that the extended approach which fuses both face-to-face expert delivery and peer discussion/coaching with periods of self-directed application and follow-up does foster both motivation and impact. The growth suggested in all areas of Professional Capital suggests good value related to external time input (and therefore budgetary commitment). It is therefore recommended that schools encourage and facilitate such professional learning communities based around aspects of practice seen as important to teachers.

Whilst many professional subject associations have long extolled the virtue of research -informed practice, the increasing profile of the Chartered College of Teaching has played a role in making the concept of evidence-informed teaching more visible and asserting the value of such activity on professional learning (Stoll et al, 2018). Again, there is clear recognition that senior leaders play a key role in establishing a culture of research-informed practice in schools and actively encouraging collaborative research within and beyond the school (Coldwell et al, 2017).

TPACK, based on the findings from this study, represents a valuable theoretical perspective with significant potential to foster powerful reflection by teachers on their practice relating to their use of technology to support learning. In combination with the professional development approaches described, this is offered for consideration by practitioners although it is recognised that for maximum potential for roll-out, the commitment of school leaders is important to create the time and freedom needed for teachers to personally invest. Similarly, leaders must recognise the control they have over contextual factors that can help or hinder integrated pedagogy (Chandra, 2016).

An additional consideration arising from the findings of this study concerns the need for further exploration of the role of handheld devices and the licence afforded to students by schools to make use of their own devices. A culture of 'bring your own device' is endemic in Higher Education. Schools perhaps now have a duty to work towards creating a culture of appropriate use and conduct in classrooms so that the advantages of handheld devices can be exploited to better effect in children's learning. This, however, must take place in the face of current resistance as exemplified by the current Chief Inspector of Ofsted who claims that technology contributes to low-level disruption, backs heads who see banning handheld devices as the answer and suggests that 'the place of mobile phones in the classroom seems to me dubious at best' (Turner, 2018). Avoiding the need to help students to learn to self-regulate may, however, be counterproductive in terms of supporting the development of digital literacy. It is reassuring, however, that this debate is still live.

6.2.3 Teachers

For teachers, the implications of this study revolve largely around the issue of empowerment. This study reinforces that professional development which teachers can relate to their daily practice and exploit to attend to needs they themselves identify during reflective practice empowers them as agents of change.

The toolkit of resources created includes the TPACK assessment tool which, although needing further exploration in terms of its capacity to identify changes in practice, has demonstratable capacity to generate results that might be used diagnostically to support discussion regarding which aspects of a teacher's practice might be worthy of focus to support development of TPACK as a whole during targeted activity. A perceived relatively low score in the TCK domain might, for example, suggest that an important part of subsequent CPD activity would include exploration with colleagues of the variety of opportunities or resources that might exist to support delivery within a specific topic area. A low score for TK might recommend that paired activity might be of use in school to support the potential impediment that operational skills might present.

Despite the financial constraints of school budgets, the findings do support recommendations for collegial approaches to CPD and that these merit, at least in part, some face-to-face activity as well as the opportunity for application in the classroom. A sequence of professional development events for theoretical input and follow-up activities, interspersed with practitioner application, appears to provide a meaningful compromise between the financial commitment required by external training and the lack of focus of which twilight training was accused above.

Independent phases of activity were usefully supported by the T-CoRe which scaffolded the independent thinking previously enacted in groups using, for example, the TPACK game. The provision of structure and the expectation that participants report back to the group appear to foster engagement and accountability that sustain the activities over an extended CPD project as recommended by the DfE Standard and other sources. The inclusion of opportunities for collaboration and discussion render the activities valuable in terms of the human capital they can foster and the

opportunity to tap into the human capital of others. Whilst the number and pattern of collaborative and independent activities might be subject to further investigation, a hybrid approach is endorsed for ongoing teacher professional development activity.

6.2.4 Initial teacher education

Mouza (2016) suggests that there is still little research about preparation for technology integration by new teachers in teacher education programmes. Like much of the TPACK literature, this relates to a U.S. perspective but there is little to suggest that the situation in UK initial teacher education programmes is any different. Indeed, US teacher preparation accreditation includes a standard dictating that these programmes include a focus on technology allowing trainees to model and apply the use of technology in planning, teaching and assessment to the benefit of both learning and professional practice (Borthwick & Hansen, 2017).

Although technology can be applied to many aspects of the UK teachers standards, there is no specific mention of its application and the removal of an ICT skills test as a prerequisite for entry to teacher training might be regarded as downplaying its importance. It might therefore perhaps be argued that there is now an unwritten responsibility on the part of teacher educators in the UK to develop new teachers' skills and beliefs so that this can be enacted during and beyond their formal training.

Voogt et al (2016) make a distinction between what they term 'espoused' TPACK and 'in-use' TPACK (p.40) suggesting that the former represents TPACK fuelled by existing knowledge and skills and that the latter is a product of experience. That beginning teachers may have strong operational skills and implied espoused TPACK but limited 'in-use' TPACK due to a 'lack of repertoire for teaching with technology' (ibid.) reinforces the need to ensure that trainees are exposed to the requisite thinking to enable them to make a running start in terms of their pedagogical consideration of technology.

The use of the toolkit of activities and the inclusion of pedagogical consideration of technology within course tasks has challenged even those beginning teachers who are

self-professed power users of technology to consider the 'why' and not simply the 'how' of technology use in the classroom. It is therefore ventured that the toolkit of resources created and used within this project might be of interest and value to the wider Initial Teacher Education community to support new teachers' pedagogical integration of technology.

6.3 Original contribution

In the introduction, I suggested that this study had potential to make an original contribution in three areas: contribution to the body of literature surrounding the assessment of TPACK; demonstrating that TPACK could be operationalised in teacher development; and to contribute a UK perspective to TPACK literature which currently is dominated by overseas contexts.

6.3.1 Assessment of TPACK

The model of data collection, analysis and presentation afforded by the TPACK assessment tool developed during this study is offered for further scrutiny, use and development. Problems relating to the 'fuzziness' associated with the TPACK subdomains, as commonly reported within TPACK research, have been encountered but steps to address this in the assessment tool have shown that it is possible to adapt tools to good effect and improve the focus of statements used to assess these to the benefit of both users' ability to distinguish the domains in practice, and the validity of measures of self-reported confidence. The linear relationship demonstrated between TPACK and its constituent subdomains has, to my knowledge, not been previously indicated and raises questions about the academic merit of attempting to quantify inherently fuzzy measures. These considerations might usefully add to the ongoing debate in the TPACK literature regarding not just how to measure the construct but also the extent to which measurement has any practical purpose. One potential indicator derived from this study advocating assessment might be the potential to assess and visualise TPACK as a diagnostic upon which to personalise professional development.

6.3.2 Operationalisation of TPACK in teacher development

TPACK has demonstrated significant benefit as a vehicle by which to foster deep reflection on practice both for established and beginning teachers. A shared understanding of TPACK can foster highly productive, supportive and challenging dialogue between teachers which can help overcome some of the intrinsic and extrinsic barriers that contribute to 'TPACK inertia' and limit development of practice beyond the liminal states in which teachers may operate. Key to this are the patterns of thinking promoted and scaffolded by the structured professional development described; thinking, here dubbed 'TPACK thinking'.

The resources developed for use during this project have each demonstrated potential to stimulate TPACK thinking. In combination, as an innovative professional development intervention, the assessment/diagnostic tool, the TPACK card game, and the T-CoRe are offered as having potential to lead to transformation of practice.

6.3.3 A UK perspective

The tools developed here are explored in the context of UK teachers and trainee teachers. The assessment tool was developed from Archambault & Crippen (2009) which was originally devised for use with online educators in the United States and required recontextualization to reflect the curriculum and language within which UK teachers operate. Given the body of literature reflecting somewhat negatively on the state of integrated technology use in UK education, it is hoped that the materials developed here can be offered to support ongoing professional development activity for UK teachers as well as being open for further modification as required by the wider TPACK community.

6.4 Limitations of the study

Assertion that TPACK does indeed have practical application and transformative potential is based on the perspective gained from cohorts of trainee science teachers and a small group, although suitable for the purposes of this study, of experienced teachers. The groups involved offer a degree of perspective triangulation although it is acknowledged that the numbers can offer only a limited degree of what Jones (1998) termed 'satisfaction'. Further studies in this area either by myself or other researchers will add the perspective of an increased number of teachers to support concrecence or offer contradiction of findings as the body of experienced teachers upon which the judgments are so far made increases.

That much larger numbers of trainee teachers could be recruited to support evaluation of the tools was a distinct advantage. A slight tension existed between the time available to each cohort of trainees and the potential for eliciting demonstrable change. This does, however, support the notion of extended professional development experiences for serving teachers as something worthy of further exploration.

The study involved teachers and trainee teachers of science. In addition to my having good access to science teachers, science is a particularly rich subject in terms of the potential value of technology integration.

Science teachers may or may not be representative of the wider population of teachers and, as such, generalisation can only be offered in the context of science teachers with speculation that others will find the same tools of equally significant use.

6.5 New directions and next steps

Voogt et al (2013) reported that TPACK was a cause for significant ongoing scholarly debate given that its theoretical appeal was evident and limited by capacity to measure it. This probably still holds true. Suggestions that the way forward with TPACK would be in terms of its capacity for operationalisation (Polly & Brantly-Dias, 2009) still represent a challenge into which I hope I have made some inroads. There is clearly further to go.

The potential of TPACK as a vehicle for professional development has been demonstrated in the context of science teaching. It would seem prudent to seek to share findings beyond the science community and offer the tools created for evaluation in other subject areas to determine whether it meets their specific needs with minimal modification.

Having demonstrated the transformative potential of TPACK, there is still plenty to explore. The T-CoRe has proven useful but the quality of the introduction given and weight placed upon it has resulted in differing levels of engagement with different groups of trainee teachers. Although improved over successive cohorts, an optimal form of introductory activity is worth seeking to support the efficacy of the tool itself.

The use of the TPACK assessment tool and the visualisation afforded by the use of radar diagrams appears to lend itself to more considered use as a diagnostic at the start of an extended professional development activity. Whether this has potential for development into a module as part of a practice-based masters course may be worth exploration but the assessment tool, minus the expectation to identify domains, could easily be used prior to training so that this information can be gained in advance of face-to-face elements of training since this version of assessment requires no prior knowledge of TPACK or how domains can be defined.

The apparent difference in quantitative outcomes for experienced and beginning teachers has given rise to speculation regarding levels of conscious or unconscious competence/incompetence which affects participants' perceptions of their abilities before and after use of the toolkit in professional development. Whilst suggesting that quantitative measures might be misleading and it not entirely clear what the metric was measuring, results appeared to be consistent within each group which suggests that there is more to find out about how the needs of these separate groups might be identified and met to help each rise to the challenge of integrated pedagogy.

The value of extended professional development activity affording both opportunities for collaboration and personalisation of activity in a work-related context appears to lead to the potential for impact suggested by convergence of the literature explored in this research. It is hoped that this study therefore lends practical weight to the ideas

expressed in other such convergent literature, e.g. DfE (2016a), van Driel (2012) and Twining (2013).

6.6 Final conclusions

It is my hope that this thesis documents the learning journey made, not only in terms of the study undertaken directly, but of the philosophical and methodological journey involved in development of the study. Becta (2003) suggested that effective use of technology in the classroom would be contingent upon planning, preparation and pedagogical consideration and it is hoped that the study described here goes some distance towards realising this ambition.

It has been demonstrated that TPACK has transformative potential which can lead teachers from what, as expressed by Vescio et al (2008, p.88), can be seen as knowledge of practice to knowledge for practice. Through its operationalisation as suggested and explored in this study, TPACK can provide a medium through which pedagogy and digital literacy can fuse to form an integrated pedagogy.

TPACK thinking has potential to exert influence beyond formal professional development activity. The impact and ongoing potential for transformation of practice due to TPACK-inspired professional development is best summarised in the words, during interview, of one of the participants in this study, Teacher A, to whom the final words of this study are given:

‘I think it’s made me a better teacher…
using technology by looking in the middle.’

7 Appendices

Contents:

7.1 Appendix 1: TPACK assessment tool

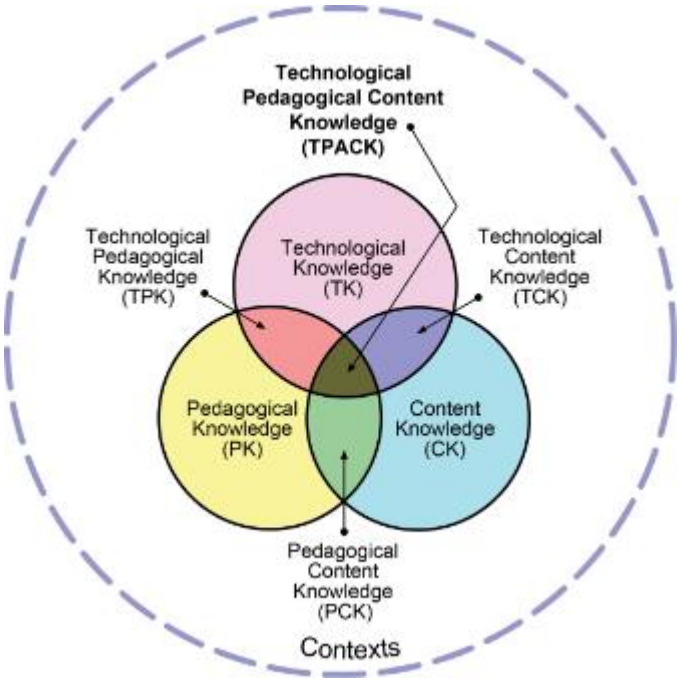
You and your TPACK **Name:**

_____

For each statement in the table below:

a) Assign a level to indicate your confidence in relation to your classroom practice

b) Suggest the TPACK domain to which you think the statement relates



		My confidence level is: 1 (low) to 5 (high)	I think this belongs to the domain… (PK, TK, CK, TCK, PCK, TPK or TPACK)
A	My ability to troubleshoot technical problems associated with hardware (e.g. network connections)		
B	My ability to interpret specific statements in the National Curriculum		
C	My ability to use a variety of teaching strategies		
D	My ability to articulate age-appropriate learning objectives		
E	My ability to use online assessment tools to inform future planning as part of Assessment for Learning		
F	My ability to design tasks so that I can distinguish between correct and incorrect problem solving attempts by students		
G	My ability to address various computer issues related to software (e.g. downloading appropriate plug-ins, installing programmes)		
H	My ability to use technology to meet the needs of different students		
I	My ability to anticipate likely misconceptions within a particular topic		

		My confidence level is: 1 (low) to 5 (high)	I think this belongs to the domain… (PK, TK, CK, TCK, PCK, TPK or TPACK)
J	My ability to choose classroom strategies to meet students' needs		
K	My ability to use technology to assess students' skill/understanding of a particular topic		
L	My ability to implement different methods of teaching using ICT		
M	My ability to make links between ideas in different parts of the curriculum		
N	My ability to manage students' use of ICT during a lesson		
O	My ability to use technology to present subject matter in different ways		
P	My ability to inspire confidence in the use of ICT by students		
Q	My ability to assist students with troubleshooting technical problems with their computer/tablet		
R	My ability to use a variety of approaches to assess students' learning		
S	My ability to interpret curriculum documents to produce lesson plans which satisfy curriculum learning objectives		

		My confidence level is: 1 (low) to 5 (high)	I think this belongs to the domain… (PK, TK, CK, TCK, PCK, TPK or TPACK)
T	My ability to use technological representations (e.g. multimedia, visual demonstrations, simulations) to support the teaching of specific concepts in my subject specialism		
U	My ability to assist students in noticing connections between various concepts in a curriculum		
V	My ability to use technology to access additional resources related to the curriculum		
W	My ability to use technology to create effective representations of content that depart from textbook knowledge		
X	My ability to use/adapt ICT resources to help students achieve intended learning outcomes		
Y	My ability to choose the most appropriate teaching strategy for a particular concept		
Z	My ability to use technology to find resources which relate to curriculum content		

Please note that your name will not be included in any publication or materials arising from the use of this questionnaire. Your name is only asked for so that any change in practice arising from the project can be tracked.

Thank you for your participation.

7.2 Appendix 2: Adaptation of published resources

1. Leanna Archambault as first author of Archambault & Crippen (2009), relating to adaptation of the questionnaire.

Sent: 28 September 2015
Dear Leanna,

I am currently studying for a doctorate in education whilst teaching in the School of Education here in Leicester, UK. My thesis revolves about ways in which TPACK can be operationalised to provide meaningful professional development experiences for teachers relating to their use of ICT as a pedagogical tool.

One of the tools I am developing involves a survey instrument to allow teachers to articulate their competence in TPACK subdomains and to assess their ability to recognise these domains pre- and post-intervention.

Of the tools suggested in the literature, I would like to adapt the statements suggested in the paper you produced (Archambault, L., & Crippen, K. (2009). Examining TPACK among K-12 online distance educators in the United States *Contemporary Issues in Technology and Teacher Education*, *9*(1), 71-88) so that they reflect the context in which I am working, namely face-to-face professional development activities with UK teachers.

As a point of courtesy, I wanted to seek permission to include reference (credited appropriately) to the survey items you identify as the source adapted to allow me to develop an appropriate tool. It would seem ethically more sound to be able to add 'adapted with permission' rather than suggesting originality on my part.

I hope that is acceptable? I'd be happy to answer any questions you have.

With many thanks and best wishes,
Jon

Received: 29 September 2015
Dear Jon,
Thanks for your email and request. Yes, I would be happy for you to use/adapt our instrument as part of your doctoral research. The suggested citation (APA format) is
Archambault, L. M. & Crippen, K.J. (2009). Examining TPACK among K-12 online distance educators in the United States. Contemporary Issues in Technology and Teacher Education, 9(1). Retrieved from
http://www.citejournal.org/vol9/iss1/general/article2.cfm

Best wishes with your graduate work!
Leanna

Leanna Archambault, Ph.D.
Associate Professor
Arizona State University
Mary Lou Fulton Teachers College

2. Pamela Mulhall as first author of Mulhall et al (2003), relating to the adaptation of Content Representations (CoRes) into Technology CoRes (T-CoRes).

Sent: 28 September 2015
Dear Pamela,

I am currently studying for a doctorate in education whilst teaching in the School of Education here in Leicester, UK. My thesis revolves about ways in which TPACK can be operationalised to provide meaningful professional development experiences for teachers relating to their use of ICT as a pedagogical tool.
One of the tools I am developing involves developing Content Representations which specifically reflect the subdomains within the TPACK model.
As a point of courtesy I wanted to seek permission to include reference (credited appropriately) to the PCK CoRes you developed with colleagues at Monash as the source adapted to allow me to develop technology CoRes.
It would seem ethically more sound to be able to add 'adapted with permission' rather than claiming ownership.

I hope that is acceptable?
I'd be happy to answer any questions you have.

With many thanks and best wishes,
Jon

Received: 29 September 2015

Dear Jon,

I have consulted with my colleagues, John Loughran and Mandi Berry, and we are all very happy for you to go ahead as outlined in your email.

Good luck in your research!

Best wishes,

Pam

--

Dr Pam Mulhall
Faculty of Education
Monash University
AUSTRALIA

3. Matt Koehler, creator of the TPACK game

Sent: 4 December 2016
Dear Matt,
Firstly, thank you for the inspiration to undertake my doctoral studies in the area of educational technology. It is proving a fun challenge looking at ways to operationalise the TPACK model.

My research relates to the use of TPACK as a vehicle for teacher professional development and the creation of a toolkit of resources to scaffold thinking and teacher ownership.
I based a card activity on your TPACK game for one of the professional development sessions I ran recently and was delighted with the discussion this afforded when used collaboratively.
I would very much like to refer to this in my thesis and descriptions of my project - and wonder, if attributed appropriately, if you would be happy with this?

Very many thanks and best wishes,
Jon

Received: 4 December 2016

Thanks for the kind email. Of course you can use / cite it! I suggest citing this:

http://www.matt-koehler.com/the-tpack-game/

Thanks,

Dr. Matthew J. Koehler

Professor

Michigan State University

Web: http://matt-koehler.com/

7.3 Appendix 3: TPACK Content Representation (T-CoRe)

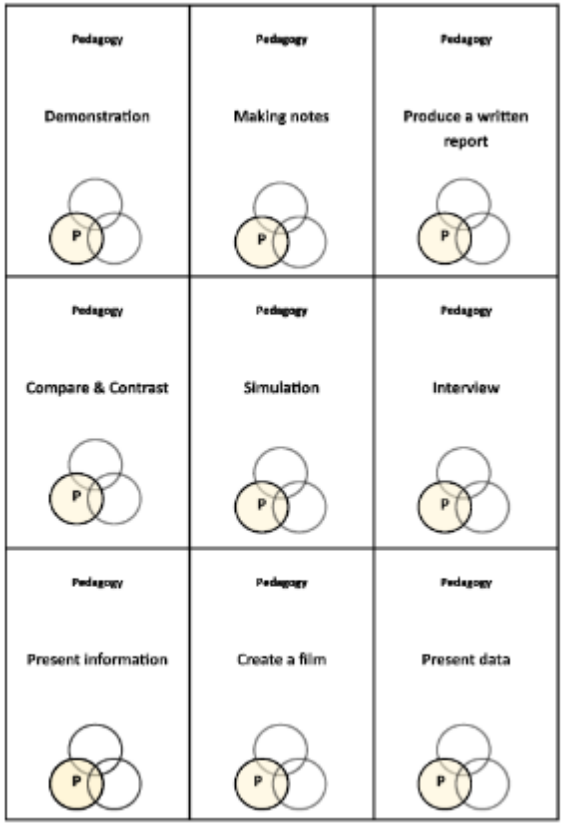
Domain	Consider…	ILO 1	ILO 2	ILO 3
CK	Why is it important that students know this? (e.g. skills, curriculum links)			
CK	What do you know that you do not intend students to know yet?			
PCK	Difficulties associated with teaching this idea			
PCK	Likely misconceptions or student difficulties			

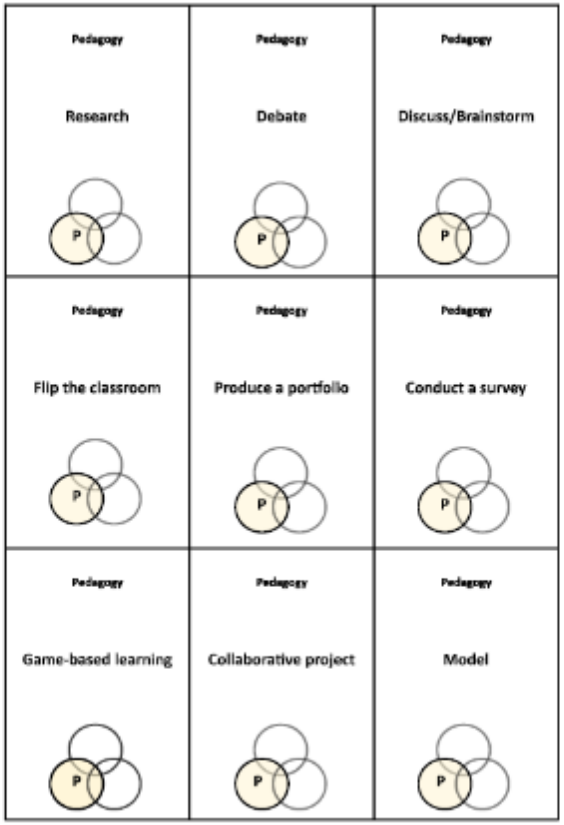
PCK	How will you know students have achieved this Intended Learning Outcome?			
PCK	Other factors influencing your teaching of this idea			
PCK	Opportunities for 'Working Scientifically'			
PCK	Opportunities for assessment activities (formative/summative)			
PK	Proposed teaching strategy (and reasons for using them to engage with this idea)			

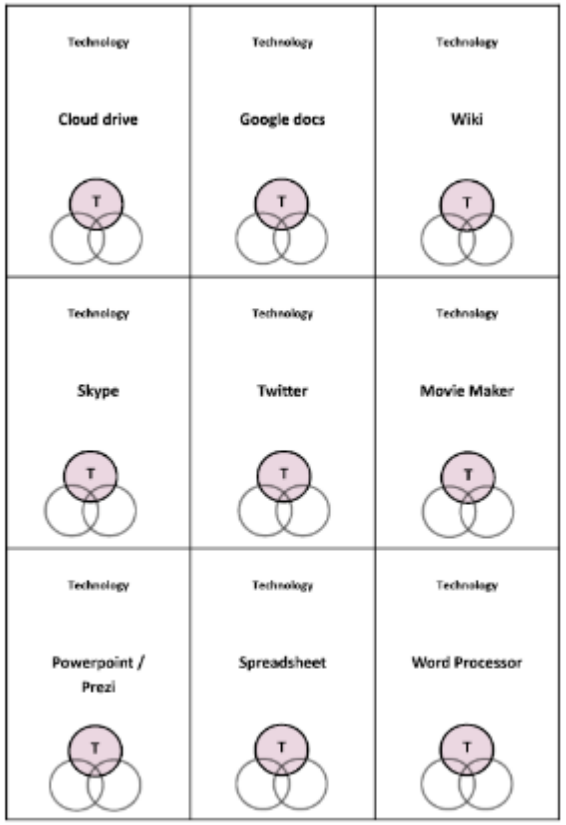
TPK	Forms of technology that may be useful to develop students' ideas about this			
TCK	How your knowledge of the technology may affect its use in class			
TPACK	What forms of technology best suit the learning needs of your students for these ideas?			
TPACK	Why is your chosen tool, particularly suitable for achieving this ILO with your students?			
TK	What do you need to do to become confident using this technology?			

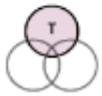
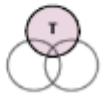
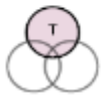
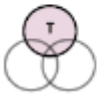
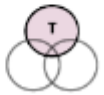
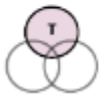
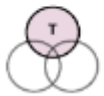
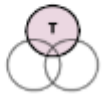
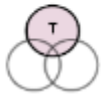
TPK	How will you need to prepare students to use the technology selected?			
TPK	What additional challenges are likely when using this technology in the classroom?			
TPK	How will you plan to mitigate these challenges?			

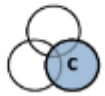
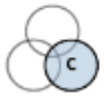
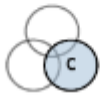
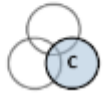
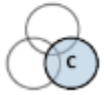
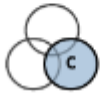
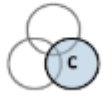
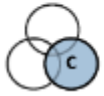
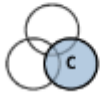
7.4 Appendix 4: TPACK card game

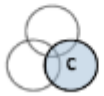
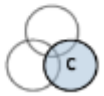
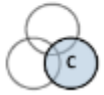
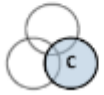
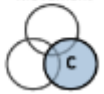
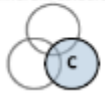
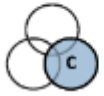
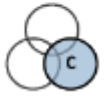






Technology Web Browser 	Technology Screen Capture 	Technology Sensors / Datalogger 
Technology Voting system 	Technology Coding 	Technology Animation software 
Techology Webcam / Phone camera 	Technology Augmented Reality 	Technology Shockwave Flash 

Content Describe the pros and cons of nuclear power 	Content Explain how blood flow is one-directional in veins 	Content Explain why sound cannot travel in a vacuum 
Content Prove that green leaf extract contains more than one pigment 	Content Explore how vaccination has affected life expectancy 	Content Find out whether left-handed people are more likely to have blue eyes 
Content Assess whether dinosaurs were more like reptiles or birds 	Content Compare the effectiveness of different insulators against heat loss 	Content Argue who you think the most important scientist who ever lived was 

Content Plan an investigation to identify the optimum temperature for salivary amylase 	Content How would you convince the public that wifi signals are harmless 	Content Develop a group theory about why we have an appendix 
Content Explain the various stages of a sewage treatment works 	Content Describe how the gut and cardiovascular system are linked 	Content Demonstrate how muscles and bones work together to cause movement 
Content Explain to someone in another country how fireworks can be different colours 	Content Given the base sequence for a virus, calculate how many fragments digestion with different restriction enzymes would create 	Content Demonstrate the conservation of momentum 

7.5 Appendix 5: Interview schedule

Interview schedule

End-of-project interviews will be semi-structured, consisting of (a) some standard questions relating to the research questions as well as (b) some stimulated recall discussion relating to the participants' use of the T-CoRe.

Final questions may evolve based on interim discussions about the practicalities of the T-CoRe and the aspects chosen by participants on which they will base their action research.

N.B. Throughout the project, the term 'educational technology' is used in a manner synonymous with 'technology enhanced learning', as opposed to what we are terming 'classroom technology' which can serve a purely administrative purpose.

A) Standard questions:

For the purposes of an interview focused on the four research questions articulated in the ethical approval submission and appended here, and to ensure interview times do not generate unwieldy amounts of data, ten questions are suggested.

1. How do you think engaging with TPACK has supported the development of your approach to the use of educational technology? (RQ1)
2. How do you think engaging with TPACK has challenged the development of your approach to the use of educational technology? (RQ1)
3. How useful was the TPACK questionnaire in stimulating thinking about the ways in which you use educational technology? (RQ1)
4. You completed the TPACK questionnaire twice. How do you feel your performance against the different TPACK domains may have changed? (RQ1, RQ2, RQ4)[1]

[1] This can then be discussed further using visual results afforded by analysis of individuals' questionnaires

5. The two introductory sessions were approached in different ways (one through individual study and the second through group tasks). What were the benefits and challenges of each approach? (RQ3)
6. How useful were T-CoRes in scaffolding your thinking about your use of educational technology? (RQ1, RQ4)
7. Did you work with another colleague on your T-CoRe(s)? Why/why not? If so, how useful was this approach? (RQ1, RQ2, RQ3)
8. How has your practice changed in respect of the area you chose for your action research activity? What will/can you do next with this new practice? (RQ1, RQ4)
9. How useful do you think consideration of TPACK might be for colleagues' professional development? Why? (RQ1, RQ3, RQ4)
10. Do you have any suggestions about how the professional development experience provided by this project might be improved? (RQ1, RQ4)

B) Stimulated recall discussion:

Questions will form prompts during discussion about individual participants' use of the T-CoRe during the action research component of the project, again under the umbrella of the four component research questions, RQ1-RQ4.

These may include:

(General)

- Were any aspects of the T-CoRe harder to engage with than others? Why?
- Were any changes made to the questions used to scaffold TPACK thinking to make the T-CoRe easier to work with? Why?
- If sections have been left blank – why? Explore understanding of the domain articulated by the statement and whether different wording may be helpful.
- Which sections were most useful to stimulate thinking about the pedagogical affordances of selected forms of educational technology?
- Were T-CoRes used collaboratively? Who with? How useful was this?
- What was the most useful aspect of working with the T-CoRe?
- What suggestions would you make regarding the use of T-CoRes in future?

- Do you think you will make use of the T-CoRe in future?

  (Content specific)

- Given the selected topic/concept covered by the T-CoRe, why were the selected pedagogies chosen?
- Can you explain how the selected technology contributes to the pedagogical aims set out in the T-CoRe?
- How did you set about developing the skills (yours or students') needed to deliver the content successfully?
- To what extent did the learning by students support your decision to include this form of educational technology?
- How important was the T-CoRe in leading you to make use of this form of educational technology in the classroom?

Research questions:

How can teachers be encouraged to take ownership of professional development regarding their use of educational technology?

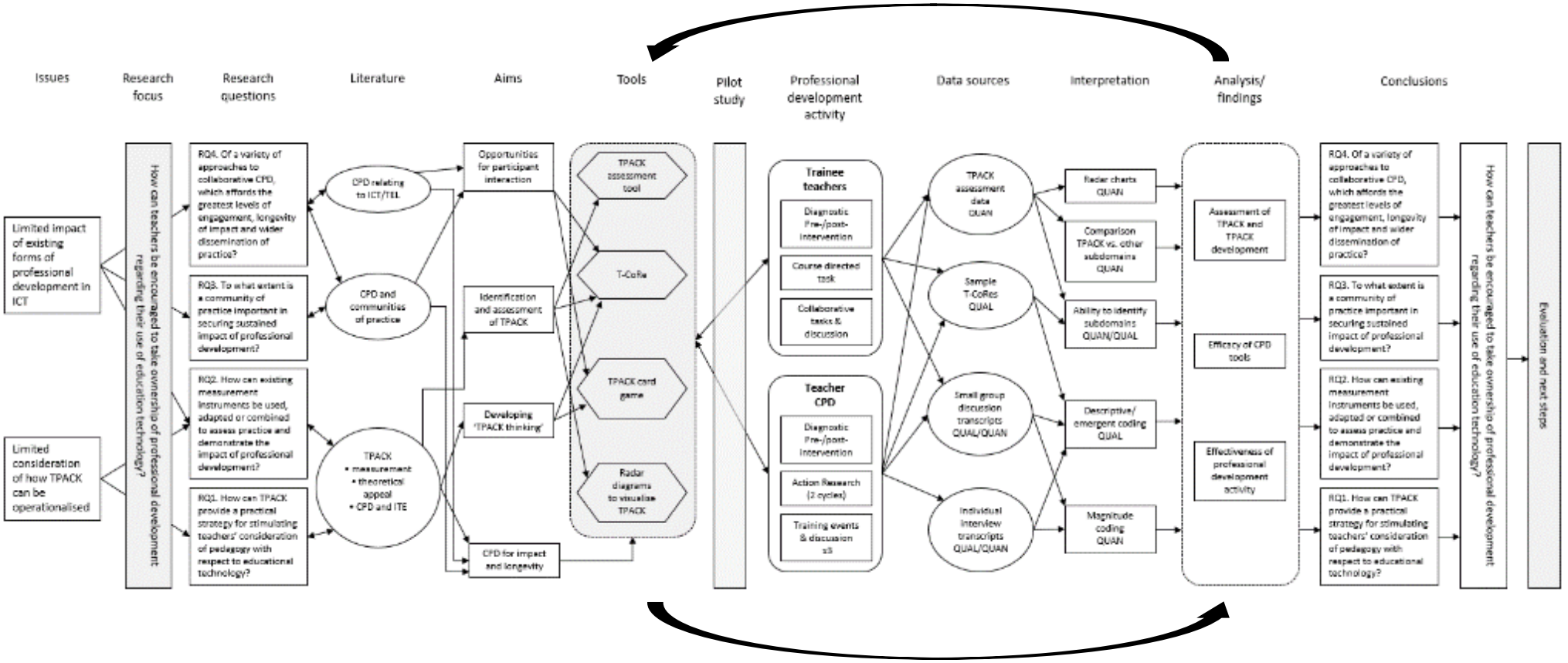
RQ1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology?

RQ2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development?

RQ3. To what extent is a community of practice important in securing sustained impact of professional development?

RQ4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination

7.6 Appendix 6: Research flowchart



7.7 Appendix 7: Coding table

Code	Relevance to research questions	Inclusion criteria	Example	
Questionnaire				
Q-2	RQ1 RQ2	Statements relating to success of assessment tools	Strong positive comment	
Q-1	RQ1 RQ2		Positive comment	
Q-0	RQ1 RQ2		Neutral comment/unsure	
Q-NEG	RQ1 RQ2		Negative comment	
Q-REC	RQ1 RQ2	Suggestions for development	Would be better if…	
Q-QUOTE	RQ1 RQ2	Statement that concisely captures issue relating to this idea		
Q-INTERPRET	RQ1 RQ2	Statements regarding interpretation of the items on the questionnaire	I wasn't sure…	
T-CoRe				
TCORE-2	RQ1 RQ2 RQ4	Statements relating to success of assessment tools	Strong positive comment	
TCORE-1	RQ1 RQ2 RQ4		Positive comment	
TCORE-0	RQ1 RQ2 RQ4		Neutral comment/unsure	
TCORE-NEG	RQ1 RQ2 RQ4		Negative comment	
TCORE-REC	RQ1 RQ2 RQ4	Suggestions for development	Would be better if…	
TCORE-QUOTE	RQ1 RQ2 RQ4	Statement that concisely captures issue relating to this idea		
TCORE COLLAB	RQ1 RQ2 RQ4	Reference to actual/potential for collaborative use of T-CoRes	e.g. ref to use within department planning	
TCORE-DIFFICULTIES	RQ1 RQ2 RQ4	Statements highlighting difficulties relating to the use of T-CoRes		
TCORE-INTERPRETATION	RQ1 RQ2 RQ4	Statements highlighting ease/difficulty interpreting questions on T-CoRes		
TCORE-ORDER	RQ1 RQ2 RQ4	Statements addressing/challenging order of questions presented on T-CoRe		
TCORE-POTENTIAL	RQ1 RQ2 RQ4	Statements identifying potential benefits of further use of the T-CoRe		
TCORE-PROCESS	RQ1 RQ2 RQ4	Statements emphasising process vs. product as of greatest importance when using T-CoRes		

TCORE-REFLECT	RQ1 RQ2 RQ4	Reference to reflection (annotated or otherwise) about use of T-CoRe	e.g. changed mind about item or perception of importance of item	
TCORE-TIME	RQ1 RQ2 RQ4	Reference to the time taken to complete the T-CoRe		
TCORE USEAGAIN	RQ1 RQ2 RQ4	Reference to being likely/unlikely to use T-CoRes again in future	I would use this [in this way]…	
TCORE-USEFULNESS	RQ1 RQ2 RQ4	Statements relating to usefulness of the T-CoRe document		
Professional development activities				
CPD-2	RQ1 RQ3 RQ4	Statements relating to success of professional development activity	Strong positive comment	
CPD-1	RQ1 RQ3 RQ4		Positive comment	
CPD-0	RQ1 RQ3 RQ4		Neutral comment/unsure	
CPD-NEG	RQ1 RQ3 RQ4		Negative comment	
CPD-REC	RQ1 RQ3 RQ4	Suggestions for development	Would be better if…	
CPD-QUOTE	RQ1 RQ3 RQ4	Statement that concisely captures issue relating to this idea		
CPD-CARDGAME	RQ1 RQ3 RQ4	Ideas related to use of the card sorting activity		
CPD-PROBLEMS	RQ1 RQ3 RQ4	Identification of potentially problematic issues surrounding CPD		
TPACK framework				
TK	RQ1	Clear demonstration of/reference to TK	Statement about use of IT	
TCK	RQ1	Clear demonstration of/reference to TCK	Awareness of IT related to content	
CK	RQ1	Clear demonstration of/reference to CK	Clear reference to subject knowledge	
PCK	RQ1	Clear demonstration of/reference to PCK	Statement linking pedagogy and content	
PK	RQ1	Clear demonstration of/reference to PK	Identification of broad teaching strategy	
TPK	RQ1	Clear demonstration of/reference to TPK	Statement about how IT supports learning	
TPACK	RQ1	Clear demonstration of/reference to TPACK	Statement links T, P and C.	
UNDERSTANDING	RQ1	Reference to ease/difficulties associated with interpreting the TPACK framework		
CONTEXT	RQ1	Reference to broader issues of context affecting implementation of TEL	Personal/institutional/demographic ideas beyond immediate barriers	

DATA	RQ1 RQ2	Ideas relating to interpretation of data from the shared results of questionnaires	Reference to pre/post results and their interpretation	
FUZZY	RQ1	Reference to difficulties differentiating domains in the TPACK framework	What's the difference between…	
TPACK INERTIA	RQ1	Reference to resistance to change	Reasons offered for sticking with existing/preferred strategies	
Other general themes				
COLLAB	RQ3	Reference to collaborative activity	Statement about working with others	
THINK	RQ1	Reference to thinking	Statement about thinking provoked (except 'I think…')	
USEFULNESS	RQ1 RQ4	Reference to usefulness	Comments about usefulness of activity	
QUESTIONS	RQ1	Reference to questions raised	Identification of questions raised by process	
BARRIERS	RQ1 RQ4	Reference to barriers to use of ICT	Identification of barrier that limits use	
AFFORDANCES	RQ1 RQ4	Identification of specific affordances of ICT (not linked to differentiation or engagement)		
AfL	RQ1	Reference to Assessment for Learning or success criteria		
ALTERNATIVES	RQ1 RQ4	Demonstration of thinking about alternative methods		
BARRIERS OVERCOMING	RQ1 RQ4	Reference to solutions trialled or suggested to address identified barriers		
BENEFITS-PARTICIPANT	RQ1 RQ4	Identification of benefits of participating in the project		
BENEFITS-STUDENTS	RQ1 RQ4	Wider benefits of TEL to students	e.g. peer-assessment, peer tutoring, differentiated work, independence	
CHALLENGE	RQ1 RQ4	Challenge in discussion between participants	e.g. 'Can you…?', 'Could you…?', 'You could…'	
CHAMPION	RQ3 RQ4	Reference to the importance of a 'champion' practitioner to share practice/motivate colleagues	e.g. 'No-one knows how to use it…'	
CHOICE	RQ1	Justification made of particular choices		
CONTINGENCY	RQ1	Reference to planned contingency to pre-empt technical difficulties	e.g. 'I put lots of countermeasures…'	
DEVELOP CONFIDENCE	RQ1 RQ4	Identification of how confidence has been affected by particpation		

DEVELOP PRACTICE	RQ1 RQ4	Identification of how aspects of practice have changed or plans to further practice in future		
DIFFERENTIATION	RQ1	Statements identifying differentiation as a specific outcome of planned use of TEL		
DIG-LIT	RQ1	Statements making specific reference to teachers' or students' digital literacy		
ENGAGE	RQ1	Statements identifying engagement as a specific outcome of planned use of TEL		
FEEDBACK	RQ1 RQ4	Feedback between participants	e.g. affirming practice, encouraging	
FUSION	RQ1 RQ4	Participants in group discussion combine ideas from different areas		
IMPACT	RQ1 RQ4	Statements revealing impact of activities undertaken [Possible overlap with DEVELOP PRACTICE – check on 2nd coding]		
ITERATIVE	RQ1 RQ4	Reference to iterative use of TPACK in cycles of activity	e.g. action research	
LEARNING	RQ1	Specific reference to learning afforded by use of technology		
MOTIVATION	RQ1 RQ4	Identification of intrinsic/extrinsic motivation for engaging with technology or the research project		
NEXT STEPS	RQ1 RQ4	Reference to planned next steps in the light of activity undertaken	e.g. dissemination of activity	
OTHER QUOTE		Statement that concisely captures ideas not directly related to the tools/activities captured in other coding areas		
OWNERSHIP	RQ1 RQ4	Statements evidencing ownership of, or personal investment in, activities chosen/planned		
PLAY	RQ1 RQ4	Reference to curiosity-driven exploration of pedagogical affordance of types of technology		
PREP	RQ1 RQ4	Reference to the importance of preparation or practice prior to use of technology in a classroom situation		
QUESTIONS	RQ1 RQ4	Questions raised by participants whilst undertaking 'TPACK thinking'		
RELEVANCE	RQ1 RQ4	Reference to need for relevance to own working context		
RISKS	RQ1	Identification of risks associated with using technology in teaching		
SPECULATION	RQ1 RQ4	Thinking about future affordances of technology	e.g. 'One day we might be able to…'	
SUCCESS		Identification of factors likely to contribute to successful outcomes	e.g. willingness to take risks; the notion of 'buy-in'	

7.8 Appendix 8: Ethical approval

University Ethics Sub-Committee for Sociology; Politics and IR; Lifelong Learning; Criminology; Economics and the School of Education

28/04/2016

Ethics Reference: 5542-jph40-education

TO:

Name of Researcher Applicant: Jonathan Heywood

Department: Education

Research Project Title: How can teachers be encouraged to take ownership of professional development regarding their use of educational technology?

Dear Jonathan Heywood,

RE: Ethics review of Research Study application

The University Ethics Sub-Committee for Sociology; Politics and IR; Lifelong Learning; Criminology; Economics and the School of Education has reviewed and discussed the above application.

1. Ethical opinion

The Sub-Committee grants ethical approval to the above research project on the basis described in the application form and supporting documentation, subject to the conditions specified below.

2. Summary of ethics review discussion

The Committee noted the following issues:

Thank you for your application which is now in order.

3. General conditions of the ethical approval

The ethics approval is subject to the following general conditions being met prior to the start of the project:

As the Principal Investigator, you are expected to deliver the research project in accordance with the University's policies and procedures, which includes the University's Research Code of Conduct and the University's Research Ethics Policy.

If relevant, management permission or approval (gate keeper role) must be obtained from host organisation prior to the start of the study at the site concerned.

4. Reporting requirements after ethical approval

You are expected to notify the Sub-Committee about:

- Significant amendments to the project
- Serious breaches of the protocol
- Annual progress reports
- Notifying the end of the study

5. Use of application information

Details from your ethics application will be stored on the University Ethics Online System. With your permission, the Sub-Committee may wish to use parts of the application in an anonymised format for training or sharing best practice. Please let me know if you do not want the application details to be used in this manner.

Best wishes for the success of this research project.

Yours sincerely,

[redacted]

Chair

7.9 Appendix 9: Participant consent

Thank you for your interest in participating in this project. I hope you will find it both interesting and useful.

In order to give your informed consent to participation, please read the aims below:

The over-arching aim of the research project can be summarised as:

How can teachers be encouraged to take ownership of professional development regarding their use of educational technology?

To explore this, you will be asked to participate in a programme of professional development activities involving some group activities at the university and a small piece of action research in school. As we evaluate these activities later in the year, it is hoped we can answer some of the more focused research questions below:

RQ1. How can TPACK provide a practical strategy for stimulating teachers' consideration of pedagogy with respect to educational technology?

RQ2. How can existing measurement instruments be used, adapted or combined to assess practice and demonstrate the impact of professional development?

RQ3. To what extent is a community of practice important in securing sustained impact of professional development?

RQ4. Of a variety of approaches to collaborative CPD, which affords the greatest levels of engagement, longevity of impact and wider dissemination of practice?

You will be asked to participate in 4 twilight events across the academic year (2015-16) and to collect evidence of your practice and reflection in school. This will not detract from time devoted to lesson content in school but will focus on the pedagogy involved.

Any materials collected or shared during the project will be anonymised in any publication deriving from this work to protect the identity of participants and schools.

Participant consent:

I freely consent to participating in the project and understand that the anonymity of myself, my pupils and school will be preserved in any publication arising from this work. I understand that I have the right to withdraw at any stage.

Participant name: _____ Signature: _____

Headteacher consent:

I consent to the involvement of the above in the CPD activities described above and action research to be undertaken in my school. I understand that the anonymity of the school and any individuals involved will be preserved in any publication arising from this work.

Headteacher name: _____ Signature: _____

School: _____

7.10 Appendix 10: Extract of discussion during use of the card game

Teacher B: Explain how blood flow is one directional in veins. Ah…now that's a very good one.. cos kids don't get that… and it's very… I always make drawings on the board so it's quite a good idea to think about what kind of model you could use to show that. So I think that it would be quite interesting to use animation software and make something with the animation software to show what actually happens – rather than having to draw it on the board all the time – and really think about how can I make that visible in a way that they really understand it. Can they, with the animation software, can they just try to make the blood flow in the vein? And why can it only go one direction – so there would be quite a long time to work on that and if you make a resource like that, then it needs to be something that is really working and that you can use all the time

Teacher C: But I also imagine you could actually access pre-made animations of…

Teacher B: So you need to look for that first. So you need to do some research on that.

Teacher A: I think that's useful if there's a particular way that you've always drawn it that helps them - then there might not be something so specific to the way that you do it..that you could use it again and again

Teacher B: no – the thing is if I can draw it well and they all get it, I don't need it do I? It's only useful if they touch it and do something with it so that they really get it which they can't do with my drawing – so that's the idea of the animation software I think, where they can play with it

Teacher A: there'll always come a point where your diagram won't work with a certain class so you've got to change your idea, you've got to introduce it in a different way. So I think you should not have one way of explaining how that works and there needs to be another way for them to find that out. So this could be one way… Could you do anything else with that. You could do a demonstration of something – never thought about that…now talking about it. Do a demonstration of something that has…that you can push something up and then you get… and it has like valves in the tubing

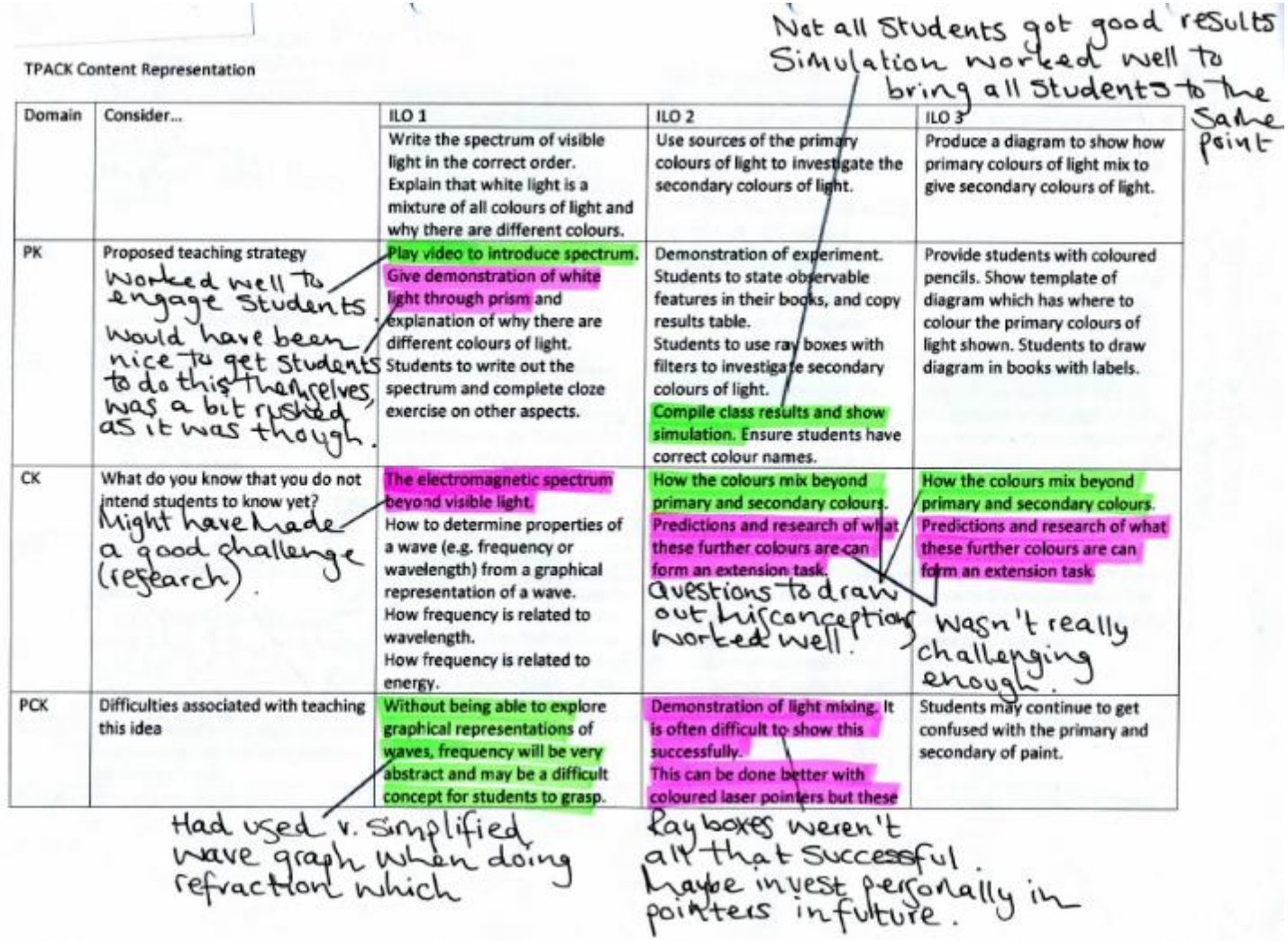
Teacher C: I'm trying to think of an object that has a one-way valve system in it

Teacher B: But that would be really useful and you could film that if it's difficult – and then you could show the film of that and talk with the film. So for that you would use Movie Maker. So the demonstration, if it's a difficult demonstration, you can film it. So you use phone camera and you use movie maker to help that… So this is quite a lot more than I've ever done with that…but it's very interesting to think about how you could make that work and make it more… they can better imagine what is really going on there… and it's quite a complex idea. Can you think of anything else? So you need a simulation.

Teacher C: I don't think in this scenario you necessarily thought how can technology help solve this problem, you just thought what is the best way…

Teacher B: But what is the best way. I actually think this is a good question cos I think so many kids don't get this. And that's where we need to start thinking about how can we use technology to help them understand it better.. can we really do that and it's a matter of taking some time and taking the risk of time and energy into that… it might not work and then you need to think why it didn't work. Is that because of my design of how to use the technology or don't they get it anyway? Because some concepts are very difficult for kids and it depends on which age they are – but once you make this you can use it at every key stage, can you not? And it makes you really think about what actually is important here, rather than just a few sentences you always quickly use to explain it.

7.11 Appendix 11: Example of an annotated T-CoRe



TPACK Content Representation

Domain	Consider...	ILO 1 Write the spectrum of visible light in the correct order. Explain that white light is a mixture of all colours of light and why there are different colours.	ILO 2 Use sources of the primary colours of light to investigate the secondary colours of light.	ILO 3 Produce a diagram to show how primary colours of light mix to give secondary colours of light.
PK	Proposed teaching strategy Worked well to engage students. Would have been nice to get students to do this themselves, was a bit rushed as it was though.	Play video to introduce spectrum. Give demonstration of white light through prism and explanation of why there are different colours of light. Students to write out the spectrum and complete cloze exercise on other aspects.	Demonstration of experiment. Students to state observable features in their books, and copy results table. Students to use ray boxes with filters to investigate secondary colours of light. Compile class results and show simulation. Ensure students have correct colour names.	Provide students with coloured pencils. Show template of diagram which has where to colour the primary colours of light shown. Students to draw diagram in books with labels.
CK	What do you know that you do not intend students to know yet? Might have made a good challenge (research).	The electromagnetic spectrum beyond visible light. How to determine properties of a wave (e.g. frequency or wavelength) from a graphical representation of a wave. How frequency is related to wavelength. How frequency is related to energy.	How the colours mix beyond primary and secondary colours. Predictions and research of what these further colours are can form an extension task.	How the colours mix beyond primary and secondary colours. Predictions and research of what these further colours are can form an extension task.
PCK	Difficulties associated with teaching this idea	Without being able to explore graphical representations of waves, frequency will be very abstract and may be a difficult concept for students to grasp.	Demonstration of light mixing. It is often difficult to show this successfully. This can be done better with coloured laser pointers but these	Students may continue to get confused with the primary and secondary of paint.

Not all students got good results Simulation worked well to bring all students to the same point

Questions to draw out misconceptions worked well.

Wasn't really challenging enough.

Had used v. simplified wave graph when doing refraction which

Ray boxes weren't all that successful. Maybe invest personally in pointers in future.

			might not be available.	
PCK	Likely misconceptions or student difficulties Could have emphasised this more.	Students may have heard the song that goes, "red and yellow and pink and green..." and think that this is the spectrum. Students may think that different wavelengths of light must have different speeds.	Students will be familiar with the primary and secondary colours of paint and may struggle to grasp that these are different for light. No such students in this class.	Student will be familiar with the primary and secondary colours of paint and may struggle to grasp that these are different for light.
PCK	Other factors influencing your teaching of this idea Vast majority had good knowledge from primary school.	How well students remember the spectrum from primary school, or whether all of them covered it.	There may be colour-blind students. If there are the teacher must work with these students to explain what is being seen during the practical.	There may be colour-blind students. If there are the teacher must work with these students to explain what is being seen during this work.
TPK	Forms of technology that may be useful to develop students' ideas about this Great way to engage.	YouTube video of a song about the spectrum to introduce the order of the colours and engage. Leave this on in the background. Was very valuable as there were issues with some practicals. All brought to same point.	Simulation to show students after they have completed the practical. This could be used to reiterate ideas or as a backup plan in the case of a failed experiment.	Diagram template and complete diagram can be projected onto the interactive whiteboard. This way accurate representations of the colours can be shown, which would be difficult to do with whiteboard pens and expensive with colour printing.
TCK	How your knowledge of the technology may affect its use in class This preparation meant that there were no technical issues!	Ensure that all videos are downloaded prior to the lesson in case it is either not possible to access internet, or websites are blocked in school. Embed these into PowerPoint for ease, and set to play in a loop in this case. Also check sound before lesson.	Ensure that you are comfortable with the simulation before the lesson so that no time is wasted in getting it to work. If possible download it before the lesson in case it is either not possible to access internet, or websites are blocked in school.	Ensure that PowerPoint is working and the file hasn't been corrupted/damaged before the lesson. Be sensible and save it in more than one place.
TPACK	What forms of technology best suit the learning needs of your students for these ideas?	Videos.	Simulations (e.g. from PhET).	Images embedded into PowerPoint.
TPACK	Why is your chosen tool,	Songs can help students	Students will either receive	The colours will be more vibrant

mentioned that this was incorrect.

Saved time and provided accurate colours.

	particularly suitable for achieving this ILO with your students?	remember sequences of information. YouTube has many free resources such as these. was perhaps the most valuable application of technology.	validation that their results are correct or be able to see the intended outcome. This	on the interactive whiteboard than on printouts or if attempted to draw on the whiteboard. This will hopefully make them stick out in students' minds better.
TK	What do you need to do to become confident using this technology?	Download video prior to lesson. Check sound before lesson. All done successfully. ✓	Practise using the simulation. Download it prior to lesson. ✓	Check PowerPoint before lesson. ✓
TPK	How will you need to prepare students to use the technology selected?	No preparation required.	No preparation required.	No preparation required.
TPK	What additional challenges are likely when using this technology in the classroom?	Danger of video still not playing, even when it has been downloaded. Complete failure of laptop or interactive whiteboard.	Danger of simulation not working even after preparation. Complete failure of laptop or interactive whiteboard.	Complete failure of laptop or interactive whiteboard.
TPK	How will you plan to mitigate these challenges? Luckily non of these were necessary.	Learn song and sing it yourself! Will also be using other memory aids such as "Richard of York..." and ROYGBIV.	Prepare an alternative. Screenshot certain parts of the simulation and put these into PowerPoint so that key points are still accessible. Be confident that you can explain the phenomenon without the use of technology.	Be prepared to draw the diagram on the board and to label colours if appropriate coloured pens are not available. Print out one copy of the final diagram beforehand. Check if diagrams are present in textbooks for self-assessment.

Planning for the use of technology in this TPACK made me consider how I could best use technology to benefit students' learning much more carefully than I perhaps would ~~use~~ usually.

As the practical did not go 100% as planned the use of the simulation was extremely useful in providing the intended results when it may not have been possible otherwise

7.12 Appendix 12: T-CoRe (T3.i)

Domain	Consider…	ILO 1	ILO 2	ILO 3
		Speed - how we measure/calculate it.	What the graphs look like and how we calculate speed from a distance/time graph.	How this knowledge about speed enables us to understand acceleration.
CK	Why is it important that students know this? (e.g. skills, curriculum links)	Calculations (maths skills), practical applications - improving running using light gates, speed cameras.	New curriculum focussing on graph and maths skills. Interpreting graph from data logger into 'what it actually means'. AO3 - use of data logger e.g. Buggy/downloadable activity tracker data would be perfect for analysis.	Precursor to suvat equations - furthering maths, applications to F1, athletics etc. Instead linked to acceleration due to gravity.
CK	What do you know that you do not intend students to know yet?	That the speed is influenced by other forces/factors and may not be constant. That velocity is speed in a direction.	Speed/time and acceleration/time graphs (Ext work?). Difference between vector and scalar quantities. N/A at KS3.	Speed/time and acceleration/time graphs. Difference between vector and scalar quantities.
PCK	Difficulties associated with teaching this idea	Introduction of the equation and how to understand where the equation comes from. Measuring something very fast eg light. Re-arranging equations. Concept of 'average' speed	Using ticker tape for example introduces acceleration (which some students may be okay with, whilst others are not, differentiated support). N/A	Stretching/differentiation. Hard concept of acceleration graphs looking different again to speed/time graphs. In reality, only d-t graphs required at KS3

PCK	Likely misconceptions or student difficulties	That speed is the same as acceleration. Confusion with increasing distance = faster. Next time I wouldn't have introduced that if the time is bigger then the speed gets smaller relating to equation - too abstract.	That acceleration is speed/time so why the graphs look different eg curve/line. This they found very challenging - ticker timer/buggy would have been very useful in demonstrating this.	That s is used as a scalar for speed as well as a vector for distance. Not covered at all in KS3 spec.
PCK	How will you know students have achieved this Intended Learning Outcome?	Students will be able to successfully calculate speed from a variety of practical methods and compare their efficacy. Students achieved this as part of report write-up or in feedback where this was not the case. All students practised this using levelled questions (MA rearranged equation to find answer).	Students will be able to create a 'graph' from ticker tape, understanding why the pieces increase in size as the car moves down the ramp. They will then repeat their experiments from the day before (or use the data collected) to see if the speed was constant or if there was acceleration (+/-). Nice idea and good for lack of IT...if the school has a working ticker timer. Could not find a way around this one and as a result, I instead related acceleration to gravity to lead briefly on to terminal velocity as requested by class teacher. Would have liked to have filmed a falling object next to a metre stick in class and then used footage to work out the distance each second together and plot a graph of data, although the projector could not be seen by half the class and was too unreliable for me to be comfortable with using it (link to TK).	'Where would this be used in context? Create a job advert for someone who will calculate speed and/or acceleration as part of their job (made up or real), research and finish off for homework.' ...OR... Write up the evidence for acceleration, convincing a group of people of its existence. (Earth is not flat) Would have liked to have incorporated this into literacy/computer literacy in Science working on laptops in class although not available in class and found out I was behind so needed to move on.

PCK	Other factors influencing your teaching of this idea	Practical element - understanding the relationship between speed, distance and time. I think that the way I taught this was too abstract for most.	Differentiation for maths skills required - mixed ability groups, differentiated tasks or help sheets which students have access to. Availability and working order of ticker tape/sensor car. The levelled qs WS was good, no equipment.	Differentiation for maths skills required - mixed ability groups, differentiated tasks or help sheets which students have access to. Availability and working order of ticker tape/sensor car.
PCK	Opportunities for 'Working Scientifically'	The problem with measuring speed over a distance (the assumption that someone is moving at a constant speed). Comparing the efficacy of each method. Focussed on 'precision', 'accuracy' and 'validity'.	Predicting what would happen if the ramp were made steeper. Context of graphing.	Report writing/learning to evidence theory.
PCK	Opportunities for assessment activities (formative/summative)	Annotated screenshots of prac work submitted via email. Write-up of findings from speed experiment and efficacy of different methods. Written report of speed investigation.	Describe and explain the digitally produced graphs. Tried to imitate this using student walking across the classroom and back and drawing out a d-t graph, then students drew what they thought would happen if they walked faster/slower/carried on walking. Described and explained graph of this.	See activities above.

PK	Proposed teaching strategy (and reasons for using them to engage with this idea)	Videoing someone running over a specified distance (must consider knowing the distance), using stopwatches (con of reaction time), suggest other ways? Investigation. Carried out the investigation using stopwatches or phones if they could justify using them. Realised after that they shouldn't have been allowed to use their phones.	Making a graph using ticker tape. Using a buggy with an accelerometer and analysing the graph. Using boardworks to show relationship between car moving and graph produced. Unfortunately none of these were options available to me due to lack of working technology. Instead, I drew a curve on the d-t graph and asked them to figure out what was happening.	Build on previous lesson's work by comparing distance/time, speed/time and acceleration/time graphs. Ideally, graph paper projected on board, draw s/t, calculate v draw new line, calculate a, new line Not on KS3 spec, also no option to draw using projected graph paper - instead students used laminated graph paper and whiteboard pens and I attempted to draw straight lines on the board - projected graph paper would have improved this greatly.
TPK	Forms of technology that may be useful to develop students' ideas about this	Using video on iPads. Using light gates. Using mobile devices/fitness trackers to compare their accuracy. Not available / shouldn't have been used - mobiles were used as they could more accurately and precisely measure the time e.g. that a wind-up toy took to cover 1m.	Boardworks, buggy. Not available.	Interactive board. Not available.

TCK	How your knowledge of the technology may affect its use in class	I'm not sure how to get speeds from fitness trackers or mobile devices eg efficacy of gps tracking for measuring speeds of runners. N/A	Can embed boardworks into ppt although smart board very small and hard for students to see. Board too unreliable - freezes, doesn't load up, doesn't load programs so was not confident to try to use it for teaching. Buggy connected to laptop/computer and graph produced can be printed out for students to analyse. N/A	Ensure that I don't accidentally delete a line or am able to save lines to alleviate confusion before comparing them. N/A
TPACK	What forms of technology best suit the learning needs of your students for these ideas?	Students can use own devices or school iPads to video someone running. They could also measure the speed of a classmate running (or a remote control car) using light gates or stopwatches. If students are able to, I see no problem in them using fitness trackers as an alternative means of gathering data. N/A	Buggy if available. Boardworks best method, along with ticker tape first manual and then each group inputs speeds into excel and printed out - first calculate the speed by distance/time. Graph printed out from whole class or individual results. N/A would have used own device i.e. iPad/laptop to input data but no ticker tape, buggy, or multiple sets of equipment (1 ramp to e.g. roll ball down to record times at different distances - not time efficient).	Graph paper on whiteboard. Use ticker tape or buggy results for comparison and calculations. Differentiated because groups can be split up with HA calculating acceleration whilst MA calculate speed. Also, LA buggy group can develop interpolation skills by reading off graph. N/A - See above relating to acceleration and gravity.

TPACK	Why is your chosen tool, particularly suitable for achieving this ILO with your students?	Offers numerous extension tasks which can be accessed through their own curiosity and require a further complexity in numeracy skills. Students enjoyed carrying out speed investigation.	Focus on graph interpretation whilst giving the context of the graph. Students would definitely have benefited from seeing buggy moving down slope and curve on d-t graph drawn in real time.	Easily differentiated with stretch activity for maths skills. Digitally produced graph makes for easy comparison and modelling interpretation. Levelled maths, interpolation perhaps I could have lined up students, getting each to stop stopwatch when runner passed them. However, very easy to make errors.
TK	What do you need to do to become confident using this technology?	Dependent on the presence of fitness trackers - I would ask students to show me how they get the data off them! N/A	Practice using buggy/ticker tape. Test whether Boardworks works on ppt. N/A	Practise. N/A
TPK	How will you need to prepare students to use the technology selected?	Very little - show students that they will need to film before the runner crosses the line (ask them why - reaction time, to account for acceleration/runner moving at constant speed etc). Covered accuracy, precision and use of video so discussed the way students might use devices.	Demo both, written instructions for ticker tape. Leave excel spreadsheet open on computer - check students' awareness with IT dept. N/A	N/A

TPK	What additional challenges are likely when using this technology in the classroom?	Requires outside/use of gym or hall and a tape measure. Risks of students using own devices. No iPads available and students not allowed to use their own devices in the school.	Buggy to track speed not available. Boardworks may not work (animation instead?). Projector unreliable, no working IWB, students can't see tiny projector screen.	IWB not working - back-up plan! Also, no access to IWB of decent size.
TPK	How will you plan to mitigate these challenges?	On a day when the hall or gym is free at the same time as the class/decent forecast. Film speed of person walking in corridor. Students split up as much as possible - two running outside, one walking down the corridor, others classroom-based.	Try boardworks - use straight from shared area. 33 students in class so no room to move students so that they can see board.	Have taped together graph paper on floor/do as group activity on A3 laminated graph paper. Not practical with size of group and layout of the room.

7.13 Appendix 13: T-CoRe (T3.ii)

Domain		ILO 1	ILO 2	ILO 3
		Describe the appearance of the heart and its associated blood vessels ✓	Explain why the heart is made up of two adjacent pumps ✓	Explain how the structure of the heart is related to its functions ✓
CK	Why is it important that students know this? (e.g. skills, curriculum links)	Important for identifying structures in the heart, which is a pre-requisite of understanding the cardiac cycle and the pressure changes in later lessons. Also links to how its structure links to function (ILO 3)	To show/demonstrate to students the role of pressure in the cardiovascular system, links to thickness of walls in capillaries and drop in pressure after lungs.	Students often asked how the heart is adapted to function in exam questions, especially about left ventricle adaptations.
CK	What do you know that you do not intend students to know yet?	Reasoning for coronary arteries seen on outside of heart → link to CV disease in later lessons ↳ ended up finding out about this in extension work.	↳ Saw sequence, not named as yet. The sequence of the cardiac cycle (both sides pumping simultaneously) and the pressure changes involved during cycle	Elasticity of Aorta → recoil leads to rise in pressure. Knowledge about how and why valves close (higher pressure against flow forces closure).

PCK	Difficulties associated with teaching this idea	Difficult to students to visualise as a concept as a whole, students used to 2D structure. Lots of different diagrams and visualisations of the heart available, lots of different names e.g. atrioventricular valve vs. bicuspid valve. → overcame this well.	Students may lack understanding of importance of vessel structure and pressure in cardiovascular system. → This was the case, had to link it back to alveoli function	Requires good understanding of structures of the heart prior to linking to function → This was combatted by meeting this LO last.
PCK	Likely misconceptions or student difficulties	Left/right confusions Red and Blue blood in difference sides of heart Lots of different names → a lot to learn and digest This was a problem as Anatomy 4D had this the opposite way round..!	One responded like this before discussion "the blood wouldn't be oxygenated enough" "One side pumps blood in, one side pumps blood out" "The left ventricle contains more blood than the right" ↳ addressed well.	"The left wall is thicker to prevent blood escaping through walls" "Blood is at higher pressure so the left needs a thicker wall" Valves cause blood to flow, rather than stop it flowing back → One student had this misconception

PCK	How will you know students have achieved this Intended Learning Outcome?	LO designed Kahoot questions, multiple choice answers ✓ Completion of labelled heart diagram ✓ Responses to questions following starter activity with Anatomy 4D app → Good. Made activity flow. Exam practise question	LO designed Kahoot questions, multiple choice answers ✓ Through discussion as a group. Explanations peer checked after discussion ✓ Exam practise question	LO designed Kahoot questions, multiple choice answers ✓ → Worked really well, data collected on progress. Identifying differences between atria and ventricles Researching function of valves and coronary artery Exam practise question
PCK	Other factors influencing your teaching of this idea	GCSE class found difficulty converting between different diagrams of the heart → give students practice looking at a few different diagrams to overcome this – Not so much an issue	Knowledge of why larger animals have a double circulatory system compared to smaller organisms Good opportunity to discuss and recap lungs	↳ Pushed to next lesson. Students have touched upon this in exam question → push for greater detail ↳ This was good & gave a good basis.
PCK	Opportunities for 'Working Scientifically'	Using correct terminology Using research to compare scientific models + observation	Opportunity for scientific debate → why is not a single circulatory system?	Observing differences (between ventricles/atria using an image of heart)
PCK	Opportunities for assessment activities (formative/summative)	Formative: Discussions, questioning, peer assess ✓ labelling of heart ✓ Summative: Kahoot, ✓ Practise Exam Questions ✓ ↳ Not enough time to mark in lesson ↳ Starter next lesson.	Formative: Discussions, questioning Summative: Kahoot, Practise Exam Questions	Formative: Discussions, questioning Summative: Kahoot, Practise Exam Questions

PK	Proposed teaching strategy (and reasons for using them to engage with this idea)	1) Students will look at a 4D model of the heart and identify: a) appearance b) sides of the heart using colour of blood indicator c) observing difference between left and right d) looking at the different vessels. This strategy will allow students to see the heart as a whole structure and describe its appearance. As defined in LO. 2) Students will then research the heart structure to then label a diagram of the heart on paper. This will allow them to see various images of the heart and translate these into completing a labelling task on another heart.	3) Students will watch an animation to demonstrate the double pump action of the heart. Students will then have an extended period to discuss why the heart needs two adjacent pumps. Discussion will be student led, and teacher will guide and correct if wrong or misconceptions occur. Finally the full explanation will be available on board and explained by teacher	1) As an extension to the LO1 task on heart research, some students will find out the function of the heart's valves and the function of the coronary artery. Answers will be discussed and students questioned on what each valve does. 4) Students will watch a second animation of the heart which more specifically shows atrial and ventricle wall action. Atria are thin, elastic and stretch as it collects blood. Ventricles are thick and muscular and pump then relax. Discussion and questioning to aid.

Students LOVED this.

Animation didn't aid answering of LO but did show action.

Task alongside grounded activity & focused "playing" well.

Good use of extension.

This was fine, questions about "why different diagrams" - which was good.

Discussion needed to be led by teacher as students struggled for ideas when.

↳ Questioned high achiever to get suggestion.

This was really good, students noticed this thanks to animation

TPK	Forms of technology that may be useful to develop students' ideas about this	iPads – Anatomy 4D – App produces excellent 4D image of the heart and students can explore different parts and remove certain sections iPads – Google images – Images of the heart structure will provide ***lots*** of different examples for students to see how different heart structures may look Kahoot questions at end	Animation showing oxygenated and deoxygenated blood being pumped through the body will show students the cardiac cycle. Good visualisation for those that did not understand cycle prior to lesson. Kahoot questions at end	Similar heart animation on continuous loop showing diastole, atrial systole and ventricular systole. This animation exaggerates the elasticity and stretching of atria, muscular wall of ventricles and action of the atrioventricular and semi-lunar valves Kahoot questions at end
TCK	How your knowledge of the technology may affect its use in class	Know how to use 4D anatomy to remove certain structures to look into heart. Have worked out through playing that you can look down the vessels and see the semi-lunar valves.	Knowledge of using google images to get animation using the tool section allows it to be embedded in a PowerPoint and loop continuously, rather than a video being clicked over and over.	Knowledge of using google images to get animation using the tool section allows it to be embedded in a PowerPoint and loop continuously, rather than a video being clicked over and over

Awesome! Students loved it, use as a starter, was perfect as students happy to move on.

No issues with this, did exactly what I wanted.

↳ One issue, 1 high ability didn't need Google so didn't look.

Didn't contribute to LO massively...

↳ However this did help some.

Brilliant, students enjoyed, data collected, misconception traps found & corrected.

↳ Perfect animation for this LO, students understood immediately

Students were grateful for this info & how best to do it, ie. what to remove first.

↳ Students struggled to do this.

Could I have found a more relevant image?

Knowledge of Kahoot – previous experience has seen that students rush when speed points are involved. Found a setting which means speed is irrelevant, therefore students can take time to choose answer, making the results more representative of knowledge.

↳ This is great → recommend. May only be well received in sixth form as competition element removed.

TPACK	What forms of technology best suit the learning needs of your students for these ideas?	Technology that provides a visual aid for the concept.	Technology that provides a visual aid for the concept	Technology that provides a visual aid for the concept, showing both structure and function's interaction.
TPACK	Why is your chosen tool, particularly suitable for achieving this ILO with your students?	It is an exciting and unique way to look at the 4D appearance of the heart without the use of a dissection. It is interactive and a brilliant visual aid for the topic. Using iPads, with a Google image search is a quick and easy way to get access to a diverse range of heart diagrams to help the students identify the key parts.	It gives a slow, repeating image of the double circulatory system for students to watch as many times as they like and digest, before attempting to discuss with their pairs. Particularly useful if students don't remember much from GCSE.	The animation gives the students the chance to look at an exaggerated model of the atria and ventricles, slowly and on repeat. Students can then make conclusions from their observations about the structure's relation to function.

Kahoot allows students to test their understanding with multiple choice questions, and give data afterwards to track student answers, so the teacher can check if they met the ILO. Questions are designed to test ILOs – if they get them right, they have met it, if they get it wrong, they can be corrected.

Only this animation would have helped!

Not that suitable for LO - but a useful animation for cardiac cycle, use again not lesson.

→ This was really good. It identified to me that one student struggled on naming → gave more practice qus.

TK	What do you need to do to become confident using this technology?	Practice use with iPads, the more time spent, the better. ↳ This helped identify which structures to remove first & how to see valves.	Using Google Image search regularly with the Animation tool filter. Be able to find best animations for the topic available through searching. ↳ Maybe look @ videos for this next time.	Using Google Image search regularly with the Animation tool filter. Be able to find best animations for the topic available through searching.
		Create Kahoots and test run them before lesson to check they are effective and answers are correctly selected. Continued use will improve use, such as rules for students when playing and decisions on whether a time bonus being available is detrimental to tracking.		
TPK	How will you need to prepare students to use the technology selected?	I will use AirPlay Mirroring to demonstrate how to use it in the introduction. I will do this again to show how to find the valve. → Unfortunately Air Mirroring didn't work! Had to describe instead. This was OK.	Give a brief description alongside the animation to explain what is happening. This will allow students to understand what the animation is showing. ↳ Had to go into more detail about where each vessel lead → lack of recall from previous lesson on double circulatory system.	Showing them the previous animation, then preparing them that this animation highlights a different part of the structure (atria and ventricles) specifically. Let students have time to observe and reflect on what they're seeing.

TPK	What additional challenges are likely when using this technology in the classroom?	Downloading the App onto the school's iPads system took a lot of organising with IT department If the student struggles with using app, then they may not get much value. Incorrect naming through using non-UK exam board terms by using Google images	Students not being able to link the visual image to what is happening.	Students not being able to link the visual image to what is happening.
TPK	How will you plan to mitigate these challenges?	Spoken to IT in advance and checked 2 times that all iPads had software. Give advice about best use e.g. put iPad on stand and move paper, not the iPad. Use AirPlay Mirroring so all can see benefit if struggling. Use peer marking to check they have the same answers and provide acceptable answers to avoid incorrect labelling.	Walk through each step with the students, highlight which points describe which part of the animation.	Walk through each step with the students, highlight which points describe which part of the animation.
		Kahoot – Book extra iPads. Ensure all iPads are working at start of lesson with students		

One student needed a lot of guidance

Checked well

What if AirPlay mirroring doesn't work? Gather round and show?

This worked well, all checked.

Day of the lesson had to fix one!

↳ This happened on this, needed more guidance

↳ Not an issue

Kahoot – All students will need one iPad each. Internet access problems will cause issue

↳ Students did not like that they weren't ranked. In this setting, correct answers didn't get points, so all were level...

Sucss!

7.14 Appendix 14: T-CoRe (Teacher B, 1st cycle)

TPACK Content Representation (T-CoRe) **Homework / Revision Task Transcription & Translation, KS5 Biology using Go-Lab**

Domain	Consider...	ILO 1	ILO 2	ILO 3
		To recall the basic overview of transcription and translation	To formulate questions based on the two processes for pupils in KS4 and KS5	To link the role of transcription and translation to other processes within a living organism
PK	Proposed teaching strategy	This has already been taught and the students need to summarise watching a YouTube film on transcription and translation. This task clearly need to be introduced for some students and maybe it is important to show the site and explain why this task needs to be done	In the previous lessons students have been asked to pose questions to each other at their own level. This is an open task to see how students write questions for KS4 students in particular. This also needs a short introduction, maybe a class task in which they practise this with a short evaluation about what would be good questions for KS4.	Students have been writing essays in which they needed to link processes using scientific terminology at KS5 level. Several strategies were used to help them develop writing like this, in particular the task of writing down any topic they can remember and all the keywords related to this topic and the definitions of those keywords. By the time students get to this task they become very short with their descriptions. Again in class it needs to be made clear how important this task is and what it needs.

CK	What do you know that you do not intend students to know yet?	The students don't need to know in detail how transcription factors work, but could eventually be introduced to the effects of oestrogen. They don't need to know more enzymes than DNA polymerase, RNA polymerase, helicase and peptidyl transferase. There are a lot more enzymes involved and maybe they want to know that it is RNA polymerase II which is mainly used for eukaryotic gene expression.	They don't need to know the complete syllabus of KS4 and the pedagogy needed for asking the right questions or setting the right tasks. It is mainly for their own understanding and the ability to explain something in simple words before going into detail. On reflection it appears to be quite important to know what kind of questions you can ask, so probably they need a bit more help with this (see above)	At this point the students need to know as much as possible about every topic and need to be able to relate all the different processes. This is a very demanding task. They can even score extra marks by knowing things outside the syllabus. They need to be told this task doesn't need to be done within a certain time limit and they are advised to read around the subjects during completing this task.
PCK	Difficulties associated with teaching this idea	Students find it difficult to summarise processes in the right order using the right scientific terminology and the meaning of keywords. Teaching by example giving several ways in which students can practise this are approached and a lot of differentiated questioning when working through an example. This is clearly needed. Most students need practice before starting this task. Although in the SOW there are quite a few summarising tasks it clearly needs more scaffolding.	Students are not used to asking questions at the right level for KS4 students and may need some help. The majority needs help with this, because otherwise the questions are too simple or too difficult. However, it doesn't really matter, as long as the students learn from this experience what they need to know and understand, and as long as they are able to state the obvious, something they often forget when they answer exam questions.	Students find it very difficult to link ideas. It is very important to give examples of how to do that and have Q&A sessions on possible ideas. It sometimes helps to collaboratively draw spider diagrams or concept maps to help draw out idea and consolidate knowledge and understanding.

PCK	Likely misconceptions or student difficulties	Student can mix up the terms transcription and translation. They find it difficult to remember all the required terminology and often forget the importance of using the word 'sequence' for both bases and amino acids. Students also often mix up the terms triplet and codon and forget to mention that a polypeptide sequence needs to undergo structure change to become a functional protein. They seem to struggle with the enzymes and their roles as well.	Students may think that KS4 students are more familiar with terminology than they are. They may not understand that is it not about the right level but more about whether they can actually explain a process in simple terms. This clearly appeared a key problem, stating the obvious first before using too much terminology.	Students don't necessarily have an overview of the syllabus and therefore cannot make the necessary links. They compartmentalise because of how the syllabus and the textbook are presented. As stated above, students didn't have the energy anymore to do this task properly and **need to be reminded**. It can be done later and doesn't need to be finished.
PCK	Other factors influencing your teaching of this idea	Students could work on this task together so that they can practise explaining to each other before writing anything in the required boxes. It is important that they can deal with long answer questions and explain processes step by step with a lot of detail. They also need to think about how to link processes.	By formulating questions for other students and thinking about what they know and those students don't need to know they have to really think about all the aspects of the processes they need to know about. It is similar to having to think about the pedagogy for this framework. In the future this task can be built up a lot more and it could be obligatory to work in pairs or even larger groups. They can check each other's questions as well.	For essay writing it is particularly important that the students can link ideas, using all the keywords and meanings and being able to describe processes, e.g. in this case the idea of complementary structures and the importance of proteins, either as receptors, hormones, antibodies, antigens or enzymes. This is just another way for students to practise this. Again it would be helpful if the students get time to discuss this first.

TPK	Forms of technology that may be useful to develop students' ideas about this	Animations are particularly useful because the structures involved are too small to film. Interactive simulation is probably even more helpful. The students preparing a powerpoint presentation using given structures and keywords to put in the right place. Online quizzes for recall of knowledge. Go-Lab enquiry space.	Using an Inquiry Space stimulates students to really think about what the main ideas are. It is also very useful to be able to give feedback as a teacher and make them think even more about this. They can log in as each other and look at each other's work without being able to copy it. They can even look at what feedback the teacher has given.	Using an Inquiry Space stimulates students to really think about what the main ideas are. It is also very useful to be able to give feedback as a teacher and make them think even more about this.
TCK	How your knowledge of the technology may affect its use in class	In this case the knowledge of how to use a Go-Lab framework for completing an inquiry space. Knowledge on how to find and use on-line resources in an effective way. A lot of time gets lost because of working out how to use the technology and making sure everything works.	The technology is mainly designed for independent work but I have already noticed that it may be a good idea to introduce everything in class before they start working with this and have at least a short Q&A session on what is expected. This has been discussed before and clearly is an issue.	Not really applicable for this particular learning outcome.
TPACK	What forms of technology best suit the learning needs of your students for these ideas?	They need a variety of technology but the most important are an animation and interactive simulation to visualise the processes and consolidate the learning.	Not really applicable for this particular learning outcome.	Not really applicable for this particular learning outcome.
TPACK	Why is your chosen tool, particularly suitable for achieving this ILO with your students?	The animation will consolidate their learning and should help them to write a clear and concise summary of the main processes.	The good thing about this Inquiry space is that students can go back to it and edit it, before or after teacher comments.	The good thing about this Inquiry space is that students can go back to it and edit it, before or after teacher comments. They can also look at other student's work.

TK	What do you need to do to become confident using this technology? Same for all LOs	I will need to create more inquiry spaces using more animations, simulations and boxes created specifically for Go-Lab, thinking creatively about what I can use that has already been used. I will need to collaborate with people who are more confident with using any on-line technology.	I will need to create more inquiry spaces using more animations, simulations and boxes created specifically for Go-Lab, thinking creatively about what I can use that has already been used. I will need to collaborate with people who are more confident with using any on-line technology.	I will need to create more inquiry spaces using more animations, simulations and boxes created specifically for Go-Lab, thinking creatively about what I can use that has already been used. I will need to collaborate with people who are more confident with using any on-line technology.
TPK	How will you need to prepare students to use the technology selected? Same for all LOs	All the students need is an email with instructions. It is important the instructions are clear. The students will need to have had good lessons on the topics using some of the PCK described above and making sure that describing clear summaries are modelled and scaffolded examples are given.	All the students need is an email with instructions. It is important the instructions are clear. The students will need to have had good lessons on the topics using some of the PCK described above and making sure that describing clear summaries are modelled and scaffolded examples are given.	All the students need is an email with instructions. It is important the instructions are clear. The students will need to have had good lessons on the topics using some of the PCK described above and making sure that describing clear summaries are modelled and scaffolded examples are given.
TPK	What additional challenges are likely when using this technology in the classroom? Same for all LOs	This is not in the classroom. The problem with using Go-Lab is that not all their software works how you want it to work and that the student task needs to be performed in Google Chrome (not all school computers have that installed) and doesn't always work well on an I-Pad. There are some strange ways of working that you easily forget. This means you can spend a long time trying to work it out again.	This is not in the classroom. The problem with using Go-Lab is that not all their software works how you want it to work and that the student task needs to be performed in Google Chrome (not all school computers have that installed) and doesn't always work well on an I-Pad.	This is not in the classroom. The problem with using Go-Lab is that not all their software works how you want it to work and that the student task needs to be performed in Google Chrome (not all school computers have that installed) and doesn't always work well on an I-Pad.

TPK	How will you plan to mitigate these challenges?	When doing this as a task in school make sure all computers have Google Chrome. Tell students to copy the link in Google Chrome or use another device if it doesn't work on an I-Pad (it usually does). Next time I will prepare a lot more in class to make sure the students can write a summary.	When doing this as a task in school make sure all computers have Google Chrome. Tell students to copy the link in Google Chrome or use another device if it doesn't work on an I-Pad (it usually does). Next time I will prepare a lot more in class to make sure the students can pose proper questions.	When doing this as a task in school make sure all computers have Google Chrome. Tell students to copy the link in Google Chrome or use another device if it doesn't work on an I-Pad (it usually does). Next time I will prepare a lot more in class to make sure the students can link ideas better.

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