University of Strathclyde

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From Teaching Physics to Teaching Children: The Role of
Craft Pedagogy

by

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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ABSTRACT

Current policy developments in Scottish Education have increased the emphasis on constructivist teaching approaches from 3 – 18 as a way to raise pupils' attainment by increasing teachers' skill levels.   The aim of this study was to explore student teachers' developing pedagogical content knowledge about teaching electricity, which is a traditionally difficult topic in physics, during a one year PGDE course, the following Probationary Year and beyond.   Some of the cohort volunteered to be interviewed about aspects of the electricity syllabus taught in the Scottish secondary school curriculum.   An interview schedule was developed based on a typical line of development through the basic electricity syllabus in Scotland.   Semi-structured interviews were carried out at the beginning and end of the PGDE year and again at the end of the Probationary Year.   A fourth interview was carried out nearly four years after completing the PGDE year.   The repeat interviews were analysed using an analytical framework based on Shulman's pedagogical content knowledge as interpreted within science education research using thematic analysis.   Most of the student teachers showed a change from concentrating on how to teach physics (to these children) to how to teach these children (physics).   The analysis suggested that the teachers had learned how to present their knowledge by interacting with pupils. In the course of this analysis a Craft Pedagogy framework was developed to account for their development: they developed individual Craft Pedagogies.   The thesis presented here is that these individual Craft Pedagogies can be synthesised to generate a new Craft Pedagogy framework with wider application to teachers' learning.

Chapter 1 Background and Rationale

1.1 INTRODUCTION

The research reported in this thesis set out to explore how beginning teachers of physics in Scotland changed their explanations for electrical concepts as they gained experience teaching.

The research was influenced by the changes in education policy introduced first by the Scottish Executive and then by the Scottish Government over the course of the past decade.   Educational policy in Scotland has been influenced by changes in international approaches to education which currently reflect an increased interest in constructivist approaches to teaching and learning.   One of the major influences on these constructivist approaches to teaching and learning has been Black and Wiliam's (1998) work on formative assessment in the classroom.   In the Scottish context this has been implemented in the form of the Assessment is for Learning (AifL) programme, Learning and Teaching Scotland (2002).   As a result, constructivist approaches to teaching and learning have influenced Initial Teacher Education (ITE) in Scotland in general and the institution where this research was based in particular.

Another influence on this research was Shulman's (1986 and 1987) concept of pedagogical content knowledge (PCK).   According to Shulman this is a teacher's form of professional knowledge.   Within the context of research in science teaching, PCK is usually seen as occurring at the intersection of teachers' curricular knowledge, their science content knowledge and their general knowledge of pedagogy.   The tripartite form of PCK provided the initial analytical framework for this research and provided a focus for the investigation of ideas which the author was aware presented difficulties through her normal work with Initial Teacher Education (ITE) students as they learned to work with pupils while on teaching practice.

The remainder of Chapter 1 explores the Scottish background for this research. Chapter 2 discusses the role of constructivism in detail and, in particular, explores

the nature and role of models in science teaching.   Chapter 3 explores the reasons why electricity is a conceptually difficult concept to understand and some of the difficulties this causes for teachers.

Chapter 4 introduces the aims and research questions which were derived as a result of the literature review described in Chapters 2 and 3 before going on to describe the methods used for data collection and analysis.

Chapter 5 provides an analysis of the data collected.   As a result of the data analysis, the thesis put forward is that a new framework for the development of beginning teachers' knowledge can be proposed.   This new framework has been termed Craft Pedagogy because it is based on the way in which beginning teachers learn from their pupils and use this learning to develop their own individual theories of pedagogy.   These are synthesised to form the overarching framework for Craft Pedagogy.

Chapter 6 summaries the findings of the research and critically analyses the research methods used in the thesis.

Figure 1.1 on the next page summarises the findings of the research in the form of a V diagram.   V diagrams were developed by Gowan and are described in Novak & Gowin (1984) and in more detail in Gowin & Alvarez (2005).   V diagrams provide a visual method to consider complex ideas and the interactions between their components.

Teaching Physics or Teaching Children: The Role of Craft Pedagogy

THEORETICAL

METHODOLOGICAL

Focus questions

What is Craft Pedagogy?

Where did the idea come from?

How can it be applied in teacher education?

2. World view
Constructivist – cognitive, social or radical constructivism

3. Philosophy / epistemology
Critical realism
Pragmatic approach to epistemology - qualitative methods allow the development of an inductive theory following data analysis

4. Theory
Pedagogical Content Knowledge (PCK) as analytical framework
Deductive analysis based on analytical framework
Inductive analysis based on data

5. Principles
Underlying electrical theory: Sefton (2002)
Models and analogies: Gilbert et al. (1998a and b)
Harrison and Coll (2008)

6. Concept
Operationalised (sic) analytical framework based on PCK – initial and emergent versions: Shulman (1986 and 1988).
Bishop and Denley (2007)

12. Value claims
Craft pedagogy is an explanatory framework for beginning teachers' professional development

11. Knowledge claims
Development of components of PCK
Transformation of teachers' physics knowledge into a form which is suitable for use with pupils by interaction with pupils
Re-organisation of the components of PCK into Craft Pedagogy framework

10. Transformations
Tables from analysis of concept maps
Analysis of DIRECT 1.2 questionnaire
Coding and analysis of longitudinal interview transcripts

9. Constructs
PCK as initial analytical framework

8. Records
Science student teachers' electrical concept maps
Physics student teachers' electrical questionnaires (pre-validated DIRECT 1.2 Engelhardt and Beichner(2004)
Repeated, semi-structured interviews – set of 6 teachers plus 9 others

7. Objects and/or events
Working with PGDE student teachers of physics as well as science (volunteers)
Concept mapping with student teachers of science (physics, chemistry and biology)
DIRECT 1.2 electrical questionnaire with student teachers of physics
Four, semi-structured interviews with beginning physics teachers over 4½ years

Figure 1.1   V diagram summarising the background to Craft Pedagogy.

1.2   SCOTTISH CONTEXT

The Scottish Education system is one of the distinctive features of Scottish life, Humes & Bryce (2008), along with the law and the church.   Education in Scotland has been a devolved responsibility since the establishment of the Scottish Parliament in 1999.   One of the first pieces of legislation passed by the Parliament was the Standards in Scotland's Schools etc. Act (2000) and the Parliament has taken an active role in developing education policy since then.

In Scotland, Initial Teacher Education (ITE) and the Teacher Education Institutions (TEIs) are located in the university sector, Menter (2008), but the Standard for Initial Teacher Education is determined by the independent General Teaching Council for Scotland (GTCS) (2006b).   The Standard for Initial Teacher Education determines the standard to be reached by student teachers at the end of their one-year Professional Graduate Diploma in Education (PGDE) course.   The GTCS (2006a) also set out the Standard for Full Registration which must be achieved for Probationer Teachers to become fully registered teachers.   As a result of the McCrone Agreement, Scottish Executive (2001), after the PGDE year, beginning teachers are guaranteed a Probationary Year to attain the Standard for Full Registration.

Within this broad context of ITE in Scotland, the author is employed as a teacher educator in physics and mathematics, partially on the basis of her experience as a secondary school teacher of physics and mathematics.   Menter (2008) discussed the tensions between teaching and research which arose when the Scottish TEIs changed from being Colleges of Education and merged with universities.   Part of the motivation for undertaking this study was the continuing professional development of the author in the field of educational research to complete the change from being a secondary school teacher to being a university lecturer and researcher.   The study itself involved investigating changes in beginning physics teachers' pedagogical content knowledge (PCK) about teaching electricity.

1.3 POLICY

Schools policy

As discussed in section 1.1, the legislation governing education in Scotland is passed by the Scottish Parliament.   After the implementation of the Standards in Scotland's Schools etc. Act (2000) and the McCrone Agreement (2001), one of the next major policy initiatives by the Scottish Executive was *Ambitious, Excellent Schools* (2004) which set out the agenda for change in Scottish Education and led to the production of the *Curriculum for Excellence* (CfE) document by the Curriculum Review Group (2004).

The CfE programme is currently being implemented in Scottish schools.   CfE built on and included the earlier Assessment is for Learning (AifL) programme, which was renamed from the *Assessment development programme action plan*, Learning and Teaching Scotland (2002), which in turn built on the work of P. Black & D. Wiliam (1998b) and the *Inside the Black Box* approach to Assessment for Learning (AfL).   One of the requirements of the Scottish Executive (2004) in *Ambitious, Excellent Schools* was that all schools implement the AifL programme by 2007. Both the AifL programme and CfE were built on broadly constructivist approaches to teaching and learning.   Constructivism is discussed in section1.3.

ITE policy

Initial teacher education in Scotland is within the remit of the Scottish Government (2009a) and the General Teaching Council for Scotland (2006b) although ITE courses are offered in the universities (Menter, 2008).   The entry requirements for the one-year PGDE course, Souter (2007), are specified in the Memorandum for Entry to the Teaching Profession (2009a).   The entry requirements include a pass at Higher English or equivalent and a total of 80 credits in relevant subjects.   40 of the credits must be at Scottish Credit and Qualifications Framework (SCQF) (2007) level 8 or above.

1.4 THEORY

1.4.1 Constructivism

Constructivism is a theory of learning which builds on the premise that learning cannot be directly transmitted, but that learners need to construct meaning for themselves. The basic idea about learners constructing their own meanings was discussed by Ausubel (2000).

In his discussion about the role of constructivism in science education research, Taber (2006, p. 135) discussed what he called the core tenets or axioms of the "Active Construction of Knowledge in Science (ACKiS) research programme." Science teachers and educators would probably agree that these tenets would describe a constructivist approach to learning and teaching. These core tenets are, Taber (2006, p. 139):

1. *Knowledge is constructed by the learner, not received*

2. *Learners come to science learning with existing ideas about many natural phenomena*

3. *Each individual has a unique set of ideas*

4. *Knowledge is represented in the brain as a conceptual structure*

5. *It is possible to model learners' conceptual structures*

6. *The learners' existing ideas have consequences for the learning of science*

7. *It is possible to teach science more effectively if account is taken of the learners' existing ideas*

These ideas are all implied in the discussion about constructivism in science teaching in section 2.2 of this thesis.

1.4.2 AfL and AifL

The research programme in Assessment for Learning (AfL) was reported in the 1998 review by P. Black & D. Wiliam (1998a) called *Assessment and classroom learning*. According to Simpson (2006), the review was probably more influential among school teachers in the form of the *Inside the Black Box* pamphlet, also by P. Black & D. Wiliam (1998b). Ideas about formative assessment as the assessment of learning and as a means to improve attainment can be construed as sitting within a constructivist approach to teaching and learning.

1.4.3 PCK in science education

The idea that teachers' pedagogical content knowledge (PCK) is the specialised knowledge of teachers was introduced by Shulman (1986) and (1987). Shulman's initial introduction of PCK included a variable number of components. According to Gess-Newsome (1999), Grossman (1990) introduced the common tripartite division of PCK into curricular knowledge, content knowledge (sometimes known as subject matter knowledge) and general pedagogical knowledge.

Since its introduction by Shulman, PCK has been used by numerous authors to investigate science teachers' PCK. Gess-Newsome & Lederman (1999) explored uses of PCK in science education. In 2008, a special edition of the *International Journal of Science Education, 30(10),* was devoted to *Developments and Challenges in Researching Science Teachers' Pedagogical Content Knowledge: An international perspective*. In her (2009b) review of PCK in science education, Kind discussed some of the many approaches to using PCK in science education research since 1986. The importance of constructivism in science teacher education will be considered further in section 2.2.

1.5   PRACTICE

Constructivist teaching in schools

Constructivist approaches have become common in Scottish schools with the implementation of the AifL programme and the ongoing introduction of the Curriculum for Excellence.   According to Bryce (2008), Local Authorities have offered Inservice Courses to teachers to prepare for the introduction of AifL and CfE.   One author who is likely to have been influential in developing teachers' approaches is Clarke (2005) and (2008) who has published a number of books about implementing formative assessment in the classroom.   Other likely influences on the use of formative assessment in schools have been the books published by Black, Harrison, Lee, Marshall, & Wiliam (2003) and Gardner (2006).

One interpretation of the discussions of science education in Scotland found in Bryce & Humes (2008) by Buchanan (2008), Gray (2008), MacMillan (2008) and Souter (2008) is that aspects of science teaching in Scottish schools are broadly constructivist.

Constructivist tenets 5 and 6 reported in section 1.3.1 above require teachers to know about children's alternative conceptions or misconceptions.   Research about children's alternative conceptions in science has been reported by Driver, Guesne, & Tiberghien (1985), Driver & Bell (1986) and Driver, Squires, Rushworth, & Woods-Robinson (1994) in a form which is accessible to teachers.   More recently, Allen (2010) has discussed pedagogical approaches to help teacher to deal with pupils' misconceptions in primary science.

Constructivist teaching in ITE

Entry requirements

As discussed in sections 1.1 and 1.2, ITE in Scotland is situated in the university sector.   The entry requirements for PGDE courses are set by the Scottish Government (2009a), but the decision about the suitability of specific degrees is determined by the TEIs.

The degree should normally contain 80 SCQF credit points relevant to the teaching qualification or qualifications being studied. Forty of the credit points must have been studied at SCQF level 8 or above.

Scottish Government (2009a, p. 7)

At the host institution, candidates for the Physics PGDE course have a number of different types of degree which meet the above requirement. These degrees range from honours degrees in physics to engineering degrees. Candidates with physics degrees are automatically invited to attend for interview. Candidates with other types of degree provide a copy of their degree transcript to determine if the contents of the degree meet the Entry Requirements. As a result, student teachers on the Physics PGDE course come with a wide range of subject knowledge about different areas of the secondary school physics curriculum.

Constructivist science teaching

The influences of constructivist research and the AifL and CfE programmes have resulted in a generally constructivist approach to teaching and learning on the PGDE course for secondary teachers in the host institution. This can be seen in the choice of Bryce & Humes (2008) and L. Cohen, Manion, & Morrison (2004) as the prescribed course texts.

A number of generally constructivist science teaching pedagogy textbooks are available in the United Kingdom and internationally such as Wellington & Osborne (2001), Kind & Taber (2005), Wellington & Ireson (2008), Hassard & Dias (2009), Allen (2010) and Wenham & Ovens (2010). A number of these are recommended or available to science student teachers in the host institution.

The specific PGDE course considered in this thesis is Physics with Science. This is because one of the requirements of the General Teaching Council for Scotland (2006b) for science teaching is that all science teachers have a general science component in their training. The general science component of the PGDE physics course uses Wellington & Ireson (2008) as an essential text and currently

recommends the use of Wenham (2005) and Wood-Robinson (2006) to prepare for science teaching. There is currently no recommended text for learning about the pedagogy of physics teaching. However, the student teachers are referred to texts such as Sang (2000) as appropriate.

Particular attention is paid to physics topics which are difficult for pupils and teachers and which permeate the entire secondary physics curriculum. The three main difficult topics in school science are forces, electricity and energy. Misconceptions and conceptual difficulties about these topics are discussed by Driver, et al. (1985), Driver, Leach, Scott, & Wood-Robinson (1994), Ross, Lakin, & Callaghan (2004), Allen (2010) and Wenham & Ovens (2010). These are also topics that university students find difficult, as reflected in the Physics Education Research (PER) literature, for example Engelhardt & Beichner (2004), Halloun (1985) and Singh & Rosengrant (2003).

Several years of professional experience and discussion with colleagues suggested to the author that PGDE students can find it difficult to reconceptualise force, Kibble (2006), Millar (2008), electricity, Taber et al. (2006), and energy topics, Millar (2005), to teach them to school pupils. Students are asked to consider some of the difficult concepts in school physics in order to allow them to begin to engage with these ideas and to transform their own subject understanding into a form that is suitable for use with pupils. This allows the student teachers to develop this component of their pedagogical content knowledge (Kind & Taber, 2005 and Bishop & Denley, 2007). A major focus of this work is on the topic of electricity because this is one of the areas where both pupils and teachers may have difficulty.

1.6   AIM AND RESEARCH QUESTIONS

Within the broad framework of the changing educational landscape in Scotland, the research described in this thesis was set within the context of the continuing professional development of a physics teacher educator in a Scottish TEI.   The aim of the thesis was to investigate whether student physics teachers changed their explanations about electricity as they developed as teachers.

To achieve this aim, a number of research questions were developed based on Shulman's (1987) version of PCK:

1.   Does the teachers' content knowledge change over time?
2.   Does the teachers' pedagogical knowledge change over time?
3.   Does the teachers' curricular knowledge change over time?

The rationale behind the development of these questions is explained in section 4.1.2.

1.7 THESIS OVERVIEW

This section provides an overview of the remainder of the thesis contents by using the first paragraphs of each chapter.

In Chapter 2, the role of social constructivism as a paradigm for science education and science teacher educators is discussed.   The rationale for choosing the social constructivist paradigm is contextualized by a discussion of other constructivist paradigms.   This Chapter also discusses the role of student teachers' pedagogical content knowledge (PCK) in their development as teachers, Shulman (1986) and Shulman (1987). The link between PCK and social constructivist approaches to teaching and learning is explored.

According to Shulman (1987), content knowledge is a major component of teachers' pedagogical content knowledge.   Chapter 3 summarises the content knowledge required to teach electricity and discusses a number of possible pedagogical approaches.

Literature on teaching electricity tends to concentrate on difficulties for learners (Millar & King 1993, Engelhardt & Beichner, 2004 and Rosenthal & Henderson, 2006, for example) and there is not much about how teachers could develop their practice in this area (Mulhall, McKittrick and Gunstone, 2001). Chapter 3 compares primary and secondary school curricula in Scotland and England.   School textbooks and pedagogy texts for teachers as well as academic journals were reviewed to explore conceptual difficulties and pedagogical approaches including the types of electrical explanations adopted.   Chapter 3 concludes by re-stating the aim of the study, which was to explore whether or not beginning teachers' explanations for electricity changed with experience.   The research questions were framed drawing on the Scottish electricity curriculum and using PCK as the analytical framework.

Chapters 2 and 3 reviewed literature on constructivism, science education, and teaching electricity respectively.   Chapter 4 begins by deriving a number of research questions based on the literature review and professional issues about physics teacher education to allow changes in physics teachers' approaches to teaching electricity to

be investigated using an analytical framework based on Shulman's 1987 conception of pedagogical content knowledge. Chapter 4 then evaluates the appropriateness of a number of research methodologies to address the research questions. The Chapter discusses the rationale for the research methodology adopted and concludes by describing the data collection and analysis strategies.

As discussed in Chapter 4, the initial analytical framework for the initial interview analysis was deductively derived from Shulman's pedagogical content knowledge (PCK), see figure 4.2. Chapter 5 discusses the results of the initial analysis. During the initial analysis, new concepts emerged inductively from the interview data. These emergent concepts were used to carry out a second stage of analysis. The analysis using the emergent concepts highlighted the importance of the teachers' craft knowledge of teaching (Leinhardt, 1990 and Burney 2004). This suggested that the emergent concepts could be reconceptualised to develop a new model of teachers' knowledge of teaching. The new model of teacher development is called Craft Pedagogy because it is based on teachers' craft knowledge and is discussed in section 5.5.

This study was set within the context of a Professional Graduate Diploma in Education (PGDE) Physics course in a Scottish Teacher Education Institution. The analytical framework for the study was based on Shulman's 1987 version of pedagogical content knowledge. The aim of the study was to investigate if beginning physics teachers' pedagogical content knowledge about electricity changed as they gained experience of teaching. Chapter 6 will show how this aim was achieved by discussing how and to what extent the research questions were answered. The development of a new model of teacher development, named Craft Pedagogy, is discussed and the implications for further research about teachers' practice and teacher education practice are explored.

Chapter 2 Constructivism and Science Education

In this Chapter, the role of social constructivism as a paradigm for science education and science teacher educators is discussed. The rationale for choosing the social constructivist paradigm is contextualized by a discussion of other constructivist paradigms. This Chapter also discusses the role of student teachers' pedagogical content knowledge (PCK) in their development as teachers, Shulman (1986) and Shulman (1987). The link between PCK and social constructivist approaches to teaching and learning is explored.

2.1 CONSTRUCTIVISM

Constructivism is currently the dominant paradigm for science teaching. Although there is considerable debate about the nature of constructivism and whether there are alternatives to constructivist approaches to teaching in general, and science teaching in particular, constructivism provides a coherent approach to teaching school science and a rationale for the pedagogical approaches currently used by science teachers.

2.1.1 Forms of constructivism

The roots of constructivism can be traced to Piaget (2001), Vygotsky (1978) and von Glaserfeld (1981) and (1984). The three authors are associated with cognitive constructivism, social constructivism and radial constructivism respectively. Piaget and Vygotsky treated the existence of the real world as unproblematic. Piaget's theory emphasised the role of individual children developing their own cognitive understanding of the world. Vygotsky's theory emphasised the social aspects of learning and the role played by an expert peer or adult so that the child is able to achieve more than would be possible individually. Von Glaserfeld's theory of constructivism was labelled radical because he denied that the real world could be known directly, but only through the mediation of the senses.

Piaget and Vygotsky started their work in Switzerland and Russia respectively in the 1920s and 1930s. However, their work only became known through English translations at a later date. According to von Glaserfeld (2005), the first use of the phrase "the construction of reality" was by Piaget in 1937, although the first outlining of constructivist ideas was by Vico in 1710.

Piaget – cognitive constructivism

Piaget (2001) focused on how individual children learn. He theorised that children go through sequential stages of cognitive development and that as a result need to have reached a particular developmental stage to learn particular things.

Later writers have criticised Piaget's stage theory for underestimating what children can achieve at early stages of development, for example Donaldson (1978).   Other authors, such as Shayer, Kuchemann, & Wylam (1976), found that Piaget had underestimated the age at which adolescents were able to carry out formal operations.   Another criticism of Piaget's stage theory was that Piaget did not offer a mechanism to explain children's cognitive development through the various stages, for example Stanton (1993).

Despite these criticisms, Piaget's stage theory of children's development provides a way to conceptualise the learning of individual children.   Piaget's theory has implications for children learning about science in general and electricity in particular.   Children in western societies become aware of electricity at an early age.   However, electricity is a conceptually demanding subject.   Piaget's theory suggests that children may have difficulty understanding the more conceptual aspects of any subject, including electricity, until they have reached the stage of abstract conceptualisation, which may not have happened by the end of secondary schooling. Elyon & Lynn (1988) provided a breakdown of the percentage of American high school students at different Piagetian stages according to age.   According to Elyon and Lynn, two thirds of high school students had not attained the formal operations stage by the age of 17-18.

Vygotsky – social constructivism
Vygotsky focused on how children learn in social situations by interacting with others.   Vygotsky (1978, p. 86) theorised that learners can achieve more together than individually when they work in their zone of proximal development with more experienced peers or a teacher.   In Vygotsky's theory, language and language development play important roles because all learning takes place through the use of language.

Wood, Bruner, & Ross (1976), and particularly Brunner, built on Vygotsky's theories to suggest that the support provided by the more expert peer or teacher could

be regarded as a form of "scaffolding".   According to Schaffer (2004, p. 204), this metaphor should not be taken literally to imply a rigid form of support, but an adaptive form of support which is gradually removed.

Von Glaserfeld – radical constructivism
According to von Glaserfeld (2005, p. 10) radical constructivism means "going to the roots" or being "uncompromising".   In this case, Dykstra (2007) argued that the uncompromising idea is the rejection of realism as the underlying philosophy of Western thought.   In its place is the acceptance that the only way of knowing the world is through our own experiences.   We cannot deduce from this that there is an external, real or "ontic" world.

> *I have never said (nor would I ever say) that there is no ontic world, but I keep saying that we cannot know it.*
>
> von Glaserfeld (1991, p. 19)

> *It (radical constructivism) is based on the simple realization that, as our thinking, our conceptualising, and our language are developed from and in the domain of our experience, we have no way of incorporating anything that lies beyond this domain.*
>
> von Glaserfeld (2005, p. 11)

Constructionism
According to Hepburn (2006), constructionism is the overarching term for a number of theories which deal with the construction of knowledge, including the forms of constructivism discussed above.   In particular, social constructionism places a

greater emphasis on the role of discourse to construct knowledge, Gergen (1985) and (1994). In his discussion about the distinction between constructionism and constructivism, Crotty (1998) made a similar point.

2.1.2 Constructivist debates

Several authors, including Solomon (1994), Osborne (1996), Irzik (2000) and Taber (2006), have questioned the dominant role of constructivism within science education research, and by implication, within science teaching. In this section, the critiques of these authors are discussed and a justification given for using constructivist teaching approaches discussed in sections 1.4 and 2.2.

The different forms of constructivism all accept that knowledge is a human construction, Osborne (1996) and Irzik (2000), but von Glaserfeld (1993) called this "trivial" constructivism. However, according to Solomon (1994), "trivial constructivism" also includes the investigation of children's ideas about science, which has proved to be fruitful within science education research.

Solomon (1994) argued that the greatest benefit of constructivism was to provide a vocabulary to think about how children learn science. According to Solomon, Driver and Easley's (1978) paper synthesised the unsystematic common knowledge among science teachers and educators about children's learning in science and provided a useful way of conceptualising children's informal learning in science. However fruitful this approach has been, constructivism has not provided a structured approach to organising the science curriculum to develop children's learning in science or an approach to understand the difficulties children have in learning science.

Osborne (1996) argued that constructivism has provided a useful method to develop pedagogy in science education. However, he went on to argue that it is a mistake to conflate constructivism as a method with constructivism as a theory of learning, or referent. According to Osborne, there is also confusion within constructivism about the role of the individual learning directly about the world through their senses and

learning about the view of the world as constructed by society. His conclusion was that constructivism should offer a varied approach to pedagogy rather than only one approach.

Irzik (2000) argued that much of the confusion described above arose because the originators of constructivism, such as von Glaserfeld and Driver, lacked an academic training in philosophy. He also argued that most science educators also lack an academic training in philosophy. This lack of philosophical training has resulted in the propagation of fundamental philosophical misunderstandings.

Taber (2006, p. 126) adopted a different approach to constructivism in science education by proposing a model of a constructivism as a progressive Lakatosian research programme. By following Lakatos's approach, Taber argued that he was able to define a core-constructivist research programme which incorporated previous work and which provided guidance for new researchers in the field and suggestions to move the constructivist research programme forward.

Windschitl (1999) provided an alternative approach to using constructivism in the classroom by proposing that teachers could be helped to move towards a more coherent understanding of constructivism by viewing the classroom as a cultural system. The implication of this is that teachers can understand constructivism more fully and therefore by analysing their own classroom adapt their teaching to put constructivist approaches into practice in a more reasoned way.

Despite the debates about the role of constructivism in science education and science education research, constructivism still has a dominant role in science teaching in secondary schools, as discussed in section 2.2.1.

2.2 ROLE OF CONSTRUCTIVISM IN SCIENCE TEACHING

Constructivism is the currently dominant paradigm in science teaching, and has been for some time. According to Driver, Asoko, Leach, Mortimer, & Scott (1994, p. 5), the view that knowledge cannot be transmitted but must be constructed by the mental engagement of learners underpins contemporary perspectives on science education. This can be seen in pedagogy texts for science teachers, by for example Leach & Scott (2000), Alsop & Hicks (2001), Bennett (2003), Ross, et al. (2004), Wood-Robinson (2006), Wellington & Ireson (2008), Hassard & Dias (2009) and Liversidge, Cochrane, Kerfoot, & Thomas (2009) as well as articles such as C. C. Tsai (2000), Russell, Lucas, & McRobbie (2003), Dykstra (2005) and Bennett, Hogarth, Lubben, Campbell, & Robinson (2010). The dominance of constructivist teaching is recognised even by those who would argue that constructivism has been taken too far and is hampering the developing of a more relevant paradigm for science teaching and research such as Solomon (1994), Irzik (2000) and Taber (2006) among others.

Constructivist science teaching meets the policy focus on active engagement of learners seen in Scotland with the Curriculum for Excellence, The Curriculum Review Group (2004), in England through parts of the National Curriculum, QCA (1999), and internationally, in America "Science for all Americans," Rutherford & Ahlgren (1990) and in New Zealand, Ministry of Education (2007), among other countries.

2.2.1 Constructivist science teaching

Constructivist approaches to science education can be broadly defined to include the idea that learners must construct knowledge for themselves rather than receive knowledge directly from the teacher. This view was expressed by Driver, Asoko, et al. (1994, p. 5) as:

> *The view that knowledge cannot be transmitted but must be*
> *constructed by the mental activity of learners underpins contemporary*
> *perspectives on science education.*

Piagetian constructivism has been applied to science teaching in the Cognitive Acceleration via Science Education (CASE) programme. The results of the CASE programme have been reported by Adey (1992) and Shayer (1999).

A number of science teacher educators have identified several features of constructivist teaching which are based on radical constructivism. These authors include Driver & Bell (1986, pp. 453-454), Bennett (2003, p. 42), Scaife (2008, p. 74) and Hassard & Dias (2009, p. 284) who summarised these as the active involvement of learners in learning and the fact that learning allows learners to adapt to their experiences.

Dykstra's (2007) discussion of this approach was summarised as four principles by Hassard & Dias (2009, p. 285). Baviskar, Hartle, & Whitney (2009) arrived at Dykstra's four principles, apparently independently, via a literature review. According to Baviskar et al.:

> *... the four essential features of constructivism [are] eliciting prior*
> *knowledge, creating cognitive dissonance, application of new*
> *knowledge with feedback, and reflection on learning.*

Eliciting learners' prior knowledge will often result in the finding that learners hold alternative conceptions or misconceptions rather than the scientific view. A radical constructivist approach to learning and teaching science would argue that learners' experience of the world leads them to develop conceptions which explain phenomena to the learners' satisfaction. These conceptions would be described as alternative conceptions rather than misconceptions because the conceptions make sense to the learners even if they do not agree with scientific conceptions. This approach was adopted by Driver, et al. (1985) and Driver, Squires, et al. (1994). In this section, the term used is misconceptions rather than alternative conceptions because the learners need to develop the scientific understanding of a phenomenon.

Consequently, if learners were to express a different view after teaching, as suggested by Gilbert & Watts (1983), it would be a misconception.   This is also the view implied in the recent pedagogical text by Allen (2010).

Constructivist teaching approaches stress the need for the learner to construct their own understandings by building on their existing knowledge to make links to the new knowledge.   The teacher is no longer the authoritative font of knowledge, Huffman (2006), but organises the learning environment so that the learner can construct their own knowledge.   This is similar to the view expressed by Bullock (1975, p. 50):

> *It is a confusion of everyday thought that we tend to regard*
> *'knowledge' as something that exists independently of someone who*
> *knows. 'What is known' must in fact be brought to life afresh within*
> *every 'knower' by his own efforts.*

The role of the teacher is now to find out about the learners' prior knowledge and to be aware of the learners' likely and actual misconceptions about the topic.   This information is then used to guide the learner's active construction of their own knowledge, Ausubel (2000).   Clearly establishing the wider context or "big picture" for learning also helps learners to build on past learning and to make connections to future learning. The active construction of new knowledge rather than its passive transmission is one of the key features of constructivism.   This may be one of the reasons why constructivism has been well received in science education.   A constructivist approach provides a justification for the role of practical work in school science education.

An important feature of constructivism is starting where the learner is, and this requires knowledge of likely misconceptions as well as the actual starting point of the learners.   To help the learners develop their understanding, the teacher must have a clear conceptual understanding of the topic and of how to organise the teacher's knowledge to help the learner to learn.   This is the idea behind the well-worn finding

of beginning teachers that they did not understand a topic until they had to teach and apply what they already knew, Scaife (2008, p. 81).

Learning is always a social activity – even if the learner is only interacting with artefacts such as books or videos, which have been created by other people.   This gives a great deal of scope for social learning in the classroom (Driver, et al., 1994b). Social learning could include group and cooperative learning, which may or may not be linked to constructivist teaching approaches (Baviskar et al., 2009).

In summary, constructivism is often used as an organising principle in secondary science education, and often in a composite form.   The idea that children have to develop their own understanding could be linked to Piaget's cognitive constructivism.   Social learning, in the form of group work, plays a role in science education and can be explicitly linked to Vygotsky's social constructivism.   Von Glaserfeld's radical constructivism also underlies the core ideas about constructivist science teaching.   A constructivist understanding of science teaching drawing on all three varieties of constructivism can be seen in a number of pedagogy texts for science teachers, including Scaife (2008), Hassard & Dias (2009) and Hohenstein & Manning (2010).

An understanding of the role of constructivism in science teaching is part of science teachers' professional knowledge.   Shulman's (1986 and 1987) discussion of the role of teachers' professional knowledge introduced the concept of pedagogical content knowledge (PCK).   PCK is defined in section 3.3 and its role in science teaching discussed.

Despite the important role of constructivism in science teaching, there is a debate about the role of constructivism as a paradigm for science education research which was discussed in section 2.1.2.

2.3 PCK

2.3.1 Shulman's ideas

Pedagogical content knowledge is the particular professional knowledge of teachers, and is the knowledge that defines teachers as professionals. The first explicit discussion about PCK was by Shulman in 1986 and 1987. Although there are general pedagogical strategies which are part of the armoury of all teachers, which have been described in textbooks like L. Cohen, et al. (2004), there are also subject specific components of teachers' PCK. According to Shulman, PCK encompassed

> *... for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others.* *Shulman (1986, p. 9)*

Since Shulman's original formulation of the concept, it has been developed in different directions. At the level of curriculum planning, Gess-Newsome & Lederman (1999) discussed the relevant aspects of PCK. At the level of the classroom teacher, Bishop & Denley (2007) developed the metaphor of a spinner to represent the dynamic interaction between the components of PCK.

The concept of pedagogical content knowledge was initially introduced by Shulman (1986, pp. 9-10). In this initial paper, Shulman discussed pedagogical content knowledge and curricular knowledge as the two components of content knowledge. In a later paper, Shulman (1987) introduced a minimum of *six* components of PCK. Nevertheless, PCK is often conceptualised in the tripartite form introduced by Grossman (1990). The inter-relationship between the three components is often, but not always, shown as a Venn diagram, Gess-Newsome (1999, p. 12), Figure 2.1.
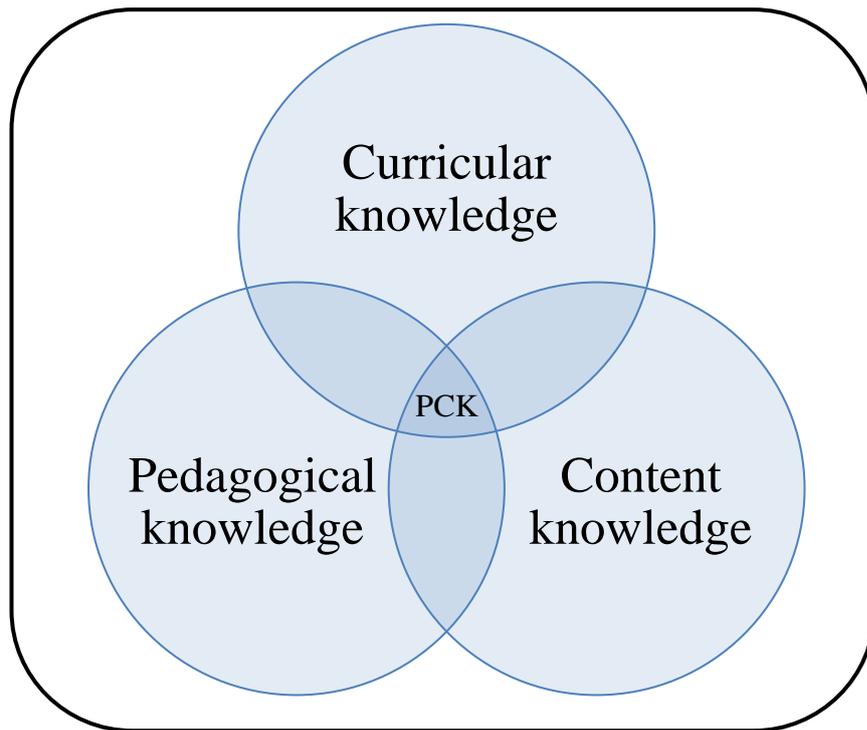
Figure 2.1   Pedagogical content knowledge (PCK) occurs at the intersection of curricular knowledge, pedagogical knowledge and content knowledge. (Based on Grossman (1990) and Gess-Newsome (1999))

The general concept of PCK has been applied specifically to science teachers as discussed generally in Gess-Newsome & Lederman (1999) and in particular by Magnusson, Krajcik, & Borko (1999, p. 99).   This will be discussed in more detail in section 2.3.2

A number of authors have used a selection of Shulman's original six components of PCK in various ways.   A recent review of the role of PCK in science teacher education was carried out by Kind (2009b).   Cochran, DeRuiter, & King (1993) introduced the more dynamic concept of Pedagogical Content *Knowing* (PCK*g),* which included knowledge of learners and their context as a fourth component as well as the three components identified by Grossman (1990). In fact, the fourth component of Cochran et al.'s model combines Shulman's categories of knowledge of learners and knowledge of context.   More recently, Bishop & Denley (2007, p. 9) used all six components of PCK, including knowledge of educational ends, purposes

and values in their 'spinning top' metaphor for the developing professional knowledge of science teachers.

Using content knowledge, curricular knowledge and pedagogical knowledge as the three main components of PCK provided a useful overview of the concept. However, the other three components of PCK identified by Shulman in 1987 also provided useful ways to think about teachers' PCK as shown by their use in other models for PCK. Consequently, this thesis will regard knowledge of pedagogy as subsuming knowledge of learners, contexts and values as illustrated in Figure 2.2.
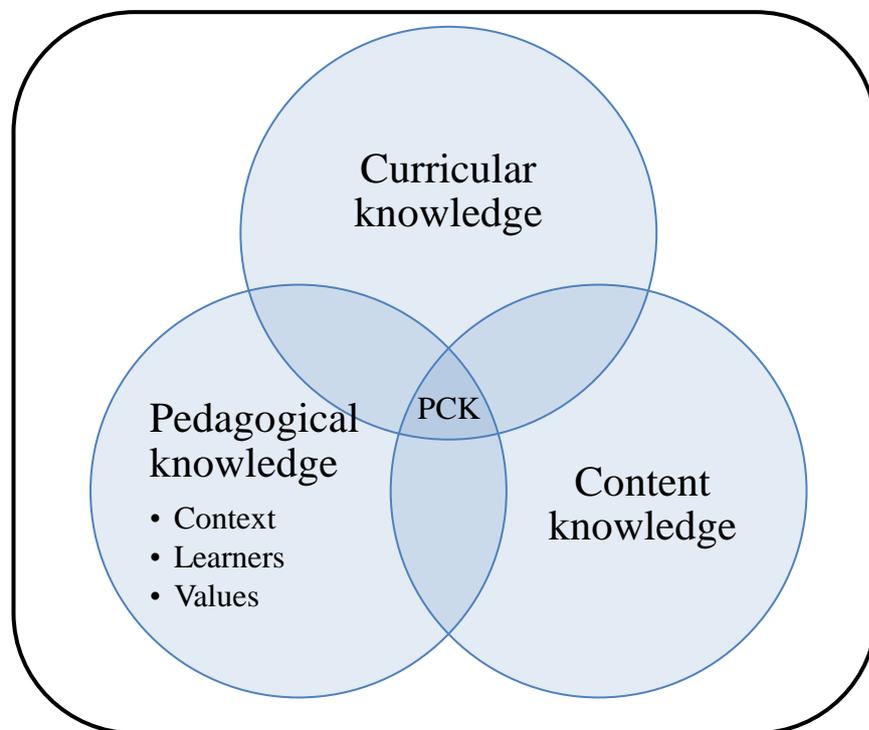
Figure 2.2   In this figure, PCK stills occurs at the intersection of content knowledge, curricular knowledge and pedagogical knowledge. However, pedagogical knowledge is conceptualised more widely to include knowledge of the learners and their context and educational values.

For science teachers, pedagogical knowledge includes knowledge of models and analogies, Shulman (1986, p. 9). The use of models in science education is discussed in section 2.5.

The role of PCK in science teacher education can be problematic. According to Loughran, Mulhall, & Berry (2008, p. 1301):

> *While the development of pedagogical content knowledge (PCK) is considered to be a goal of teacher education, teaching about the concept itself is an unusual practice.*

The next section discusses the role of PCK in science teaching and science teacher education.

2.3.2 PCK in science teacher education

The role of PCK in conceptualising science teachers' development has been explored by a number of authors. The contributions of Gess-Newsome and Bishop and Denley have been discussed in section 2.3.1. This section considers recent use of PCK in science teacher education research.

Two recent reviews of the use of PCK in science teacher education research have taken different approaches. Abell (2008) commented specifically on the contents of a special issue of the *International Journal of Science Education, 30(10), Developments and Challenges in Researching Science Teachers' Pedagogical Content Knowledge: An international perspective*. Returning to Shulman's (1987) conception of PCK, Abell (2008, p. 1407) identified transformation of other forms of knowledge into content knowledge as one of the core issues around PCK. She also identified the importance of changes to PCK over time rather than viewing PCK as a static concept. Kind (2009b), in a review of PCK, took a broader perspective and addressed the wide range of approaches taken to PCK by researchers since its introduction by Shulman in 1986. Both Abell and Kind addressed the implications of using PCK as an analytical framework for all stages of teacher education and for research in science education.

PCK has been used as an analytical framework by a number of authors to investigate the development of student teachers on ITE courses. Nilsson (2008) followed four student teachers in detail over one year and emphasised the importance of transformation in the development of PCK. An explicit approach to developing student teachers' PCK in ITE was discussed by Loughran, et al. (2008) and explained in more detail in Loughran, Berry, & Mulhall (2006). Loughran, et al. (2008) found that an explicit focus on teaching about PCK in ITE helped student teachers to develop their teaching. Loughran et al.'s (2008) approach to teaching about PCK used Content Representations and Pedagogical and Professional-Experience Repertoires (CoRes and Pap-eRs).

In their discussion of PCK in initial teacher education in physics, Sperandeo-Mineo, Fazio, & Tarantino (2006, p. 235) highlighted the importance of the interaction between subject matter knowledge (or content knowledge) and pedagogical knowledge in the development of physics teachers.

As part of a wider project about experienced science teachers' acting as mentors, Lee, Brown, Luft, & Roehrig (2007) and Lee & Luft (2008) reported on the development of beginning science teachers PCK. Lee, et al. (2007) found that the beginning teachers developed significantly in their knowledge of pupils learning.

The ways in which experienced Israeli teachers developed their PCK about higher-order teaching in science were explored by Zohar & Schwartzer (2005). They found that changes in the science teachers' PCK about teaching higher-order thinking could be measured.

A wider focus on PCK in ITE was provided by Segall (2004) who argued that ITE should explicitly teach about PCK. Others who have suggested that it would be beneficial to teach explicitly about PCK in ITE include Käpylä, Heikkinen, & Asunta (2009) and Kind (2009a) who discussed the need to transform student teachers content knowledge into a form suitable for pupils. Abell, Rogers, Hanuscin, Lee, & Gagnon (2009) took this a step further by arguing for the inclusion of teaching about PCK to prepare science teacher educators in the United States of America.

2.4　CONCEPT MAPPING

Concept maps were originally developed by Novak, Novak & Gowin (1984) and Novak & Musonda (1991) as a way to organise the information obtained in research interviews with pupils learning science. Information about how to construct concept maps can be found in Novak & Cañas (2008). Concept maps display information hierarchically, building concepts or "atoms" of meaning, Novak, Mintzes, & Wandersee (2005), into propositions. Propositions are formed by joining concepts explicitly with linking phrases. Propositions can be linked together to form a concept map. Shavelson & Ruiz-Primo (2005) introduced a different vocabulary for linked concepts, defining concept maps as (mathematical) graphs.

According to Edmondson (2005), concept maps by subject experts are better structured than those produced by learners. Consequently, concept maps have been used to assess learners' and experts' subject knowledge because they make the way in which knowledge is structured explicit. Two main approaches to assessing concept maps have been described. The first approach is to score the propositions contained in the concept map. This approach is exemplified by Shavelson & Ruiz-Primo (2005) who described three approaches to scoring concept maps, see below. The second approach is to look at the obvious feature of concept maps: their topological structure. This approach is exemplified by Kinchin, Hay, & Adams (2000) and more recently and more mathematically by Koponen & Pehkonen (2010). Kinchin, et al. (2000) classified maps as chain, spoke and net depending on their structure. Van Zele, Lenaerts, & Wieme (2004) argued that qualitative methods provided a better picture of the students' understanding than scoring methods.

Scoring concept maps is often perceived as problematic. In their review, Ruiz-Primo & Shavelson (1996) noted problems deriving reliable and valid ways of scoring concept maps. Similar issues were reported by Ruiz-Primo (2000) and Stoddart, Abrams, Gasper, & Canaday (2000). Nevertheless, in their 2005 Chapter, Shavelson and Ruiz-Primo defined three ways to score concept maps: the proposition accuracy score; convergence score; and salience score. The different scoring methods are defined next.

The proposition accuracy score is calculated by scoring propositions on a five-point scale, where zero points are gained for an incorrect proposition and four points for a totally accurate proposition.   To calculate the convergence score, an expert concept map, or criterion map, about the topic is produced.   The number of accurate propositions in the map to be assessed is compared to the number of accurate propositions in the criterion map.   The salience score is the proportion of totally accurate propositions to the total number of propositions on a map.   According to Shavelson & Ruiz-Primo (2005), the proposition accuracy score gives the most accurate measure of understanding.   However, calculating proposition accuracy scores is time-consuming.   They recommend using the salience score for large-scale research.

İngeç (2009) compared concept mapping and an attainment test as a method to assess student teachers' understanding of momentum and impulse.   The results of the attainment test showed that the student teachers had a good understanding of momentum and impulse.   However, the scores for the concept maps were low and the concept maps did not reveal the structure of the student teachers conceptual knowledge.   These results suggest that there may be problems using concept maps to assess student teachers' conceptual knowledge despite the suggestion by Shavelson & Ruiz-Primo (2005) that concept maps and other forms of assessment assess different types of understanding.

2.5   MODELS

Science teachers teach about scientific models and science learners learn about scientific models.   According to Gilbert (1994, p. 3) and Ratcliffe (2001, p. 57), "a model is a representation of an object, event or idea."   This section discusses a typology of scientific models.   This is important, because science teachers spend a great deal of time teaching about particular scientific models or teaching models which approximate to the scientific model to a greater or lesser extent.

2.5.1 What is a scientific model?

The word model has a range of meanings within the scientific and science teaching communities, Gilbert, Boulter, & Rutherford (1998b) and Gilbert, et al. (1998b)   and Gilbert, Boulter, & Elmer (2000) see Figure 2.3.   Models themselves are in many ways the stuff of science:

> *A model in science is a representation of a phenomenon initially produced for a specific purpose.   As a "phenomenon" is any intellectually interesting way of segregating a part of the world-as-experienced for further study, models are ubiquitous.*
>
> *Gilbert* et al. *(2000, p. 11)*

The everyday understanding of models, usually a physical scale model, is also present in science teaching.   Examples are models of torsos in biology; ball-and-stick models of molecules in chemistry and vibrating ball bearings as a model of solids, liquids and gases in physics and chemistry.   These physical models also share other characteristics.

The models are models of things that happen or exist in the real world, in other words phenomena.   The models attempt to show aspects of the physical world in another way: a plastic model of a torso, which is roughly to size or a plastic or metal model of atoms and molecules which is greatly magnified.   The models are constructed using a number of concepts or entities which may be physical or mental.

The vibrations in the kinetic model are to show the random motion of the particles in a gas, which is analogous to the macroscopic temperature of the gas. Other models can be more abstract, for example the mathematical models which dominate physics dealing with ideas like energy and force which are abstract.

Models and analogies

Models and explanations of models permeate the school science curriculum. Harrison (2008c) argued that models are based on analogies. An analogy is a comparison of the way that two things are *like* one another. To explain a *target* concept, the teacher starts with a familiar, and hopefully well-understood, system which is called an *analogue.* Ratcliffe (2001) explored these ideas in relation to teaching about atoms and molecules in the early secondary school.

Harrison's (2008c) link between models and analogies also contained the warning that the model or analogy is **not** the phenomenon itself, but a representation of the phenomenon. The warning that a model is not the phenomenon had also been expressed earlier by Gilbert, Boulter, & Rutherford (1998a, p. 95). There can be a tendency among teachers and learners to confuse the model with the reality which it represents, which leads to the misconception that understanding the model means that the phenomenon has been understood. This naïve approach ignores the fact that the analogue only corresponds to some aspects of the target. Wellington & Ireson (2008, p. 8) and Harrison (2008b) Chapter 4 discussed the necessity to use different models and to examine the limitations of the models and where they break down to try to avoid conflating the model and reality.

Gilbert & Boulter (2000, p. 12) identified nine different kinds of model which may be used in science teaching. The scientific model about a topic is the consensus view held by the scientific community. The scientific model may be controversial in the wider community. For example, the theory of evolution is well-accepted and uncontroversial among the community of evolutionary biologists and the wider biological and scientific community, Jones & Reiss (2007), but controversial among

sections of the general public. Dawkins (2009) has recently tried to reduce public scepticism about evolution.

However, a scientific model must begin as a private mental model that is shared by becoming an expressed model. An expressed model which is agreed among a community will become a consensus model. A consensus model within the scientific community would become a scientific model. Some scientific models will be taught to learners, probably in the simplified form of a curricular model. As scientific models are superseded by new scientific models, the old version would be referred to as a historical model.

A teaching model, or sequence of teaching models, is the simplified and educationally justified approach used by science teachers to meet syllabus requirements. Teaching models may be developed by teachers or learners and draw on a range of curricular, historical and consensus models as appropriate. Teaching models may be previous consensus models, for example Bohr's 1913 model of the atom, described by Nave (2006), is used in the Scottish Higher Physics syllabus, SQA (2004b, p. 8). Pupils may be introduced to a sequence of progressively more scientifically accurate models as they mature, following Bruner's (1986) ideas about the spiral curriculum.

Hybrid models are used for teaching and draw on the different models described above as appropriate. However, to use models effectively in the classroom, teachers have to develop an appropriate model of pedagogy which draws on a wide range of knowledge. The aim of teaching is to have a learner's private mental model, which can only be accessed via some form of expression, agree with the target teaching or curriculum model.

Figure 2.3 is a concept map which shows the links between the different kinds of models described above. Figure 2.3 allows a visual exploration of the links between the different kinds of models discussed above. Figure 2.3 shows a complex web of connections between the different types of model and illustrates one of the reasons why using models in science teaching can be difficult.
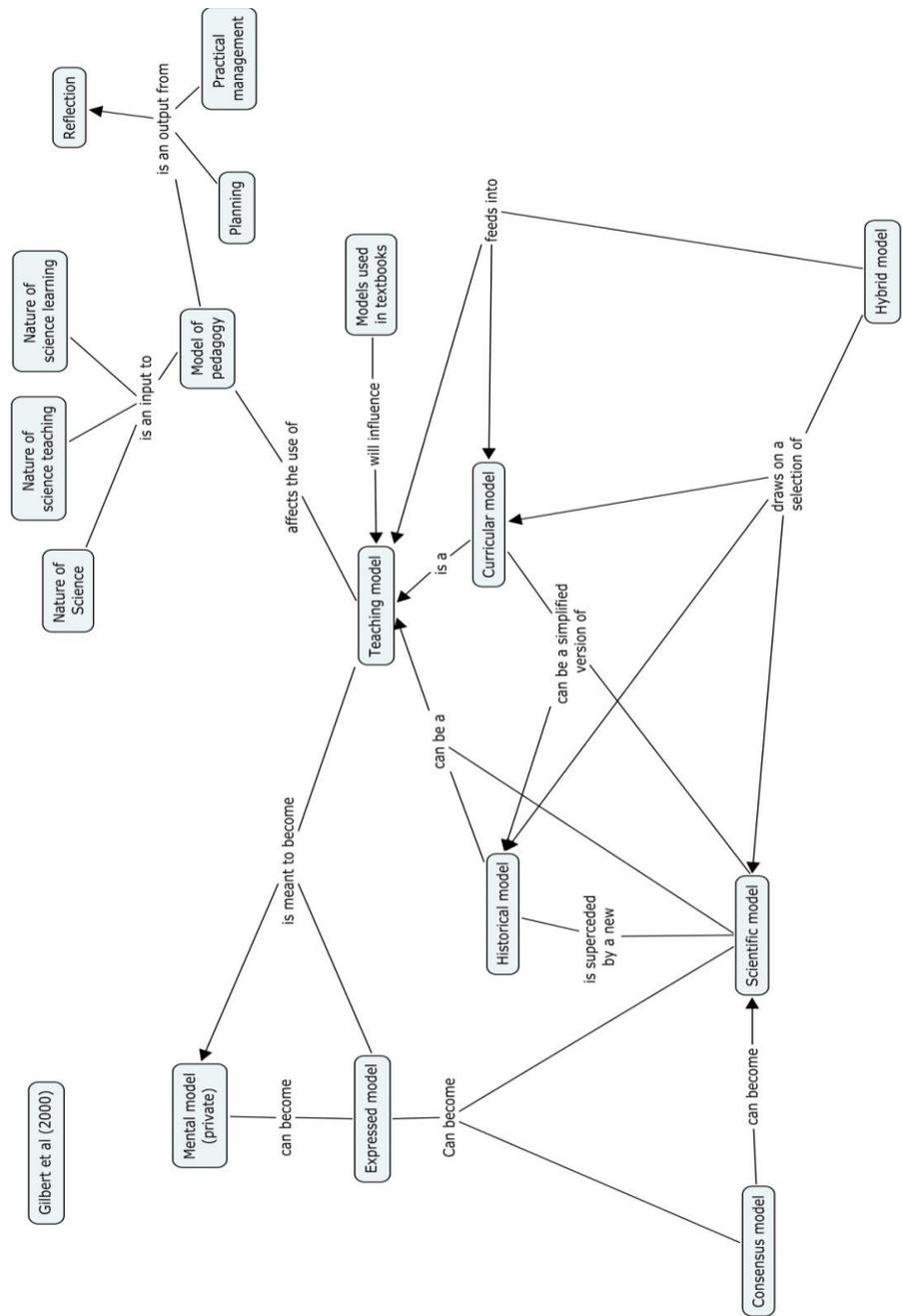
Figure 2.3   Concept map showing the inter-relationship between different types of models used in school science.   The concept map was developed from Gilbert, et al. (2000).

CHAPTER 3   Teaching electricity

According to Shulman (1987), content knowledge is a major component of teachers' pedagogical content knowledge.   This Chapter summarises the content knowledge required to teach electricity and discusses a number of possible pedagogical approaches.

Literature on teaching electricity tends to concentrate on difficulties for learners (Millar & King 1993, Engelhardt & Beichner, 2004 and Rosenthal & Henderson, 2006, for example) and there is not much about how teachers could develop their practice in this area (Mulhall, McKittrick and Gunstone, 2001). This Chapter compares primary and secondary school curricula in Scotland and England.   School textbooks and pedagogy texts for teachers as well as academic journals were reviewed to explore conceptual difficulties and pedagogical approaches including the types of electrical explanations adopted.   This Chapter concludes by re-stating the aim of the study, which was to explore whether or not beginning teachers' explanations for electricity changed with experience.   The research questions were framed drawing on the Scottish electricity curriculum and using PCK as the analytical framework.

3.1 WHAT IS ELECTRICITY?

Electricity has a ubiquitous role in modern life, and as a result, it is included in the school science curriculum at both primary and secondary school levels. The current Scottish electricity curriculum is contained in a number of documents: Scottish Executive (2000b), SQA (2004e), SQA (2004c), SQA (2004d) and Learning and Teaching Scotland (2009). Despite the inclusion of electricity in the school curriculum from an early age, work by Shipstone (1984), Shipstone, et al. (1988), Rosenthal & Henderson (2006) and others suggests that it is often poorly understood by school pupils and university students. Arguably, according to Gibbons, McMahon, & Wiegers (2003) and Gunstone, Mulhall, & McKittrick (2009) electricity is also poorly understood by some teachers, at both primary and secondary level. One reason for this lack of understanding may be that electricity is a conceptually difficult topic, as suggested by Driver, et al. (1985), Driver, Squires, et al. (1994), Galili & Lehavi (2006), Wenham & Ovens (2009) and Allen (2010). Learners may therefore construct their own incorrect understandings of the subject, R. Cohen, Eylon, & Ganiel (1983), Liégeois & Mullet (2002), and C. H. Tsai, Chen, Chou, & Lain (2007), which may be difficult to change.

3.1.1 Scientific model of electricity

School pupils are often introduced to electricity at a basic level in primary school and lower secondary school by considering what happens when a switch is closed in a simple series circuit, shown in Figure 3.1, consisting of a cell (often incorrectly called a "battery") connected to a lamp (bulb) by leads (wires).
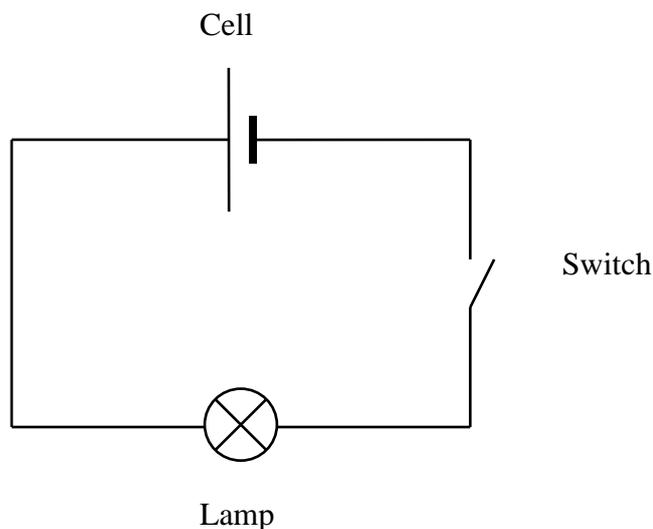
Figure 3.1   Labelled circuit diagram of a simple electrical circuit.

When the switch is closed, it is observed that the lamp lights.   The full scientific explanation of what is happening is complicated and is unlikely to be understood by learners unless they later study university level physics.   However, even university level textbooks may not explain this observation correctly, Sefton (2002).

Einstein once said:

> *It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.*   *Einstein (1934)*

This quotation is often paraphrased as, "an explanation should be as simple as possible, but no simpler."   Bearing this in mind, a partial explanation of why the lamp lights when the switch is closed is that free electrons move around the circuit with a very low drift velocity.   The slow drift velocity of the electrons is caused by an electric field directed along the wire. However, energy is transferred from the cell to the lamp not by the electrons but by the electromagnetic field outside the wires which is caused by the movement of the electrons.

A fuller version of this explanation was given by Sefton (2002, p. 3), embodying the consensus model for electricity:

The story of energy transfer from the battery to the globe goes like this. When the battery is first connected to complete the circuit it pushes electrons (charge) around so that they pile up on the surfaces of some parts of the circuit, leaving a deficit of electrons, and hence a positive charge on other parts of the conductors' surfaces. This pushing around of electrons is mediated by the electric field. The charge separation in turn produces electric field inside the connecting wires as well as in the wire filament of the light globe. The internal electric field is directed along the axis of the wires and is responsible for producing a drift of mobile charge carriers, current, in the wires. To explain energy transfer we need to look at what is happening outside the wires. As a consequence of the surface charges on the wires, there is an electric field in the space outside the wires (as well as inside). Also, as a consequence of having a current in the wires, there is a magnetic field in the space around the wires. It is this combination of electric field and magnetic field in the space outside the wires that carries the energy from battery to globe. Once the fields are set up, the energy travels through space, perpendicular to both the electric field and the magnetic field, at the speed of light. Energy leaves through the sides of the battery and enters the wire of the globe through the sides of the wire.

However, neither the simplified explanation, nor Sefton's fuller explanation were found in the school textbooks examined, SPACE (1993), Chambers, Marshall, Souter, & Stark (2002a), Chambers, Marshall, Souter, & Stark (2002b), Fraser & Coppock (2002), McCormick & Baillie (2006).

Analysis of the vocabulary used in Sefton's explanation revealed a variety of different types of concepts or entities, Ogborn, Kress, Martins, & McGillicuddy (1996), some of which may be problematic for school pupils.   Sefton constructed

his explanation using both concrete and abstract entities and a number of processes based on these entities.

Concrete entities

Sefton referred to concrete and visible items such as the battery, globe (lamp), wires, wire filament, surfaces, circuit and space.   This concrete vocabulary was included in the curriculum documents discussed in the next section.   The quotation also used concrete vocabulary which referred to invisible concrete entities.   Theses invisible entities were electrons, charge, and current which were included in pre-16 school science, and also charge separation, which was not.

Abstract entities

Sefton also used a number of abstract entities in his explanation.   Energy and energy transfer were included in the pre-16 curriculum documents discussed in the next section.   However, electric and magnetic fields did not begin to appear in detail until the Higher, SQA (2004b), and Advanced Higher, SQA (2004a), stages of the Scottish curriculum.   Both the Higher and Advanced Higher Physics Arrangements documents referred to electric fields in the context of electrostatic effects, not current flow.   The interaction between electric and magnetic fields to transfer energy has not been included in the Scottish electricity curriculum to date.

Processes

Sefton's explanation also used a number of processes which were based on the entities discussed previously.   He discussed the abstract idea of energy transfer and ideas about charge separation and a deficit of electrons which built on these invisible entities.   Sefton's explanation constructed new and more abstract entities from the abstract and/or invisible entities already considered.

Sefton's conclusion that, "energy leaves through the sides of the battery and enters the wire of the globe through the sides of the wire" means that in an electrical circuit, energy is **not** transferred from the battery to the lamp by a current travelling through the wires. Rather, energy is transferred from the battery to the lamp via the electromagnetic field travelling through space. The next section will show that the ideas needed to explain this concept are not contained in pre-16 curricula in Britain.

A number of authors have considered the role of surface charge when teaching about electricity at university level. Hirvonen, Sormunen and Viiri (2001) and Hirvonen (2007) discussed teaching interventions using surface charge to explain direct current. This confirmed that this level of understanding is appropriate for university students rather than school pupils.

3.2 ELECTRICITY IN THE SCHOOL CURRICULUM

Recent changes in Scotland have meant that the 5-14 Guidelines (2000) are in the process of being superseded by the Curriculum for Excellence (CfE) (2009). Additionally, the current examination system comprising Standard Grade and National Qualification examinations will be replaced by a unified system of National Qualifications, Scottish Government (2009b).   However, the basic electrical concepts to be taught in the Curriculum for Excellence are unchanged.   Therefore it is likely that the new examinable curricula will still contain similar electrical content.

3.2.1 Comparison of 5-14, CfE and National Curriculum electrical outcomes

This section discusses the electrical content in the 5-14 Guidelines, Scottish Executive (2000b); CfE, Learning and Teaching Scotland (2009); and the English National Curriculum, QCA (1999).   Before this discussion, there is a comparison of the ages at which the different levels or stages occur in the two systems, see Table 3.1.

One of the major structural differences between the English and Scottish education systems is the age of the primary – secondary transition.   In Scotland, pupils spend seven years in primary education, but in England pupils spend six years in primary education.   Table 3.1 compares the ages and stages in the two systems.   The first column shows the ages of pupils which are linked to the Scottish system of school years in the second column.   The third column shows the age range of the existing 5-14 levels.   Column 4 shows the CfE levels which will replace the 5-14 levels.   The final two columns show the English system of school years and the Key Stages of the English National Curriculum.   The comparison of the levels and stages in the Scottish and English curricula was necessary because although there is a degree of overlap between the levels in the 5-14 curriculum and CfE and the Key Stages, there is not a perfect match.   Table 3.1 also shows the different ages for the primary –

secondary transition in Scotland and England.   In Scotland, the primary – secondary
transition occurs between P7 and S1 and will now occur between the Second and
Third levels.   In England, this transition occurs between Years 6 and 7 and between
Key Stages 2 and 3.   The Scottish documents explicitly recognise that not all pupils
would have achieved the expected level at the same age.

Table 3.1   Comparison of ages and stages in the English and Scottish education
systems.   (Adapted from Bryce (2008), Table 70.3, p.588 by showing
ages and adding the CfE levels.)

Age	Scottish school year	5-14 Levels Scottish Executive (2000b)	CfE levels Learning and Teaching Scotland (2009)	English school year	Key Stage QCA (1999) and QCDA (2009)
3 - 4			Early		EYFS
4 - 5			Early	Reception	EYFS
5 - 6	P1	A	Early	Year 1	KS1
6 - 7	P2	A	First	Year 2	KS1
7 - 8	P3	A/B	First	Year 3	KS2
8 - 9	P4	B/C	First	Year 4	KS2
9 - 10	P5	C/D	Second	Year 5	KS2
10 - 11	P6	C/D	Second	Year 6	KS2
11 - 12	P7	D/E/F	Second	Year 7	KS3
12 – 13	S1	E/F	Third/Fourth	Year 8	KS3
13 - 14	S2	E/F	Third/Fourth	Year 9	KS3
14 - 15	S3	SG / Int 1 & 2	Third/Fourth	Year 10	KS4
15 - 16	S4	SG / Int 1 & 2	Senior	Year 11	KS4

Table 3.2 compares the electrical content of the Scottish and English electrical
curricula.   The table was constructed by linking the electrical outcomes from the 5-
14 Guidelines, CfE and the National Curriculum.   The first two columns show the 5-
14 target codes and the content of each code; the third and fourth columns show the
same for CfE; and the fifth and sixth columns show the Key Stage and the electrical
content of the National Curriculum.

Table 3.2   Comparison of the electrical content of various curriculum documents.

5-14 Target Code	Content[1]	CfE Target Code	Content[2]	National Curriculum	Content[3]
A1.3	Give examples of everyday appliances that use electricity	Early SCN 0-09a	I know how to stay safe when using electricity. I have helped to make a display to show the importance of electricity in our daily lives.	KS1	1 Pupils should be taught: a about everyday appliances that use electricity b about simple series circuits involving batteries, wires, bulbs and other components [for example, buzzers, motors] c how a switch can be used to break a circuit.
A1.4	Identify some of the common dangers associated with the use of electricity				
C1.4	Construct simple battery-operated electrical circuits, identifying the main components	First SCN 1-09a	I can describe an electrical circuit as a continuous loop of conducting materials. I can combine simple components in a series circuit to make a game or model.	KS2	1 Pupils should be taught: a to construct circuits, incorporating a battery or power supply and a range of switches, to make electrical devices work [for example, buzzers, motors] b how changing the number or type of components [for example, batteries, bulbs, wires] in a series circuit can make bulbs brighter or dimmer
C1.5	Classify materials as electrical conductors or insulators and describe how these are related to safe use of electricity				

Table 3.2 (continued).

5-14 Target Code	Content[1]	CfE Target Code	Content[2]	National Curriculum	Content[3]
D1.5	Construct a series circuit following diagrams using conventional symbols	Second SCN 2-09a	I have used a range of electrical components to help to make a variety of circuits for differing purposes. I can represent my circuit using symbols and describe the transfer of energy around the circuit.	KS2	Pupils should be taught c how to represent series circuits by drawings and conventional symbols, and how to construct series circuits on the basis of drawings and diagrams using conventional symbols.
D1.6	Describe the effect of changing the number of components in a series circuit				
E1.6	Construct a parallel circuit, following diagrams	Third SCN 3-09a	Having measured the current and voltage in series and parallel circuits, I can design a circuit to show the advantages of parallel circuits in an everyday application.	KS3	1 Pupils should be taught: a how to design and construct series and parallel circuits, and how to measure current and voltage b that the current in a series circuit depends on the number of cells and the number and nature of other components and that current is not 'used up' by components c that energy is transferred from batteries and other sources to other components in electrical circuits
		Fourth SCN 4-09a	Through investigation, I understand the relationship between current, voltage and resistance. I can apply this knowledge to solve practical problems.		
E1.7	Use the terms 'voltage', 'current' and 'resistance' in the context of simple series circuits				

Notes to Table 3.2
1   Content labels and statements from www.ise5-14.org.uk
2   Content labels and statements from http://www.ltscotland.org.uk/curriculumforexcellence/sciences/outcomes/forceselecticityandwaves/electricity/index.asp
3   Content labels and statements from http://curriculum.qcda.gov.uk/uploads/Science%201999%20programme%20of%20study_tcm8-12062.pdf

Table 3.2 shows that the basic electrical curricula in British primary and lower secondary schools do not include much detail about electric and magnetic fields. Basic electromagnetism, in the sense that there is a magnetic field around a current-carrying wire, is included in the Standard Grade, SQA (2004e, pp. 35, 67), and Intermediate 2 Physics Arrangements Documents, SQA (2004d). However, the Scottish pre-16 curricula do not include the interaction between the electric and magnetic fields in the curriculum documents discussed above. This was also the case with the Australian physics curriculum at the time Mulhall, McKittrick, & Gunstone (2001, p. 578) were writing.

Therefore, the definition of basic current electricity used in this thesis includes direct current, voltage and resistance, but excludes electromagnetism. This definition was based on the elements of the pre-16 curriculum described in Table 3.2.

3.3 DIFFICULTIES IN LEARNING ABOUT ELECTRICITY

The previous section defined basic current electricity to include direct current, voltage and resistance, but to exclude electromagnetic effects. This definition was based on the content of the British electricity curricula described in table 3.2 above. One of the consequences of this definition was that it is not possible to give a fully correct explanation for such apparently simple phenomena as a lamp (bulb) lighting to pre-16 pupils. The rest of this section discusses some possible approaches to teaching electricity within this limitation.

According to Piaget (2001), children do not begin to enter the formal operational stage until the age of at approximately 12, and many children do not reach this stage of cognitive development until several years later. As a result, it is likely that many pre-16 pupils in secondary school will struggle to understand the highly conceptual nature of electricity. This may explain why the basic electricity curriculum causes difficulties for many pupils.

Research by a number of authors including Psillos (1998), Borges & Gilbert (1999), Engelhardt & Beichner (2004) and Jabot & Henry (2007) dealing with learners' misconceptions about electricity has found generally similar, consistent patterns of misconceptions across the age range from primary to secondary and university education. Although, some differences between learners in different countries were found, the patterns of misconceptions were found to hold internationally by Butts (1985), Shipstone, et al. (1988), Pardhan & Bano (2001) and Kücüközer & Demirci (2008). Section 3.3.1 discusses pupils' conceptual difficulties understanding aspects of electricity. Section 3.3.2 discusses teachers' conceptual difficulties understanding aspects of electricity.

3.3.1 Pupils' conceptual difficulties: electricity

Electrical misconceptions

Some of the earliest work on learners' misconceptions was carried out by Driver, et al. (1985) and Driver, Squires, et al. (1994). This section begins by considering Shipstone (1984) and Shipstone (1985) which reported pupils' likely misconceptions about electricity. Later work by Shipstone, et al. (1988) considered older pupils' difficulties learning about electricity in five European countries. Shipstone et al. found that although there were some differences among learners in different countries, there were common areas of difficulty, which could be combined to form a coherent picture of pupil difficulties. The pupils' coherent, but incorrect picture agreed with the findings of Shipstone's earlier research. Pupils believed that the battery supplied a constant current, which was influenced locally rather than globally by circuit components. Components were believed to consume current, rather than loosely speaking "consuming" energy. This belief may have arisen because the pupils did not distinguish correctly between current and voltage. Duit, Jung and von Rhoeneck (1985) edited the proceedings of a 1984 conference about teaching electricity which included discussion about many of these issues. Similar results were later reported for university students, Picciarelli, Gennaro, Stella, & Conte (1991).

An alternative approach to investigating pupil's conceptual difficulties was used by Pine, Messer, & John (2001), who asked experienced primary teachers to identify topics pupils found more difficult. Electricity was one of the areas the teachers identified.

Electricity

Around the same time as Driver, et al. (1985) were investigating pupils' conceptual difficulties across a range of science topics, Duit et al. (1985) edited the book of a conference which discussed pupils' difficulties learning electricity. More than a decade later Duit & von Rhöneck (1998) reported similar findings about the difficulties pupils had learning about electricity. In their paper suggesting a

possible way to help pupils to learn about electricity more successfully, Mulhall et al. (2001) identified a number of problems for pupils learning about electricity. According to Mulhall et al. (2001, p. 580):

> *... there are not even the beginnings of any form of justified consensus about the range and nature of models/analogies/metaphors that might be appropriate for the teaching of electricity at any given level or at different levels.*

They went on to argue that the basic concepts of electricity are not clearly defined in many textbooks. The next three subsections explore pupils' likely knowledge about direct current, voltage and resistance which are the three basic electrical concepts included in Table 3.2 above.

Direct current

Exploring the final version of the Students' and Teachers' Conceptions and Science Education (STCSE) database, Duit (2009), revealed that most references to teaching one specific aspect of electricity were about direct current.

Stocklmayer & Treagust (1996) considered how novices and experts modelled direct current as did Borges & Gilbert (1999). Both sets of authors found progression in learners' ideas about current as they gained in experience and both found pupils' models did not agree with expert models.

Voltage or potential difference

In contrast with direct current, the STCSE database contained many fewer references containing only the words "voltage" or "potential difference". This may be because the traditional emphasis on teaching introductory electricity is on direct current rather than voltage. According to Psillos, Koumaras, & Tiberghien (1988, p. 29) in their introduction of voltage as the main concept in teaching electricity,

The learning of this concept [voltage] is considered as very difficult.

The meaning of voltage in electrical circuits is not well-understood by many learners. Part of the problem may be that potential difference and electromotive force (emf) may be treated as synonyms for voltage, although the three concepts have related but different meanings, as discussed by Page (1977).

Millar & King (1993) and Millar & Beh (1993) discussed the problems 15-year old pupils had understanding voltage in simple series and parallel circuits.   They concluded that many pupils struggled to answer qualitative questions about a simple series circuit and used local rather than global reasoning, as reported by other authors.   Similarly, when discussing pupils' understanding of parallel circuits, pupils again used an incorrect approach by considering the problem as being to do with adding resistors in parallel rather than voltage in parallel and applied $V = IR$ incorrectly.

Liégeois, Chasseigne, Papin, & Mullet (2003) reported that pupils tended to ignore information about resistance because they considered voltage and current to be similar concepts.   This made it difficult for the pupils to include information about resistance when trying to calculate potential difference.

In this section about voltage and the previous section about direct current, authors have argued for the use of current or voltage as the primary concept when introducing pupils to electricity. However, Silva & Soares (2007) have argued that rather than arguing for current or voltage as the primary concept, it is better to concentrate on the electric circuit as a system where the current and the voltage interact with and influence each other.

Resistance

The number of authors who dealt mainly with teaching and learning resistance was limited, perhaps because current and voltage were seen as the main explanatory concepts for teaching electricity.   Liégeois and Mullet (2002) discussed the lack of

studies about learners' understanding of resistance.   In their study, they highlighted learners' lack of understanding of the concept of resistance and also the lack of impact of teaching about resistance.   Liégeois and Mullet's research was supported by aspects of Shipstone's (1984 and 1985) earlier work about children's understanding of electrical concepts including resistance.

Cheng & Shipstone (2003a) introduced the concept of an AVOW (amps, volts, ohms and watts) diagram as a possible approach to teaching about these concepts.   Despite reporting positive effects when using AVOW diagrams with A-level learners and their teachers, Cheng & Shipstone (2003b), this approach does not seem to have been taken up more widely.

As part of her doctoral research, Engelhardt developed a test to assess understanding of basic concepts in current electricity, including resistance (Engelhardt and Beichner, 2004).   However, the focus seemed to be on current and voltage rather than resistance.

Despite the documented difficulties learners have with the concept of resistance, the Standard Grade physics syllabus, SQA (2004e, p. 29), treated the concept of resistance as straightforward.   Once the concept had been defined, it was then used in other content statements.   A similar approach was taken in the approach to resistance in the arrangements documents for the Intermediate 1 and 2 physics courses, which were developed after the Standard Grade physics course.

Conceptual understanding movement

Much of the work discussed above was carried out by interview or observation with school pupils in primary or early secondary schools.   However, the conceptual understanding movement, beginning with the Forces Concept Inventory, Hestenes, Wells, & Swackhamer (1992a), surveyed the understanding of American high school or university students about a range of topics.   For example, Maloney, O'Kuma, Hieggelke, & Van Heuvelen (2001) and Ding, Chabay, Sherwood, & Beichner (2006) investigated introductory physics students' understanding of electricity and

magnetism.   However, both the Maloney, et al. (2001) and the Ding, et al. (2006) surveys were at too high a conceptual level to investigate the understanding of basic school electricity.

Engelhardt & Beichner (2004) produced a diagnostic test to investigate pupils' understanding of direct current resistive electrical circuits.   The test was called "the Determining and Interpreting Resistive Electric Circuit Concepts Test", otherwise known as DIRECT.   This test is suitable to investigate pupils' understanding of basic electrical circuits.   Version 1.0 is available in the public domain, but version 1.2 which is not in the public domain was obtained through information on the NCSU Physics Education R & D Group (2007) "Assessment Instrument Information Page."

As argued in the earlier parts of this section, teaching electricity to pupils is difficult. Mulhall, et al. (2001) argued that electricity is a difficult topic for pupils to learn because the content is very abstract and consists entirely of models.   Additionally, there was no agreement among teachers about what should be taught at different levels. A possible solution to the first part of Mulhall et al.'s approach may have been offered by Cheng & Shipstone (2003a), who developed a diagrammatic approach to teaching about electricity holistically at post-16 level.   Their approach has been trialled in schools with some success, Cheng & Shipstone (2003b). However, this approach does not seem to have been more widely adopted.

3.3.2 Teachers' conceptual difficulties: electricity

As discussed in the previous section, many physics students have a lack of conceptual understanding in a number of areas of physics, including electricity and magnetism.   Physics teachers are a product of a university education about physics. Therefore, it is at least possible that some teachers may also demonstrate a lack of conceptual understanding about basic electricity.   The rest of this section discusses the evidence for this suggestion.

Secondary teachers and electricity

In their 1983 paper, Cohen et al. discussed students' understanding of the role of current and voltage in electrical circuits and argued that voltage is the more fundamental concept. In the same study, when a qualitative test was administered to high school teachers, the average score of the 21 teachers was 51.5%.

Since the 1983 study, other researchers have explored teachers' misconceptions or alternative conceptions and found that a number of teachers in these small scale studies have misconceptions about electricity. The teachers were found to share the same misconceptions as pupils.

Heller & Finley (1992) worked with elementary and middle school teachers on an in-service course about series and parallel circuits and uncovered a number of misconceptions all the teachers held, although the teachers did not apply the misconceptions consistently to solve problems. Stocklmayer & Treagust (1996, p. 163) found that physics teachers tend to view a current as freely moving electrons in a wire:

> *The model of current which is universally accepted is one of moving electrons in a wire, responding to a difference in potential across the ends of the wire.*

However, electrical professionals, including physics lecturers visualised the importance of the electric field in understanding electricity (Borges and Gilbert, 1999). This is more in line with the explanation given by Sefton (2002) at the beginning of this Chapter. Pardhan & Bano (2001) discussed the alternative conceptions of six middle school (12 – 16 old pupils) science teachers in Pakistan about teaching electricity. They also found that the teachers held a number of alternative conceptions about current electricity.

In their more general work about preparing pre-service and in-service K – 12 teachers, McDermott, Heron, Shaffer, & Stetzer (2006, p. 764) asked teachers to explain the brightness of a number of lamps. Only 15% of the teachers in each group were able to answer correctly. In a study of Turkish trainee and experienced

teachers who answered questions about basic electrical ideas, Kücüközer & Demirci (2008) generally found higher percentages of correct answers. The results discussed in this paragraph suggested that large numbers of physics teachers may have misconceptions about the basic electricity curriculum.

Gunstone, et al. (2009) interviewed a number of experienced high school teachers and textbook authors about their understanding of basic electricity and their approaches to teaching the subject. Gunstone et al. expressed concern about the level of understanding indicated by some of the teachers and one of the authors interviewed.

A different approach was taken by Galili & Lehavi (2006). They identified difficult physics concepts, including electric charge, electric current, and electromotive force (emf), and asked teachers to define them. This method allowed them to explore teachers' understanding of the concepts. They found that teachers tended to view a current as a flow of charge. The problem they identified with this approach was that the teachers were unable to define current precisely and therefore the concepts behind current flow were not available to the pupils. Therefore, teachers' difficulties defining electrical concepts may impact on their pupils' learning.

A more positive finding about preparing beginning teachers was reported by Kind (2009a). In England as well as Scotland, science teachers are required to teach outwith their subject specialism. Kind (2009a) explored the effect of requiring trainee science teachers to teach outwith their subject specialism. She found that "the results are counter-intuitive", page 1529. Many trainee science teachers delivered better lessons outwith their specialisms. This may have implications for teacher education within subject specialisms, including physics.

The papers discussed above dealt with the misconceptions of a number of physics teachers in a variety of countries about teaching basic electricity. The implication is that the teachers' misconceptions about electricity will have a negative impact on pupils' learning.

3.4 TEACHING APPROACHES TO ELECTRICITY

3.4.1 Electrical analogies

As mentioned earlier, according to Mulhall, et al. (2001) the role that metaphors play in teaching about electricity is limited. Sutton (1992, pp. 11-12) in a chapter called, "Fossils of old thoughts," discussed the way in which the original experiments about electricity introduced the idea of electricity as a kind of fluid, although the original ideas which led to this vocabulary are now mostly forgotten. However, the standard way to talk about electricity uses the vocabulary of a current flowing through a resistor and being able to measure the voltage across a resistor (Borges and Gilbert, 1999 and McCormick & Baillie, 2002). The word current itself suggests an analogy between an electrical current and a flow of water. This analogy is reinforced by talking about the *flow* of current *through* a resistor by analogy with the flow of water through a pipe. This further suggests a metaphor comparing voltage to water pressure or a push.

Table 3.3, below, compares the electrical analogies used in four different pedagogical texts for teachers. Each horizontal section of the table contains examples of a different category of analogy. A tick indicates that the source contained a particular analogy. The texts by Asoko & Boo (2001) and Summers, Kruger, & Mant (1997a) are for primary teachers. The chapters by Harrison (2008a) and (2008b) are for secondary teachers. Harrison's Chapters in Harrison & Coll (2008) contained more analogies and more varied analogies than the texts for primary teachers. This is probably a reflection of the fact that specialist secondary science teachers need a wider range of knowledge than primary teachers who teach a wider range of subjects.

Table 3.3   Use of electrical analogies from different sources.   Text A is Asoko & Boo (2001); text B, Harrison (2008b), Chapter 4; text C, Harrison (2008a), Chapter 8; and text D, Summers, Kruger, & Mant (1997b).

Text	A	B	C	D
Types of Analogy				
Water Analogies				
Water Circuit / water in a pipe		✓	✓	
Water Pressure		✓	✓	
Shared water flow		✓	✓	
Fire - buckets	✓			
Continuous Analogies – or transport analogies				
Continuous Train		✓	✓	
Bicycle Chain	✓	✓	✓	✓
Rope / String	✓			
Conveyor belt			✓	
Escalator			✓	
Anthropomorphic analogies				
Sweets / coins	✓	✓		✓
Electric Field - Team sports or battlefield analogy		✓	✓	
Doors / turnstiles/ school gym		✓	✓	
Muddy field				
Gravitational analogies				
Pin board				✓*
Marble run				✓

* - analogy of choice

Chapter 4 Methodology

4.1 RESEARCH DESIGN

4.1.1 Introduction to data collection and analysis

Chapters 2 and 3 reviewed literature on constructivism and science education, and teaching electricity respectively. This Chapter begins by deriving a number of research questions based on the literature review and professional issues about physics teacher education to allow changes in physics teachers' approaches to teaching electricity to be investigated using an analytical framework based on Shulman's 1987 conception of pedagogical content knowledge. The Chapter then evaluates the appropriateness of a number of research methodologies to address the research questions. The Chapter discusses the rationale for the research methodology adopted and concludes by describing the data collection and analysis strategies.

In the first section, the research questions are stated and then various research approaches are evaluated and the reasons for the methodological choices made are discussed. The second section discusses the methodologies selected and their application to this research. The third and fourth subsections describe how data were collected and analysed. In what follows, the focus is on the methodologies or methods that were appropriate for this research.

4.1.2 Research questions

The research questions were structured around Shulman's (1987) conception of pedagogical content knowledge, which was discussed in Chapter 2. Therefore the research questions covered the teachers' content knowledge, curricular knowledge and pedagogical knowledge. The questions which covered the teachers' content knowledge about electricity also drew on the electrical ideas discussed in Chapter 3. In Shulman's 1987 version of PCK, pedagogical knowledge included knowledge of learners, the context and values. The concept of reflection was added as an

additional component of pedagogical knowledge because it is an important aspect of the professional development of teachers (GTCS, 2006b).

Content knowledge

1.1 What did the student teachers know about basic (secondary school level) current electricity at the beginning of the PGDE course?

1.2 How was the student teachers' knowledge about basic current electricity organised?

1.3 Did the teachers' content knowledge about electricity change as they gained more experience?

Curricular knowledge

2.1 Did the curricular knowledge of the beginning teachers develop over time, and if so, how?

Pedagogical Knowledge

3.1.1 What types of explanations, including analogies and metaphors, did the teachers use to explain current electricity in the secondary school and did the types of explanation change over time?

3.1.2 What electrical models were adopted by the teachers and did the models change over time?

Knowledge of learners, context and values

3.2.1 What knowledge about pupils (learners) did the teachers display and did this change over time?

3.2.2   What knowledge about the context did the teachers display and did this change over time?

3.2.3   What information about their values did the teachers reveal either implicitly or explicitly?

3.2.4   Did knowledge about learners affect the way the teachers taught and if so how?

Reflection

3.3.1   To what extent did the teachers reflect on their teaching?

4.1.3 Research methodologies

One of the constraints on this research was that it was carried out within the context of the ongoing work of a teacher education course. As a result, the research instruments used required to be integrated into the ongoing, university-based work of the student teachers and therefore were not additional requirements for members of the class. This allowed the student teachers the option to participate in the interviews, with the clear understanding that, whether or not they chose to participate, the decision would not affect their relationship with either of the two class tutors.

The theme of the research was exploring change through time about approaches to teaching a particular topic, therefore interviews and / or observation would have been suitable approaches. Observation was ruled out for practical and ethical reasons. This suggested that a suitable approach to the research was a series of semi-structured interviews based around a professional discussion between the tutor and the (student)[1] teachers about their approach to teaching the Scottish syllabus for basic current electricity. In this research, basic current electricity is defined to be direct current only and considers current, voltage and resistance in simple series and parallel circuits up to and including voltage divider circuits using light and temperature dependent resistors (LDRs and thermistors.)

Quantitative approaches to surveying content knowledge

Surveys and questionnaires are common quantitative approaches to research. The development of validated instruments is time-consuming, but the use of a suitable, pre-validated questionnaire can give useful information in a relatively short time-scale. Engelhardt & Beichner (2004) discussed the development and use of a diagnostic questionnaire (DIRECT (Determining and Interpreting Resistive Electric Circuit Concepts Test) 1.1 and 1.2) which has been validated by post-test interviews. The questionnaire was designed to discover US high school and university students'

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[1] The use of "(student) teacher" indicates that the interviews were student teachers during Interviews 1 and 2 and were qualified teachers during Interviews 3 and 4.

understanding of direct current resistive circuits. Students usually attend US high schools from grades 9 – 12 and as such the Scottish equivalent is S3 to S6. This means that the DIRECT 1.2 questionnaire could be used with upper secondary pupils in Scotland studying physics and so covers some of the content knowledge the student physics teachers would be expected to know and as such was used to assess their basic electrical knowledge.

Although all the student teachers have been awarded degrees which contained a minimum number of credits in the field of electricity, the level of their content knowledge was expected to vary, Shulman (1986, p. 8). In addition, it was possible that the student teachers might not have considered their basic electrical knowledge since their own school days.

Qualitative research methodologies

This research used repeated semi-structured interviews to explore the ways in which (student) teachers of physics developed their approach to explaining electrical concepts. Thus, the research belonged to the interpretative tradition, Merriam & Associates (2002). However, it is necessary to consider where the research was situated within the range of qualitative methodologies.

A useful introduction to qualitative research methodologies was given by Creswell (2007). In the first edition (1998) Creswell's overview about qualitative research was entitled "Qualitative Inquiry and Research Design: Choosing Among Five Traditions." The second (2007) edition was very similarly titled, except that the subtitle now reads: "Choosing Among Five Approaches." The change from "traditions" to "approaches" reflected a change among qualitative researchers about how to conduct qualitative research from using one particular tradition to being more willing to choose an approach which is suitable for a particular study.

Creswell considered narrative research, phenomenology, grounded theory, ethnographic research and case study in both editions of his book. As well as considering these methodologies, the present section here also considers the

suitability of action research, focus groups, content analysis, discourse analysis and interviews for this research.

1.   Narrative research

Narrative research focuses on the stories, or narratives, told by the research participants.   These narratives could be spoken or written.   The key attribute of narrative research is that the selected material is given a narrative structure.   This broad definition partially arose from the wide range of disciplines which use narrative research, for example Chase (2005) in Creswell (2007, p. 54).   Narrative research is often based on analysis of stories told by an individual or a small group of people.   Data are collected from individuals and the people who know them.   The subjective nature of the information collected influences the range of possible methods of analysis. However, the narrative produced is the narrator's interpretation of the events, Chase (2005, p. 656).

Methods of analysis discussed by Polkinghorne (1995, p. 12) included "analysis of narratives" based on themes detected in a number of stories, or "narrative analysis" where researchers structured the stories.   Reissman (2006) also discussed a number of other forms of analysis in narrative research.   The most straightforward form of analysis discussed was thematic analysis, which was based on the assumption that language itself is unproblematic and that 'any competent user of the language' would understand the story.   In this discussion, thematic analysis focused on what was said rather than how it was said.   Interactional analysis studied the interaction between the speaker and listener and how speakers and listeners worked together to construct the exchange, for example in medical or legal and presumably also in educational settings.

Narrative inquiry has been used to investigate teacher learning, particularly beginning teacher learning, by Doecke, Brown, & Loughran (2000) who worked with beginning teachers of English in the secondary school to construct a narrative via group interviews.   Another narrative study using group rather than individual

interviews was carried out by Clemente & Ramírez (2008) who developed a narrative about teaching reading in the primary school.

Narrative inquiry has not been considered further for this study because the group of student teachers being considered was too large for a narrative account to be a useful way forward.

2.   Phenomenology

Phenomenology is an approach to human experience based on the philosophy of Edmund Husserl, Harré (2006).   This philosophical basis means that it is important for the researcher to clarify their underlying philosophical stance as part of the research process.   According to Creswell (2007, p. 62), '… phenomenology emphasizes the meaning of an experience for a number of individuals.'   Another way of expressing this is that phenomenology deals with the lived experience of individuals (van Manen, 1990).   Phenomenological approaches tend to be more interested in the experiences of a larger number of individuals than narrative analysis.

There are two approaches to phenomenology: van Manen (1990) hermeneutic phenomenology and 'empirical, transcendental, or psychological phenomenology', as described by Moustakas (1994).   According to Hammersley (2006, p. 133), hermeneutics is defined as:

> *the study of how we understand the communications, actions and*
> *products of other human beings*

As far as van Manen (2002) was concerned, the sources of meaning came from a wide variety of sources.   By contrast, Moustakas emphasised the role of 'bracketing' the experience of the researcher in order to concentrate on interpreting the participants' experiences anew. Once information has been collected from (a few) participants, significant quotes are selected to develop a "textual description" of what was experienced and a "structural description" which sets the experiences in context.

Phenomenology has been used for a range of purposes within science education. Powell (1997) investigated the lived experiences of two beginning science teachers, one who had gone straight into teaching and one who had had a previous career. Nevertheless, both teachers had adopted similar styles of teaching by the end of their first year of teaching. Papers by Volkmann & Zgagacz (2004) and Stefani & Tsaparlis (2009) applied different conceptual frameworks to phenomenology to investigate the lived experience of one physics graduate teaching assistant and a group of university chemistry students respectively.

A phenomenological approach to research deliberately brackets the researcher's preconceptions about the experiences of the research participants. However, the use of an explicit analytical framework to analyse the interviews meant that phenomenology was not an appropriate approach to this research.

3.   Grounded theory

Grounded theory is used to develop an inductive theory about a phenomenon using information gathered from interviews with participants. Classical grounded theory was developed by Glaser & Strauss (1967), based on a positivistic (scientific) worldview. After this, grounded theory was developed in several different ways. Strauss & Corbin (1990) and Strauss & Corbin (1998) developed a highly structured approach to grounded theory, the earlier version of which was systematically criticised by Glaser (1992) as being too structured and restrictive. Charmaz (2006) developed a more flexible method of constructivist grounded theory which is based on a different worldview to the positivist one espoused by Glaser & Strauss (1967).

Grounded theory has been used in science education research. Taber (2000) used grounded theory to develop a testable theory about how learners of A-level chemistry (mis)understood the processes of chemical bonding. Grounded theory was later used by Mansour (2008) to investigate how the beliefs of Egyptian science teachers affected their approach to teaching. He used a more sophisticated multi-grounded

theory approach to allow for the influence of external theories on his developing grounded theory.

Grounded theory was not used in this research because of its inductive nature. The analysis of the results was based on an analytical framework derived from theory and was therefore a deductive process which precluded using a grounded theory approach. However, one of the aspects of grounded theory and phenomenology is remaining open to the data. This was attempted during analysis of the interviews in this research.

4.   Ethnographic research

Ethnography is based on cultural anthropology and the approaches used within this discipline. As a result, ethnography is concerned with particular social groups and the relationships within them. The usual research method is participant observation, whereby the researcher becomes one of the group to be investigated, so that the group can be understood in its own terms, Creswell (2007). According to Hobbs (2006, p. 101) "it is the intense meaning of social life from the everyday perspective of group members that is sought". In most cases the size group being considered is greater than 20.

Realist ethnography is based on a traditional approach within cultural anthropology, Van Maanen (1988), where the ethnographer is an objective observer who reported on the participants objectively through the participants' own words. In this case, power lies with the observer. A contrasting approach is adopted by critical ethnography, which, according to Carspecken & Apple (1992), Thomas (1993) and Madison (2005), is concerned with power relationships and where the ethnographer typically adopts an advocacy role on behalf of marginalized groups.

Ethnographic approaches to researching teacher education include the contrasting microethnographic approaches of Dillon (1989) and Powell (2000). Dillon (1989) described her study of one class of pupils over the course of a year as microethnography because it was part of a larger study, while Powell (2000)

described his report on one case being discussed by one group of preservice teachers as microethnography because of the limited nature of the study.

Ethnographic research requires extensive participant observation of a fairly large group to uncover the inner life of the group.   This is not a possible or desirable relationship between a tutor and students on a PGDE course and therefore an ethnographic methodology was discounted for this research.

5.   Case study

Drawing on a commonsense understanding of the word 'case', Gillham (2000) gave a definition of a case study which ranged in scale from an individual to a group or to an institution or large-scale community, set within particular boundaries.   Exploring a case to give a detailed description requires the use of many methods of data collection to gain an in-depth picture of the case or cases.   Although it is difficult to define exactly what case study is, Stake (2005, p. 444), Gillham's definition was in broad agreement with the ways in which other authors have defined a case. Although Stake (2005, p. 443) stated that "case study is not a methodological choice but a choice of what is to be studied," he also emphasised the aspect of the bounded system.   Stake's work appeared in Denzin & Lincoln (2005), who talked about "research strategies" on page xiv rather than methodologies.   This suggested, that in Creswell's (2007) terms, Denzin and Lincoln (2005) regarded case study as a methodology, as did Merriam (1998) and Yin (2009).

The main decision within case studies is how to identify the boundaries of the case(s).   Once cases have been identified, purposeful sampling is used to select the cases of interest.   A wide range of different types of data are collected: for example, Yin (2009) identified six types of information to collect.   There are also several possible approaches to the analysis of the case study.

Several authors have used a case study approach to investigate science teaching in general and physics teaching and physics teacher education in particular with a variety of boundary conditions. For example, Zembylas (2004) carried out a 3-year

ethnographic case study about the development of one elementary teacher's practical, classroom approach to teaching science.   Others have used a case study approach in research carried out on pre-service and in-service teachers.   Sperandeo-Mineo, et al. (2006) used a case study approach to investigate changes in 28 preservice physics teachers' pedagogical content knowledge.   Asikainen & Hirvonen (2009, p. 658) used case study to investigate the effectiveness of a quantum physics course for both in-service and pre-service teachers.   It could be argued that some of the studies described above, while they had clear boundaries, did not seem to have a sufficiently wide range of data collection methods to be classified as true case studies.

The aim of this research was to explore how beginning teachers' PCK changed. Exploratory research of this sort could be carried out using a case study approach provided that enough detailed information is gathered to illustrate the various influences on the changing explanations and provided that the boundaries of the cases can be sufficiently tightly drawn.   However, in this instance the research concentrated on a relatively narrow range of information and extended over a prolonged period of time.   Consequently, a case study approach was not judged to be suitable in this instance.

6.   Action research

Classically, action research is a methodology used by practitioners to result in a change in practice by linking theory and research through reflection.   As a result, the action research cycle of research and change followed by more research is the main approach to action research discussed in Burns (2000), Bryman (2004) and L. Cohen, Manion, & Morrison (2007) in general and Somekh (2006) and Stringer (2007) in particular.

The exploratory approach taken to investigating the (student) teachers' developing approach to teaching meant that the action research cycle of investigation and change would not be a good fit to the aim of the research, so action research was not considered in depth as a possible methodological approach to the research.

7.   Focus groups

Defining the term "focus group" can be difficult.   Barbour (2007, p. 2), quoting Kitzinger & Barbour (1999), defined a focus group as follows:

> *Any group discussion may be called a focus group as long as the researcher is actively encouraging of, and attentive to, the group interaction.*

One of the key features of this definition is that it dealt with the interaction between the members of the group rather than the interaction between the individual group members and the moderator (focus group leader).   This agreed with the definition of focus groups given by Bryman (2004, p. 346), where the aim was to construct a consensus view about a topic between the group members.

Using focus groups to investigate what the student teachers thought about electricity would have presented several practical difficulties.   The most pertinent from the student teachers' point of view was that they would already have discussed the topic with another tutor in class and may have been unwilling to revisit the topic in this way.   Bryman (2004) also suggested that focus groups generally work better when the participants do not know one another.   From the point of view of the present research, the aim was to discover how the individual teacher's approaches varied over time and achieving a group consensus would not have revealed the differences between the beginning teachers.   In addition, in a longitudinal study, the likely drop-out rate would have meant that it would be highly unlikely that sufficient teachers would still be participating by the end of the data gathering phase to form a focus group.   Therefore focus groups were not used as part of this research.

8.   Content analysis

Content analysis has often been described as a quantitative methodology for analysing the content of texts, J. Scott (2006) and D. Scott & Morrison (2007).

Other writers, including for example, Neuendorf (2002, p. 1) described content analysis as a quantitative technique only:

> *Content analysis may be briefly defined as the systematic, objective, quantitative analysis of message characteristics.*

Neuendorf also described content analysis as "the primary message-centered (sic) methodology" (p9).   However, other authors, such as Krippendorff (2004, pp. 15-17), maintained that content analysis can be a quantitative or qualitative methodology.   In his book, Krippendorff (2004, p. xviii) described content analysis as a methodology for examining texts:

> *… in order to understand what they meant to people, what they enable or prevent, and what the information conveyed by them does.*

The formal definition which Krippendorff (2004, p. 18) gave was that:

> *Content analysis is a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use.   (Original in italics)*

It may be that part of the rationale for this broad generalization was to get away from the purely quantitative view of content analysis in later survey texts such as J. Scott (2006), D. Scott & Morrison (2007) and also Weber (1990).   Krippendorff (2004, p. 19 and following) preferred a definition which allowed "content to *emerge in the process of a researcher analyzing a text*," rather than definitions which stated that the content of a text was a property of the text itself or of the sender and/or receiver of the text.   Krippendorff's preferred definition allowed for the effect of the content analysis (or researcher) to be considered during the process of the analysis.

According to L. Cohen, et al. (2007), who titled chapter 23 "Content analysis and grounded theory," content analysis and grounded theory are closely related because they are two important forms of qualitative data analysis which have features in common such as coding to reduce the data to a manageable form for reporting results.   However, the origin of the codes is different in the two approaches.

Coding in content analysis is theoretically derived before the (deductive) analysis begins, whereas coding in grounded theory arises inductively from the data.

Content analysis appeared to be a suitable methodology to use to analyse the transcripts of the semi-structured interviews carried out with the (student) teachers. It would have allowed an analysis based on categories which were developed from consideration of components of PCK. Detailed analysis of the data interview transcripts while carrying out the content analysis would also have allowed possibility of the emergence of further inductive categories which were grounded in the data.

However, one aspect of content analysis which has not been discussed is the role of unitising, or dividing the content into units of analysis. According to Krippendorff (2004, p. 83):

> *Content analysts must justify their method of unitizing, and to do so,*
> *they must show that the information they need for their analyses is*
> *represented in the collection of units, not in the relationship between*
> *the units, which unitizing discards.*

However, PCK is a recombination of different parts of a teacher's professional knowledge into a new form which means that the relationships between the components of PCK are important (Bishop and Denley, 2007). As a result, Krippendorff's comment above means that content analysis is not an appropriate approach to analysis interview data within an analytical framework based in PCK.

9.   Discourse analysis

There has been some debate about whether discourse analysis is a method or a methodology. Muncie (2006, p. 74) seemed to regard discourse analysis as a method rather than the methodology:

> *detailed exploration of political, personal, media or academic 'talk'*
> *and 'writing' about a subject, designed to reveal how knowledges*

(sic) are organised, carried and reproduced in particular ways and through particular institutional practices.

Johnstone (2002) on the other hand, regarded discourse analysis as a fully fledged methodology.   Early on, she gave an initial description of discourse as "language in use" (p xi).   Nevertheless, her two senses of the way the word discourse was used were similar to Muncie's definition.   Johnstone's (2002, p. 2) first, and most usual, sense of discourse was "actual instances of documentation in the medium of language."   Her second sense of discourse was based on Foucault's work which stated that discourses "are conventional ways of talking that both create and are created by conventional ways of thinking," (page 3)   Johnstone also provided a clear outline of one way to carry out discourse analysis based on a six step heuristic, or method.

L. Cohen, et al. (2007) situated their account of discourse analysis within chapter 17 "Accounts" and saw it as part of the ethnographic paradigm, which tried to capture the point of view of participants and was therefore concerned with the social context of the discourse as well as what was said.

The emphasis in discourse analysis on the social context of the interaction and on detailed linguistic analysis of the language used in the discourse mean that it was not an appropriate methodology in this context.   If the research had been based on observations about how explanations are constructed in a classroom context, then discourse analysis would have been a more appropriate approach, as used by Mercer (1995) and (2000).

Content analysis and discourse analysis

Perhaps because content analysis and discourse analysis both deal with the language used in the texts being analysed, they have sometimes been confused and regarded as similar methods of analysis.   However, content analysis and discourse analysis are used for different purposes.   Content analysis is concerned with the meanings of a text, Krippendorff (2004, p. 21).   Discourse analysis is concerned with the ideas

embodied in the text and the social or power relationships which these ideas reveal. Fairclough (2003, p. 1) talked about one approach to analysing discourse as the "*social* analysis of spoken and written language."

10.   Interviews

In the first chapter of their book about interviewing, Gubrium & Holstein (2002) discussed how interviews had become a ubiquitous feature of modern life.   They also discussed how the view of interviews has changed from a simple situation where the interviewer asks questions and the respondent replies to a more complex understanding where both interviewer and respondent contribute to the interview. This is similar to a point made by Kvale (2007, p. xvii), that an interview is a specific form of conversation where knowledge is produced through the interaction between an interviewer and an interviewee.   Therefore an interview can be viewed as a metaphorical "inter view" which takes place in the space between the interviewer and respondent.

Interviews have been used in quantitative or qualitative research, Jupp (2006c).   In this sub-section, only qualitative interviewing has been considered. Despite the classification of interview research as a method rather than a methodology, interviewing has been discussed here because it is one of the most common qualitative research methods and because it yields rich data which can be analysed to provide 'thick' descriptions of the phenomenon being researched, including the context, L. Cohen, et al. (2007).   Kvale's (2007) point in the previous paragraph left the type of interview as an open question.   In their overview of different types of interview, L. Cohen, et al. (2007, pp. 352-353) recounted the types of interview listed by several authors.   Lists of different types of interview were included by Kvale (1996 and 2007) and Gillham (2005).   However, Kvale (1996) and Lincoln & Guba (1985, p. 269) classified interviews according to their purposes: how open or closed they were; and whether they were looking for facts or opinions.   This definition also covered a broad range of different interview structures, ranging from a fully

structured, survey-type interview via semi-structured interviews to open-ended interviews.

Silverman (2001), and later L. Cohen, et al. (2007), identified three theoretical approaches to interviews which depended on different research paradigms. The three paradigms were positivism, emotionalism and constructionism. This approach via research paradigms can be linked with an approach to interviews based on the metaphors of the interviewer as a miner or a traveller, Kvale (2007). Approaching interviewing like a miner would be to collect data and then analyse it rather than the constructivist approach associated with the traveller metaphor where data collection and analysis proceed together and influence one another. While the miner metaphor might be most closely associated with positivist research, it could also be associated with qualitative research approaches.

Whatever the theoretical approach to interviewing, an interview study must be designed. Kvale (2007) discussed a seven stage process to design interview research, covering thematising, designing, interviewing, transcribing, analysing, verifying and reporting.

Many studies of pre-service and in-service science teachers have used interviews as part of the research design. Studies by Asikainen & Hirvonen (2009) and Kind (2009a) as well as Van Driel & Verloop (2002), Bryce & Gray (2004), Henze, van Driel, & Verloop (2008) among others have used different types of interview to investigate a wide range of issues around teaching and learning science.

Interviewing is a useful technique for exploratory qualitative research. Within the context of initial teacher education in physics, it was appropriate to use exploratory interviews to investigate how the (student) teachers taught electricity and if this changed as they gained experience. Organising the interviews around the basic electrical arrangements documents in Scotland provided a structure for the interviews which allowed the teachers' professional understanding of teaching electrical concepts to be demonstrated in a progressive way as they gained experience. Thus using semi-structured interviews provided a consistent framework to allow

comparison between teachers and across time.   The use of semi-structured interviews also allowed for the possibility of using follow-up questions as appropriate.

4.2 THE STUDY

After consideration of the practical constraints of working with student teachers and the various methodologies which could potentially have been used, the final decision was to conduct a mainly qualitative study using repeated semi-structured interviews with student teachers who volunteered to be interviewed. Therefore, "the design of the study follows the tradition of interpretative and descriptive qualitative work", Kind (2009a) following Merriam & Associates (2002), in order to provide 'thick' description of the student teachers' teaching approaches.

The other parts of the research were carried out as classwork. Information about the student teachers' content knowledge about electricity was investigated in two ways. Additional qualitative research was carried out using concept mapping with all the General Science students. The use of the DIRECT 1.2 questionnaire with the Physics student teachers meant that there was a small, additional element of quantitative research.

4.2.1 Ethics

General ethical issues

Ethical issues arose in the ways in which the relationships between the researcher and participants were constructed. The researcher has an ethical commitment to treat participants and the information they gave in a responsible manner. At an institutional level, these relationships were encapsulated in the Ethical Guidance and the associated approval processes required. Institutional guidance was in alignment with the guidance given by the British Educational Research Association, BERA (2004), and Scottish Educational Research Association, SERA (2005). The responsibility of the researcher was not only to follow this guidance, but to put the ethical guidance into practice in such a way that participants were assured of the probity of the researcher and the confidentiality of the information that they gave.

Institutional ethical approval was sought and granted before any work with the student teachers was carried out under an earlier version of the ethical approval

process.   Additionally, this section of the thesis dealing with ethical issues was presented to the Departmental Research Committee in December 2009 to request retrospective ethical approval, which was granted.

Ethics of working with student teachers

Initially, the primary relationship between the participants and the researcher was that of student teachers and tutor on a PGDE course.   Consequently, there was a disparity in the power relationship between the student teachers and the researcher. Care was taken to ensure that the student teachers were aware that participation in the interviews was voluntary and that they were free to withdraw their consent at any time.   The student teachers were also made aware that participation or non-participation would have no effect on the final grades for the PGDE course.   This was particularly important on a PGDE course where tutors made assessed visits to student teachers while they were on teaching practice.   During an assessed visit, a tutor observed a lesson and after the lesson, discussed the strengths and weakness of the lesson with the student teacher.   This process was always a nervous one for the student teacher for a number of reasons.   Most student teachers find the process of being observed while teaching to be stressful.   However, there was the additional stress that the tutor would grade the student teacher's lesson.   This grade had a direct effect on whether or not the student teacher would successfully complete the PGDE course and therefore be able to begin to work as a probationary teacher.

Tutor visits to student teachers on teaching practice would have been a useful method of gathering data for this research.   However, it was considered that this approach would be unethical because the purpose of tutor visits was to assess the student teachers teaching.   Attempting to combine course assessment with a research exercise would have been unacceptable.   The student teachers may have felt pressured into allowing the tutor visit to be used for research in case the tutor was biased against them when the assessment part of the visit came to the fore.   Adding research to the purposes of the visit would also have added to the inevitable pressure felt by student teachers about tutor visits.   Additionally, during a tutor visit, the

tutor was concentrating intently on the student teacher's teaching with the aim of initiating a professional discussion about the lesson immediately after it had finished. Adding an additional layer of observation which was only relevant to the researcher would have been difficult practically and also unprofessional.

The student teachers received inputs about teaching electricity from a second physics tutor. In practice, this meant that the researcher was not asking the student teachers to comment on work which they had carried out with the researcher. This process depersonalized the interview about teaching electricity as much as possible under the circumstances, with the effect that the interviewer was not requesting the student teachers to comment on her teaching.

Ethics in interviews

Gillham (2005) identified a number of ethical issues associated with interviewing, including confidentiality, anonymity, security, publication, data lifetime and exceptional use of data – for example video recordings. These ethical issues are not necessarily peculiar to interview-based research, but may also occur in other forms of research.

The student teachers were assured that participation in the interviews was totally voluntary. The purpose of the interviews was explained and that anyone who chose to participate would be anonymous in any reporting of the research at conferences, in a thesis or in journal articles. The student teachers were also assured that anything that was said would remain confidential. The interview recordings and transcripts were held securely and not made available to others. Data lifetime was not mentioned explicitly, but in accordance with the institution's ethical policy, data will be destroyed after the completion of the research. Use of the interview recordings was not mentioned explicitly, but again in accordance with the institution's ethical policy, the recordings were only used by the researcher or by secretaries transcribing the interviews.

Additionally, because of the disparity in the power relationships between a tutor and a student teacher, student teachers could be considered to be a vulnerable group, where particular care needed to be taken not to exploit this relationship. In practice, positive relationships between student teachers and tutors were established during interactive teaching on-campus. The student teachers contributed fully to discussions in class and were generally willing to disagree with tutors. Consequently, it was assumed that the student teachers would agree to be interviewed, or not, without feeling pressurised to do so. In practice, 15 out of 29 student teachers agreed to the initial interview which supports the contention that the student teachers felt free not to be interviewed.

On each occasion when a student teacher or teacher was interviewed or re-interviewed, they were given an information sheet about the research; asked to complete a consent form and given a copy of the consent form. Copies of these can be found in Appendices 4.3 and 4.4. In cases where teachers had requested a subsequent interview occur at the school where they were working, permission was sought from the Headteachers before the interview took place. A copy of the letter sent to Headteachers can be found in Appendix 4.5.

Some authors, such as Kvale (2007), suggested that interviewees should be offered a pre- and post-interview briefing. This was thought to be unnecessary for this research because the student teachers knew the interviewer and were aware of the purpose of the research. An additional reason for not offering a debriefing session was that the interviews dealt with straightforward professional knowledge and did not deal with emotionally sensitive or contentious issues with the potential to upset the interviewees.

4.2.2 Investigating Pedagogical Content Knowledge

As discussed in the Chapter 1, student teachers are required to develop a wide range of skills and knowledge to reach the Standard for Initial Registration (GTCS, 2006a and 2006b). The concept of pedagogical content knowledge (PCK) (Shulman,

1987) provided the conceptual framework to investigate the development of student teachers of physics on a one-year PGDE course. The three main components of PCK, content knowledge, general pedagogical knowledge and curricular knowledge, were investigated in different ways. The main investigative strategy was a series of four repeated semi-structured interviews administered to volunteers over the course of four-and-a-half years.

As discussed above, the research questions were based around the concept of PCK. The context was given by the exploration of the student teachers' initial ideas about teaching electricity and in particular how they explained electrical concepts to secondary school pupils. Some of the research was carried out with the full cohort of student teachers as part of the ongoing work of university-based classes about teaching physics. Most of the research was carried out using 15 volunteer student teachers who had agreed to be interviewed as part of the research.

Content knowledge was investigated directly using the pre-existing DIRECT 1.2 questionnaire, Engelhardt & Beichner (2004), and indirectly using concept mapping in the form discussed by Novak & Cañas (2008). Indirect data about the (student) teachers' content knowledge were also inferred from the semi-structured interviews.

Within the framework of PCK, particular attention was paid to the development of the student teachers' developing general pedagogical knowledge using the Ogborn, et al. (1996) framework for explanations. The investigative approach used a series of four repeated semi-structured interviews across four-and-a-half years. As well as gathering data about the (student) teachers' general pedagogical content knowledge, the repeated interviews also generated data about the development of the (student) teachers' knowledge of their pupils, the wider context and the values of the (student) teachers. Data about the (student) teachers' developing curricular knowledge were also found or inferred from the semi-structured interviews.

Overall, combining a pre-existing questionnaire with concept mapping and repeated semi-structured interviews allowed the development of the beginning teachers' PCK and its components to be investigated.

4.2.3 Classwork

The Physics component of the PGDE course used a variety of interactive methods to work with the student teachers in class.   The type of work carried out in class is referred to as classwork.   The aim of using these interactive teaching methods was to model approaches which the student teachers then added to their repertoire of teaching strategies.   The classwork tasks sat within this framework and therefore provided the student teachers with possible additional teaching strategies which could be used in their own teaching.   In this way, the activities were of direct benefit to the student teachers as well as generating data for the research project.

The DIRECT 1.2 questionnaire was given to the student teachers to enable them to consider their initial understanding of basic resistive circuits.   The discussion which followed as part of the normal teaching process enabled them to explore their understanding of these concepts and the misconceptions they may have held as well and also provided a mechanism to allow them to develop their pedagogical knowledge.

Concept mapping was introduced as a powerful graphical technique which allowed learners to explore their understanding of a topic.   All of the student teachers of science were introduced to concept mapping and were then asked to develop a concept map about the basic electrical concepts they would be required to teach as part of general science courses in secondary schools.   This benefited the student teachers by helping them to develop both their own understanding of basic electrical ideas and a useful pedagogical strategy which they could use in their own teaching.

4.2.4 Repeated, semi-structured interviews

The aim of the research was to investigate how the student teachers changed their approach to teaching electricity as they gained more experience as teachers. One way to do this would have been to observe the student teachers teaching a lesson. However, this was ruled out as impractical because of potential conflicts of interest (see Section 4.2.1). If an observational approach had been selected, a different methodological framework, such as content analysis, would have been selected.

A wide range of methodological approaches was considered including narrative research, phenomenology, grounded theory, ethnographic research, case study, action research, focus groups, content analysis, discourse analysis and interviews. Each of the approaches had advantages and disadvantages for working with student teachers given the focus on how the student teachers' explanations about electrical concepts would develop. Data analysis methodologies were discussed in Section 5.1.

Narrative research would have focused on the stories told by the research participants, which was too far removed from a focus on electrical concepts to be helpful. Similarly, phenomenology would have focused on the lived experience of the student teachers, which was not the aim of the research. A purely grounded theory approach to the development of the student teachers' explanations was ruled out by the use of a deductively derived analytical framework, although for an approach to analysis which allowed themes to emerge from the data collected, see section 4.4.2. Ethnographic research and the use of participant observation were not appropriate for the relationship between a teacher educator and student teachers. Case study was ruled out by the narrow focus on the development of explanations and the prolonged nature of the study.

Other types of methodology were also considered. Action research was discounted because of its focus on changing practice rather than gathering information. Focus groups could have been a useful approach to exploring the student teachers' thinking about teaching electricity, but were discounted because data were sought about the development of individual student teachers' explanations not the information that would emerge through discussion. Some of the most commonly used data collection methodologies are the various forms of interviewing. For this research, repeated

semi-structured interviews allowed the research to focus on aspects of the development of the (student) teachers' pedagogical content knowledge related to teaching basic electrical concepts.   The repeated format was also appropriate to the nature of teaching in secondary schools where the same content is taught to new classes every year.   The repeated format also allowed changes in the (student) teachers' explanations to be tracked over time.   The next section discusses the development and piloting of the interview schedule.

Development of the semi-structured interview schedule

Designing the study

Following Kvale (2007) and Cohen et al., (2007) in the discussion about interviews in section 4.1.3, this subsection uses a seven stage format to discuss the process of designing this interview study.   Thematising the interview study was regarded as laying the groundwork for the study by answering three questions: why the study was carried out; what was already known about the subject and how the study would be carried out?   The design stage considered how the study would be carried out in more detail, and allowed for the possibility that the study would probably involve revisiting some of the stages more than once rather than expecting a strictly linear approach.   The design stage also considered the type of interview to be used; subject selection and the ethical and moral implications of the work.

At its simplest, interviewing is a form of interaction between two people. Conducting an interview put the interviewer in the unusual position of being part of the research instrument along with the interview schedule, so that what happened during the interview depended on the interaction between the interviewee and the respondent.   This interaction meant that the interviewer's interviewing skills had an impact on the quality of the interview.   The interviewer's skills, the appropriateness of the interview schedule and the nature of the follow up questions posed all affected the quality of the interview, as judged by the usefulness of the answers obtained to answer the research questions originally posed.   Kvale (2007: 80, 90) suggested

three main ways to judge the quality of an interview: the richness of the interviewee's answers, the length of the relevant answers and the clarification of the interviewee's statements.

Issues around transcribing have traditionally not been considered widely in qualitative research.   Arguably, a written transcript of an interview is not a straightforward record of what happened, but is a translation from one language to another: from oral to written language.   Translation is not a straightforward activity. The extent to which a transcript records pauses, changes of mind and hesitations in speech depends on the nature of the analysis which was planned at the design stage. Another issue is whether it was the researcher or another person who transcribed the interviews, which depended on the time or resources available (Edwards, 2006).

Once interviews had been transcribed, the next stage was to analyse the interview data.   Again, consideration was given to the method of analysis at the design stage. Broadly speaking, analysis can be classified according to whether it is primarily interested in meaning, or language, or taking either a theoretical or an ad hoc (bricolage) approach to the analysis.   These three broad approaches reflected the broad methodological approach adopted towards the study.   As mentioned above, the three methodologies were positivism, emotionalism and constructionism.

Verification was another permeating aspect of the research design process.   Using a research diary would have provided a record of the decisions which were made as part of the research process and would have allowed the development of the researcher's thinking to be reconstructed if necessary.   Other aspects of verification included concern for validity and reliability.   The extent to which validity and reliability apply only to quantitative research and the extent to which they can be extended to qualitative research are matters of debate, Bryman (2004, pp. 28-30) and L. Cohen, et al. (2007, p. 133).   Validity and reliability may be replaced by the terms transferability and generalisability in qualitative research, see section 4.2.5.

Reporting interview research in an academic manner was another important part of the design process, which was linked with the earlier stages in an iterative way.   The

research was reported in different ways for different audiences.   However, whatever the audience, the report included enough methodological detail to allow the quality of the research to be evaluated and the discussion and interpretation of the interviews represented the interviewees fairly.   Another important criterion was that the report be interesting to read.

Designing the interview schedule

Once the study had been designed, it was decided that the method to be used for data collection was repeated semi-structured interviews.   The interview schedule was designed to provide an overview of the Scottish current electricity syllabus.   After piloting, the interview schedule was shortened and, after the first set of interviews, the teachers were asked to reflect on their experience at the beginning of the interview as well as the end.

Secondary teaching in Scotland at the time of the research was based around the 5 – 14 Guidelines in Secondary 1 (S1) and Secondary 2 (S2) and either the Standard Grade or Intermediate 1 or 2 syllabus in Secondary 3 (S3) and Secondary 4 (S4) and the Higher Grade syllabus in Secondary 5 (S5).   The electrical content of the Advanced Higher Grade in Secondary 6 (S6) was deemed to be too advanced for inclusion in the survey.   Additionally, it was thought that beginning teachers were unlikely to have many opportunities to teach at Advanced Higher level.   The semi-structured interview schedule was designed to follow a chronological path through the basic resistive electricity syllabus to investigate the development of teachers' ideas about teaching electricity and through their ideas about teaching electricity, how their PCK changed (or not).   In order to keep the interviews to a reasonable length, interviewees were told that the interview would last for a maximum of thirty minutes.

Within the chronological structure of the interview schedule, in order to reflect the syllabus, questions were drawn from common textbooks in use in Scottish secondary schools and SEB and later SQA examination papers.   In order to reflect the research

literature, questions were also drawn from the literature dealing with some of the difficult aspects of teaching electricity.

The 5-14 Curriculum Guidelines, Scottish Executive (2000b, p. 1), were deliberately drawn up in general terms in order to allow teachers to adapt the curriculum to the needs of their pupils and to provide flexibility in different school contexts, Scottish Executive (2000a, p. 2). In practice, this meant that the teaching sequence in schools often followed the teaching sequence in commercially available teaching resources. Consequently, the development of the interview schedule for S1 and S2 concentrated on approaches likely to be met in school, based around textbooks such as Starting Science 1 and 2, Fraser & Coppock (2002) and Fraser, Coppock, & Partridge (2003); Spotlight Science, Johnson, Ryan, Adamson, & Williams (2003), Johnson, Ryan, Adamson, & Williams (2001) and Johnson, Ryan, Adamson, & Williams (2004); and Science 5 – 14, Chambers, et al. (2002a) and (2002b).

The Standard Grade, SQA (2004e), and Intermediate 1 and 2 Physics Arrangements Documents, SQA (2004c) and SQA (2004d), provided teachers with specific learning outcomes which pupils were required to overtake. Standard Grade General Level corresponds to Intermediate 1 and Standard Grade Credit Level corresponds to Intermediate 2 (SCQF, 2007, p. 2). The basic electrical syllabus in Standard Grade and Intermediate physics covered the same areas: current, voltage and resistance in series and parallel circuits leading to Ohm's Law and voltage dividers. The textbook most often used in Scottish secondary schools to teach Standard Grade physics was McCormick & Baillie (2002). The textbooks most often used to teach Intermediate 1 and 2 physics were Baillie & McCormick (2004) and McCormick & Baillie (2001). At the time of the research, most Scottish pupils were entered for the Standard Grade Physics examinations, so McCormick & Baillie (2002) was used as a resource to develop the interview schedule rather than the Intermediate 1 or 2 textbooks.

The first draft of the interview schedule was piloted with two volunteer student teachers towards the end of their PGCE year in May 2004 after their final block of school experience. The interviews were conducted in one of the physics laboratories

where the student teachers had been taught.   A pilot interview was also conducted with an Additional Teaching Qualification (ATQ) student in June 2004 in the school where he taught. The Additional Teaching Qualification allowed teachers who were already fully registered in one subject with the GTCS to qualify to teach an additional teaching subject in a reduced time.   In this case the teacher was already qualified to teach chemistry and when interviewed, he had also gained the ATQ in Physics.

As a result of the interviews described above, the interview schedule was adapted to focus more clearly on a chronological teaching path through the interview. Additionally, a further open question was added at the end of the interview and at the beginning of the second and subsequent interviews to allow the interviewees to add anything they thought would be relevant.   At some point in the pilot interviews, all the interviewees drew diagrams to illustrate their explanations.   As a result, another change made was to give the interviewees a blank set of diagrams, without the interview questions.   This allowed the interviewees to record information on the diagrams if they wished to do so.   The initial research design extended the questions about voltage dividers in Standard Grade physics to the related topic of Wheatstone bridges in Higher Physics.   During the pilot interviews, the Wheatstone bridge questions were seldom reached and were not included in subsequent interviews. The semi-structured interview schedule and the sheet of diagrams for interviewees are included in Appendices 4.1 and 4.2.

4.2.5 Validity, reliability, transferability and generalisability

Generally speaking, reliability, validity and generalisability are terms from quantitative research approaches, D. Scott & Morrison (2007).   There has been debate among qualitative researchers about the extent to which these concepts derived from quantitative research apply to qualitative research, Flick (2009). Alternative concepts to evaluate qualitative research had been suggested by Lincoln & Guba (1985).   The alternative concepts included credibility, transferability, defendability and confirmability.   Later, Guba & Lincoln (1989) added the further

concepts of fairness, educative authenticity, catalytic authenticity and empowerment to answer criticisms that their earlier ideas were too prescriptive, D. Scott & Morrison (2007, p. 254).

According to Flick (2009, p. 387), the various forms of validity describe the extent to which a research instrument measures what it claims to measure. Traditionally, validity is a concept which has been used to judge the quality of quantitative, experimental work, D. Scott & Morrison (2007). However, Jupp (2006a) identified three kinds of validity which are relevant to qualitative research: validity of measurement; validity of explanation, or internal validity; and validity of generalization, or external validity.

In qualitative research, Sapsford (2006) discussed the requirements for different types of validity. Validity of measurement refers to the requirement that patterns found by data analysis are genuine and not artefacts of the methods of data collection which resulted from interaction with the researcher or the research instrument. Two ways to provide validity of measurement can be to use triangulation and, in particular, reflexivity where careful attention is paid to the effect of the relationships between the researcher and the research participants and the effect of the researcher on the research.

Triangulation is the process of taking two or more approaches to data collection or data analysis in order to generate more information about the research situation. Flick based his discussion of triangulation on the earlier work of Denzin, Flick (2007) and Flick (2009). For this research project, data triangulation was achieved by collecting different types of data from the student teachers. Investigator triangulation was not possible because the doctoral research was carried out by one person. Theoretical triangulation was applied by using a combination of a priori content analysis and a posteriori inductive data analysis. The two approaches to data analysis were also conceptualised as a form of within-theory triangulation of methods.

In his discussion of validity of explanation in qualitative research, Jupp (2006b) also identified reflexivity as one of the keys to ensure that when research has been reported, the research report, detailing the various stages of the research, was accurate. Another important way to ensure that any explanation is valid was the use of analytical induction. Analytical induction was the process of ensuring that contradictory findings or conclusions were included in the analysis and not simply ignored.

Validity of generalization deals with issues around how far research conclusions can be applied in other similar and dissimilar situations. Given the exploratory nature of this research, it was thought unlikely that it would have widespread applicability to other similar situations. However, the intention was to explore the development of the teachers' explanations as the foundation for further research which may be able to be generalized more widely.

Reliability deals with the quality of a research instrument and looks for "repeatability and consistency" D. Scott & Morrison (2007, p. 208), whether dealing with quantitative or qualitative research. Accordingly, the underlying assumption is that whatever has been investigated has not changed. This was problematic for this research because the underlying assumption was that the explanations that the teachers used may have changed over time. However, it was also assumed that the interview schedule did explore the teacher's developing PCK on each occasion when it was used, although the PCK itself may not have changed. The main focus for reliability was procedural reliability, to ensure that the data collection procedures and the data itself were as originally planned (Flick, 2009).

4.3 DATA COLLECTION

4.3.1 DIRECT 1.2 questionnaire

The DIRECT 1.2 questionnaire was administered by another physics ITE lecturer to all the student teachers of physics at the beginning of an interactive class about teaching basic electricity to pupils in Secondary 3 or Secondary 4 classes in September 2004.   Once the student teachers had completed the questionnaire, their answers were used as the basis for a discussion about some of the misconceptions and difficulties which are associated with teaching electricity.   The colleague who conducted this class reported that the questionnaire appeared to stimulate more thoughtful answers from the student teachers during the subsequent class discussion about electrical concepts than had been the case with previous cohorts.

4.3.2 Data collection using concept mapping

Concept mapping formed part of the student teachers' introduction to teaching General Science to Secondary 1 and 2 pupils.   The pedagogical aim was to allow the student teachers to experiment with new teaching and learning techniques which they could use with pupils when they were undertaking teaching practice in schools. This meant that the student teachers were directly benefiting from this part of the course as well as providing data for this research.

The student teachers were given a brief, practical introduction to concept mapping in October 2004.   The introduction used an interactive teaching approach to demonstrate the construction of a concept map about atoms and molecules.   This topic was chosen because it was part of the general science curriculum all the student teachers would be required to teach at some point. After the introduction, the student teachers were given a list of electrical concepts drawn from the 5-14 Science and Technology Guidelines, Scottish Executive (2000a), and asked to submit their own concept map about electricity the following week.   Again, this task would benefit the student teachers directly by allowing them to develop their own understanding of electricity as well as providing data for the research.

4.3.3 Interview timescales

A timeline for the interview process is given in Figure 4.1 and summarised in a different way in Table 4.1.   Table 4.1 also provides information about the number of teachers interviewed at each stage.   As Figure 4.1 and Table 4.1 show, the repeated interviews were carried out over a period of just over four-and-a-half years.

Table 4.1   Timescale for interviews with beginning teachers of physics.

Interview	Date	Comment	Number
Interview 1	September and October 2004	PGDE Year, before School Experience 1	14 volunteers from a class of 29
Interview 2	April and May 2005	PGDE Year, between School Experience 2 and 3 or after School Experience 3	Eight of the previous volunteers, plus one additional volunteer
Interview 3	July and September 2006	At the end of the Probationary Year	Six post-probation teachers
Interview 4	March and April 2009	Almost three years after the end of the Probationary Year	Four of the six teachers from Interview 3

The interview schedule was arranged to reflect the student teachers' progression through the PGDE year and then their progress at the end of the subsequent Probationary Year, with the final interview taking place approximately three years after the Probationary Year, near the end of the teachers' fourth year of teaching.

Session	Month	Interview
2004 - 2005 PGDE Year	A	
	S	1
	O	1
	N	
	D	
	J	
	F	
	M	2
	A	2
	M	2
	J	2
	J	
2005 - 2006 Probationary Year	A	
	S	
	O	
	N	
	D	
	J	
	F	
	M	
	A	
	M	
	J	
	J	3
2006 - 2007 One Year Post-probation	A	3
	S	3
	O	
	N	
	D	
	J	
	F	
	M	
	A	
	M	
	J	
	J	
2007 - 2008 Two Years Post-probation	A	
	S	
	O	
	N	
	D	
	J	
	F	
	M	
	A	
	M	
	J	
	J	
2008 – 2009 Three Years Post-probation	A	
	S	
	O	
	N	
	D	
	J	
	F	
	M	4
	A	4
	M	
	J	
	J	

Figure 4.1   Timeline for interviews with beginning teachers.

The interviews were recorded in two formats. Interview 1 was recorded on audio tape only. The subsequent interviews were recorded digitally with a back-up audio tape also made. Tables 4.2a and 4.2b give the dates and lengths of the interviews. The interviews were conducted over a period of just over four-and-a-half years from September 2004 to April 2009.

The interviews were used to explore changes in the student teachers' ideas about teaching electricity at the beginning (Interview 1, n = 14) and end of the PGDE year (Interview 2, n = 9); and as teachers one year after completing the PGDE (Interview 3, n = 6); and finally almost four years after completing the PGDE (Interview 4, n = 4: one teacher was then teaching mathematics and another had returned to work in industry.) The interviews lasted between 14 and 48 minutes, with the mean length approximately 30 minutes. A total of 15 out of 29 students on the course participated at various points, including four female students.

Interview 1 took place at the beginning of the PGDE year in September and October 2004. The intention was to interview the student teachers before they started their first School Experience placement in November 2004. The first interview was intended to discover the student teachers' initial thinking about teaching electricity before they began their first six week teaching placement and before any course inputs about teaching electricity. The student teachers of physics were asked to volunteer to be interviewed and 14 out of 29 did so. Timetabling constraints meant that all the student teachers were interviewed after the electricity inputs for science in First and Second Year and for physics in Third and Fourth Year. All of the interviews were carried out in one of the physics laboratories.

Table 4.2a   Interview dates and lengths in minutes for semi-structured interviews with beginning teachers who were interviewed three or four times.

Name	Interview 1	Interview 2	Interview 3	Interview 4
Teacher 1	29.9.04 32	22.4.05 23	27.7.06 42	6.4.09 26
Teacher 2	29.9.04 24	20.4.05 43	6.9.06 40	20.3.09 36
Teacher 3	19.10.04 25	30.3.05 30	4.7.06 47	-
Teacher 4	5.10.04 26	-	4.7.06 31	31.3.09 19
Teacher 5	7.10.04 24	29.3.05 26	11.8.06 48	17.3.09 26
Teacher 6	12.10.04 30	26.5.05 41	24.7.06 36	-
Total	n = 6	n = 5	n = 6	n = 4

Table 4.2b   Interview dates and lengths in minutes for semi-structured interviews with beginning teachers who were interviewed once or twice.

Name	Interview 1	Interview 2
Teacher 7	13.10.04	6.6.05
	25	46
Teacher 8	8.10.04	27.5.05
	20	22
Teacher 9	-	25.3.05
		23
Teacher 10	29.9.04	-
	31	
Teacher 11	13.10.04	-
	29	
Teacher 12	13.10.04	-
	32	
Teacher 13	19.10.04	-
	15	
Teacher 14	21.10.04	-
	23	
Teacher 15	25.10.04	-
	14	
Total	n = 8	n = 3

Interview 2 was intended to take place after the second block of teaching practice and before the third, in April 2005.   In this case, seven of the previous 14 students were re-interviewed and there was an additional interview with another student teacher.   However, it was only possible to interview five student teachers at the intended time.   A further three student teachers were interviewed after the completion of the third block of school experience.   Therefore, the second interview drew on the student teachers' experiences after twelve or eighteen weeks of teaching in schools.   In addition to the two electricity inputs described in the previous paragraph, the student teachers had also had an additional input about teaching

electricity to pupils studying Higher Physics in the Fifth and Sixth Years of secondary school.

Student teachers who successfully complete the PGDE course have reached the Standard for Initial Registration with the General Teaching Council for Scotland, General Teaching Council for Scotland (2006b), and are guaranteed a one year post as Probationary Teachers.   Interview 3 was carried out at the end of the teachers' Probationary Year in a variety of locations.   The teachers were contacted and asked to volunteer to be interviewed again, either on campus or in a place of their choosing. In this instance, six of the teachers volunteered to be re-interviewed, mostly in July 2006.   Five of the teachers had been interviewed on both the previous occasions and the sixth had been interviewed on the first occasion only.   Four of the interviews were carried out on campus; one was carried out in a local coffee bar and the sixth was carried out in September 2006 in the teacher's school with the permission of the Headteacher.

Interview 4 was carried out towards the end of the teachers' fourth year of teaching, in March and April 2009.   Once again, the six teachers were contacted to ask if they were willing to be re-interviewed, either on campus or in a place of their own choosing.   One of the teachers was no longer teaching and one was now teaching mathematics.   Neither of these teachers was re-interviewed.   Of the four teachers who were re-interviewed, one was interviewed on campus; one in the same local coffee shop and two in their schools with the permission of their Headteachers.

4.4 DATA ANALYSIS

4.4.1 Practical choices

Transcription

In order to make it feasible to analyse the interviews, transcription was necessary. One advantage of the researcher transcribing interviews is that the researcher acquires a thorough knowledge of the interviews. Before any interviews can be transcribed, the transcription convention to be used must be chosen. In addition, if secretaries have been used, they must be given information about the transcription convention chosen.

The level of detail required in a transcription depends in part on the type of analysis being undertaken. For example, some forms of linguistic analysis, like discourse analysis, require highly detailed transcripts which include all the pauses and contradictions of natural speech. A content analysis which is concerned with establishing the main themes contained within an interview does not require such a highly detailed linguistic transcript. In this instance, following Edwards (2006), the choice made was for a simple transcription to allow the identification of themes rather than a technical transcription to allow detailed analysis of language.

For this study, because the method of analysis chosen was thematic analysis, the focus of the research was on what was said rather than the fine detail of how it was said. Therefore the transcription convention used was basic but indicated pauses in the interview. All 14 responses to Interview 1 were transcribed by the researcher. Three out of eight responses for Interview 2 and three out of six responses for Interview 3 were transcribed by the researcher. The rest of the responses to Interviews 2 and 3 and all four responses to Interview 4 were transcribed by secretaries within the Faculty.

Computer aided qualitative data analysis software (CAQDAS)

Computer aided qualitative data analysis software has become more common as a supplement or addition to manual methods of data analysis. The most important point about any CAQDAS software is that the software is an aid to analysis: the software does not carry out the data analysis (Lewins & Silver, 2007 and Flick, 2009). The researcher must still carry out the data analysis in the sense that the researcher stills designs the coding schedule and then codes the data. It is the researcher who recognises the themes that emerge from the data and then constructs a model to explain the findings.

There are other general issues about CAQDAS which were discussed by Charmaz (2006) and Lewins & Silver (2007) in relation to three of the most commonly used software packages: Altas.ti, MAXqda and NVivo. One of the main issues is the extent to which a particular software package has been regarded as encouraging the use of a particular method or approach on the researcher, particularly grounded theory. The key to avoiding this is for the researcher to exercise the critical approach which was applied to data analysis to the software. This should allow the researcher to direct the software rather than the software directing the researcher. Another approach was taken by Gibbs (2007), who discussed the same three packages and suggested that the modern versions of these packages were more flexible and less bound to one particular methodology.

The particular institutional choice of CAQDAS software is NVivo 8. NVivo can be used for a range of analysis and management tasks and so was trialled as a way to support the coding of the interview data. The initial stages of coding the data using the analytical framework were carried out using NVivo 8. Once the initial stages of learning to use the program had been completed, the advantages and disadvantages of using NVivo were compared to using manual methods. Given the number of interviews undertaken, it was found that it was just as quick and easy to use manual methods and word processing software to code the data as NVivo for this study.

In summary, a mixture of methods was used to analyse the data, including manual methods and the Word and NVivo programs. The bulk of the analysis was carried

out using manual methods and word processing software. This decision was made because the benefit of CAQDAS software is in managing large quantities of data which are being analysed by multiple researchers rather than several sets of interviews being analysed by one researcher.

4.4.2 Analysis

Initial analysis

As discussed earlier, the first stage of the analysis used PCK to provide the analytical framework. Chapter 2 discussed some of the literature relating to PCK and the approaches taken by different researchers. In the light of the number of different approaches taken to defining PCK and its components, it was decided to return to Shulman's 1987 discussion about PCK to provide the analytical framework used to code the interviews.   According to Shulman's 1987 approach, the teachers' knowledge about pupils, the context and the values of education are included as categories of general pedagogical knowledge.   The structure of the analytical framework is shown diagrammatically in Figure 4.2.   The three main categories of PCK, curricular knowledge, content knowledge and pedagogical knowledge, were selected using Gess-Newsome's 1999 approach to PCK. Content knowledge was conceptualised to include analogies and metaphors because these form an important part of science teaching.   The category of reflection was added because this is an important aspect of the GTCS approach to teacher education.   The analytical framework is important because it determined the direction the analysis would take. Although PCK is included in Figure 4.2, it was not included in the analytical framework because the research was focused on the components of PCK.
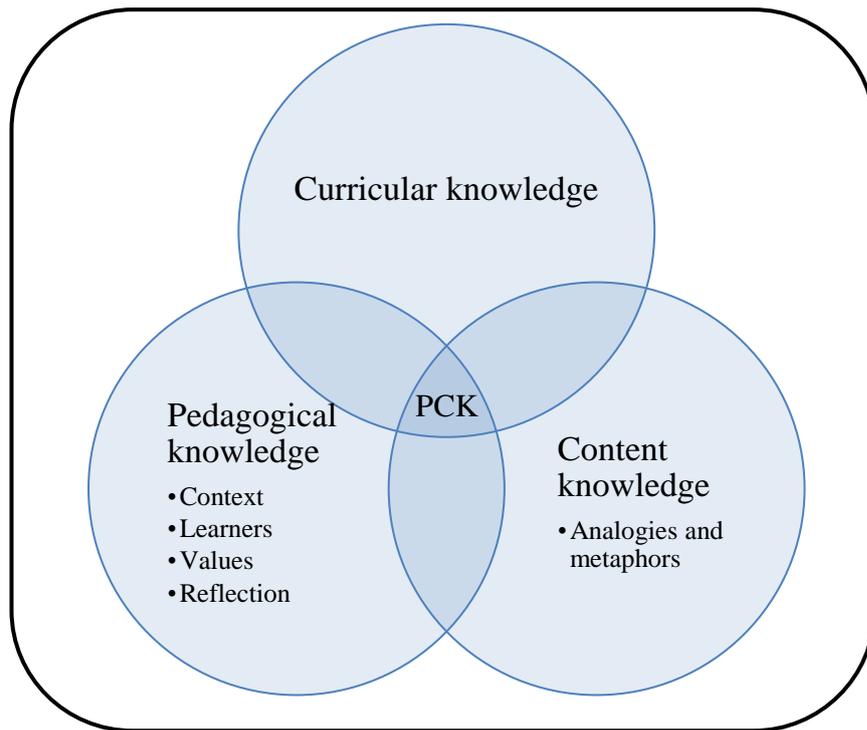
Figure 4.2   Analytical framework based on PCK.   (Adapted from Shulman, 1987 and Gess-Newsome, 1999)

The initial analysis of the data was carried out using this deductively derived analytical framework.   The three main components of the analytical framework were content knowledge, curricular knowledge and pedagogical knowledge.   According to Shulman in 1987, pedagogical knowledge contained knowledge about the context of education, the learners and the teacher's values.   For this research, the concept of values has been broadened to include examples of reflection.   Reflection was included because it is a key element of the GTCS requirements for the Standard for Initial Teacher Education, General Teaching Council for Scotland (2006b), and the Standard for Full Registration, General Teaching Council for Scotland (2006a). Again, following Shulman (1987), but also Bishop & Denley (2007), I decided to include knowledge of analogies and metaphors as a category of content knowledge.

The analytical framework was designed to set the direction of the analysis. However, because it was derived from a theoretical position and would be applied to

interview data, I had to decide which interview statements would be allocated to each category. To enable me to allocate data to categories, I developed a series of codes within each category. These codes originated in two ways. Some of the codes were generated before the data were coded. Content knowledge was defined for the teachers by their own subject knowledge and the content of the physics Arrangements Documents. Curricular knowledge would consist of reference to other aspects of the school curriculum or school years. During the initial development of the codes for reflection, I included codes for clear statements indicating reflection. However, other codes which indicated reflection emerged from the data when I had to decide how to code particular statements. For example, reflection was indicated when teachers compared the success of different approaches to teaching the same topic. A shortened version of the coding schedule derived from the analytical framework is included in Table 4.3 below. The first column shows the concepts from the analytical framework and the second column shows selected codes which were used to indicate that category.

The first stage in the analysis was to code the interviews using the coding scheme shown in Table 4.3 below. The first column in Table 4.3 shows the concept derived from the analytical framework and the second column shows some of the codes associated with each concept. The initial analysis using this framework used the six sets of interviews shown in Table 4.2a above.

I found that coding curricular knowledge and content knowledge including analogies and metaphors was unproblematic because these categories could be clearly distinguished in the interview transcripts. However, I found some aspects of coding within the pedagogical knowledge categories proved to be problematic because some of the categories overlapped.

Table 4.3   Initial analytical framework derived from PCK.

Concept	Code
Curricular knowledge	• other school years or courses • content of other courses
Content knowledge	• Concepts • Equations • Heuristics – for example current or voltage in series or parallel
Analogies and metaphors	• Analogies for physical concepts, for example an electric current is like a flow of water • Metaphors, for example a flow of current
Pedagogical knowledge	• Approaches taken to learning and teaching • Classroom organisation and management
Context	• Wider information about the school
Values	• Evidence of values

Learners	• Information about
	  o a particular class
	  o pupils

Reflection	• Statements indicating reflection:
	  o "I think"
	  o "when I was a pupil"
	  o Comparing pupils or classes
	  o Success or otherwise of different approaches

For example, according to Teacher 4 in Interview 4, Question 3b:

I would get them to build the circuit to see what happens. [T4.4.3b]

This was initially coded under pedagogical knowledge because it reflected an approach to teaching. However, it could also have been argued that an approach which used practical work to show pupils what was happening rather than telling the pupils the answer was an expression of Teacher 4's values as a teacher. This and other examples suggested that the category of "values" was a high inference category which was difficult to code accurately. This and other examples suggested me that a possible solution was to allow a new category to emerge inductively from the data which would include the idea that the role of practical work in science teaching could be an expression of a teacher's values.

The initial round of coding based on the deductively derived analytical framework also highlighted the emergence of other new categories which arose inductively from the data analysis. These categories are discussed in the next section.

Emergent analysis

By the end of the initial analysis of the interview data, I had found that the initial coding categories were too general. In addition, the analysis confirmed that I could derive new categories from the data inductively. This section discusses the relationship between the original components of PCK and the emergent coding categories. Table 4.4 shows the relationship between the component concepts of PCK and the emergent codes associated with each category. The first column of Table 4.4 shows the component concepts of PCK and the second column shows the emergent codes derived for each concept. I then used the emergent categories to carry out the second stage of the analysis. Another difference between the initial analytical framework and the emergent framework was that concepts such as the context were viewed as part of pedagogical knowledge in the initial framework. In the emergent framework, concepts like context were viewed as main concepts rather than subordinate concepts.

Table 4.4   Relationship between concepts and emergent codes for PCK.

Concept	Emergent code
Curricular knowledge	School curriculum
	School materials
Content knowledge	Doing practical work
	Know the rules
	Analogies and metaphors
Pedagogical knowledge	Pupil's misconceptions
	Pedagogical choices for classes
	Varied approaches for individuals
	Questioning
	Problem solving
Context	Teacher's experience as pupil
	ITE
	Colleagues
	School constraints
Values	Doing the best for pupils
	Role of practical work
	Ethos
	Reflection
Learners	Pupils as learners
Reflection	Teachers learning from pupils

Curricular knowledge

The interview schedule for this research was organised around the structure and content of the Scottish electricity curriculum. The effect of this was probably to reduce the number of references to curricular knowledge the teachers made. As a result, the main emergent categories within curricular knowledge were to do with mention of the school curriculum and the written materials which were used in schools.

Content knowledge

The emergent categories for content knowledge included ideas about how the teachers had adapted their own content knowledge into a form which allowed them to deal with doing practical work with classes and then codifying the conclusions of the experiment so that the pupils would "know the rules" for electricity. The two emergent categories co-existed with the original categories of content knowledge and analogies and metaphors.

Pedagogical knowledge

The PCK category with the biggest number of emergent categories (five) was pedagogical knowledge. As well as the areas of pedagogical knowledge identified in Table 4.3, the teachers' comments meant that I deduced the existence of five emergent categories. The emergent categories included discussion about the misconceptions pupils had displayed. The teachers also mentioned the pedagogical approaches which they had chosen for particular classes. This contrasted with the way in which the teachers adapted their approaches for individual pupils who were either doing very well or very badly with some sections of the course.

Context

Four new contextual categories emerged during the interviews. Teachers discussed their own experiences as pupils or learners. Several teachers discussed what they remembered learning about a particular part of the syllabus. One teacher remembered being taught about electricity by his father. As well as discussing their own learning, teachers mentioned the influence of their ITE course or school colleagues as contextual factors as well as the practical constraints which they faced in school.

Values

During the initial coding process, I found the values category required me to make high level inferences about what to include.   In the course of the coding, I found that teachers often talked about doing the best for the pupils or emphasised the importance of practical work for learning in physics.   Some teachers also talked about developing an open ethos in the classroom where pupils felt able to make mistakes.

Learners and reflection

During the initial analysis, I found that the learners and reflection categories of PCK were able to account for the data.   Nevertheless, the initial analysis showed that I could refine the focus on the learners to include a new category which incorporated the pupils' experiences as learners.   This focus on the pupils' experiences as learners also highlighted for me the ways in which the teachers talked about learning from the pupils.

Emergent analysis

Once the emergent categories had been codified, I re-analysed the interviews using the new categories, which were found to account for most of the data.   The second stage of emergent analysis confirmed the usefulness of the new categories for analysis.   Chapter 5 discusses the findings of the analysis.

Reconceptualising the data

During the emergent analysis, I showed that the new categories could account for most of the data.   At this stage, the emergent analysis was still based on the original analytical framework.   However, I realised that the emergent categories could also be conceptualised in a new way to provide a model to describe the development of beginning physics teachers.   This model is discussed in Chapter 5.

Chapter 5 Analysis and discussion

As discussed in Chapter 4, the analytical framework for the initial interview analysis was deductively derived from Shulman's pedagogical content knowledge (PCK), see figure 4.2.   This Chapter discusses the results of the initial analysis.   During the initial analysis, new concepts emerged inductively from the interview data.   These emergent concepts were used to carry out a second stage of analysis.   The analysis using the emergent concepts highlighted the importance of the teachers' craft knowledge of teaching (Leinhardt, 1990 and Burney 2004).   This suggested that the emergent concepts could be reconceptualised to develop a new framework for teachers' knowledge of teaching.   The new framework for teacher development is called Craft Pedagogy because it is based on teachers' craft knowledge and is discussed in section 5.5.

Most of the discussion in this Chapter is based on the analysis of the interviews for Teachers 1 to 6 with supporting evidence offered for this analysis using the interviews with Teachers 7 to 15.   This approach was adopted to reflect the number of interviews with individual teachers.   Teachers 1 to 6 were the only teachers to take part in Interview 3 at the end of the Probationary Year.   Four of these teachers took part in Interview 4 at the end of the data collection phase.   Teachers 7 and 8 took part in Interviews 1 and 2, Most of Teachers 10 to 15 took part in Interview 1 only, and Teacher 9 took part in Interview 2 only.

The code used to identify the quotations from the teachers in the rest of this Chapter is based on the teacher number, interview number and question number.   For example, T1.2.3c would refer to Teacher 1, Interview 2 and Question 3c.   The interview schedule can be found in Appendix 4.1.

5.1 INITIAL ANALYSIS USING PCK AS THE ANALYTICAL FRAMEWORK

This section analyses the data obtained from the teachers using PCK as the initial analytical framework. The teachers' content knowledge, curricular and pedagogical knowledge were analysed using interview data. In addition, the student teachers' content knowledge was analysed using data obtained from concept mapping and questionnaires. During this initial analysis, I derived additional analytical categories which are discussed in more detail in section 5.2.

5.1.1 Content knowledge

The student teachers' content knowledge at the start of the PGDE course drew on their own learning in school, at university, and potentially from their previous professional lives. Shulman's original 1986 conceptualisation of PCK assumed that the content knowledge of (beginning) teachers was equivalent to that of graduates in that subject. This was also the entry assumption for the PGDE course. However, applicants for the PGDE Physics course came with a wide range of degrees which had been deemed to contain sufficient relevant physics content. The minimum requirement was that applicants had first degrees which covered electricity and mechanics. The wide variety of the student teachers' background knowledge of electricity suggested that it would be appropriate to explore the student teachers' content knowledge about electricity, particularly in the light of the concerns raised about teachers' content knowledge in the literature by McDermott, et al. (2006) and Gunstone, et al. (2009) among others. Nevertheless, overall the student teachers seemed to be confident in their content knowledge about electricity and were considering how to make this knowledge accessible to pupils:

> *"This is where you get me confused [laughs] now because I know how things work myself, but then obviously how do you explain? How do you pass that information on [to pupils]?"* [T1.1.3a]

The student teachers' content knowledge about electricity was investigated using a combination of concept mapping, the DIRECT 1.2 questionnaire and repeated semi-structured interviews. The rest of section 5.1.1 discusses the results and analysis of the concept mapping exercise, the DIRECT 1.2 questionnaire and some of the results from the repeated semi-structured interviews.

Concept mapping

Concept mapping was chosen as a method to explore the student teachers' content knowledge because it would allow the student teachers of physics, chemistry and biology to demonstrate the structure of their understanding through the links that they made between the concepts in their concept maps and allowed possible differences in understanding between the subjects to be explored. A voluntary task, Appendix 5.1, was focused on 27 basic electrical concepts taken from the 5-14 Guidelines for Science (Scottish Executive, 2000). Overall, 49 out of 72 students submitted concept maps. Table 5.1 records the number of concepts maps returned by student teachers of different subjects. The "undeclared" row shows that 6 student teachers returned concept maps but had not recorded their teaching subject on the concept maps.

Table 5.1   Number of concept maps returned for each subject.

Subject	Number of concept maps
Biology	19
Chemistry	10
Physics	14
Undeclared	6
(Non-submission)	(23)
Cohort	72

Structure of concepts maps

One of the most visible aspects of the concept maps was their structure (Kinchin, Hay and Adams, 2000). The initial expectation was that, as experienced learners, the student teachers would produce expert concept maps, characterised by a network structure with multiple links between concepts (Edmondson, 2005). In practice, the student teachers drew maps which combined aspects of chain and spoke concept maps rather than net concept maps. Figure 5.1 shows an example of a concept map by a student teacher of physics which was transcribed into the Cmap programme to aid analysis. The concept map is read from the top down. Concepts are contained in text boxes and joined by linking phrases. A proposition consists of two concepts joined by a linking phrase, for example "ELECTRICTY can operate COMPONENT (sic)." The concept map in Figure 5.1 contains three main branches (or spokes) each of which is mainly composed of chains. This example is unusual in that it contains more cross-links than a typical student teacher's map. Despite the relatively large number of cross-links in the concept map, it does not display the organisation of concepts or the rich web of cross-links typical of an expert concept map (Shavelson and Ruiz-Primo, 2005).
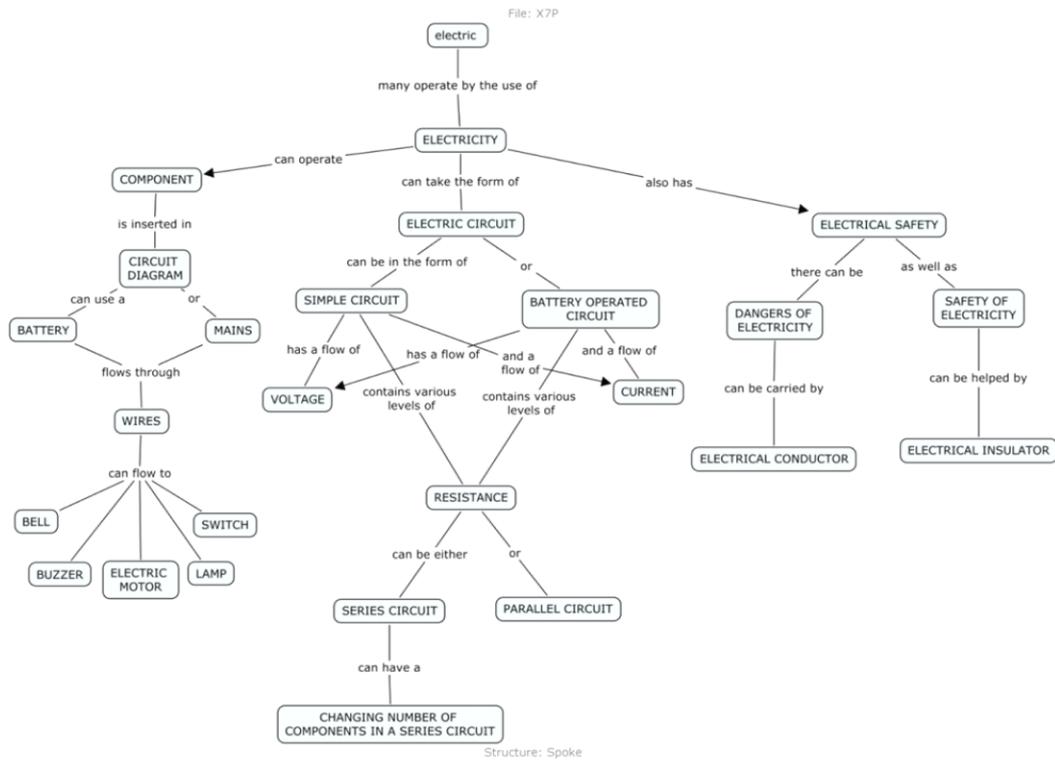
Figure 5.1   Exemplar concept map by student teacher of physics.

Statistical significance

A descriptive statistical analysis of the number of propositions in each concept map was carried out.   This showed that the numbers of concepts contained in the concept maps were not normally distributed.   The non-normal distribution meant that the analysis used non-parametric statistics, focusing on the median and semi-interquartile range (SIQR).   The data are displayed in Table 5.2 and Figure 5.2. Table 5.2 shows the median number of propositions and the SIQR in each concept map for each subject.   The median was used rather than the mean because the median was used to construct the boxplot in Figure 5.2.

Table 5.2   Median number of propositions and semi-interquartile range for each
            subject.

Subject	Median number of propositions	SIQR
All	30.0	5.9
Biology	25.5	3.8
Chemistry	23.0	7.0
Physics	27.5	3.6

Figure 5.2 displays the non-normally distributed data in a boxplot.   The box shows
the spread of exactly half the propositions in each case and the distance between
maximum and minimum points gives the spread between the maximum and
minimum number of propositions included.   The median scores of the physics,
chemistry and biology student teachers were compared using Kruskal-Wallis tests.
The results showed that there were no statistically significant differences between the
groups and hence that it was not possible to distinguish the concept maps belonging
to the different groups of student teachers.
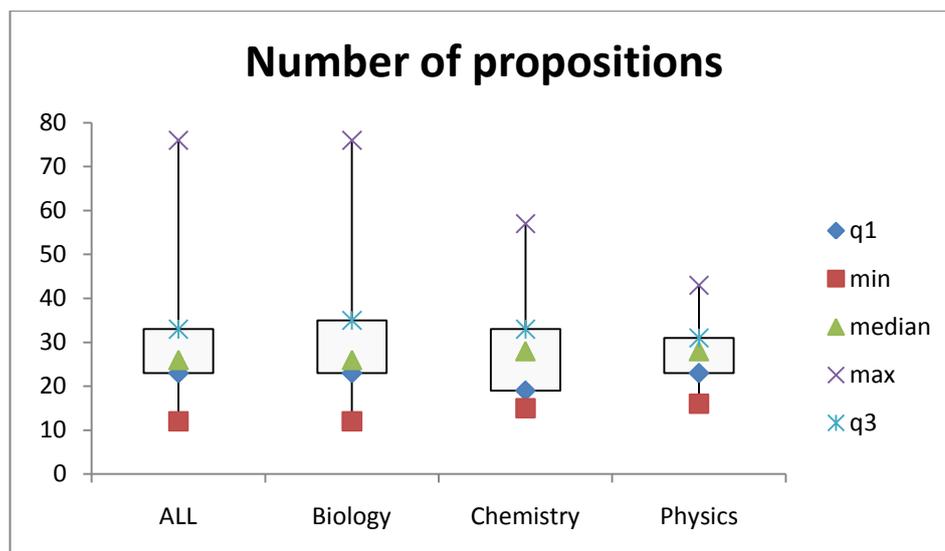
Figure 5.2   Boxplot showing the distribution of propositions for each subject specialism.

Further analysis was undertaken by calculating and comparing the proposition accuracy score (which was calculated using all the propositions on the concept map) and the salience score (the percentage of totally correct propositions).   The definitions of the proposition accuracy score and the salience score were given in section 2.4 of the literature review.   Table 5.3 shows the proposition accuracy score and the salience score for the biology, chemistry and physics student teachers, along with their respective SIQRs.   However, evaluating the proposition accuracy scores and salience scores for the concept maps showed no statistically significant difference between the groups of student teachers.   The close relationship between the two scores occurred because the salience score (the percentage of totally correct propositions) is a subset of the proposition accuracy score (which depended on all the propositions on the map.)

Table 5.3   Percentage scores and semi-interquartile range (SIQR) for proposition accuracy and salience scores for all subjects.

Subject	Proposition accuracy score (%)	SIQR for proposition accuracy score (%)	Salience score (%)	SIQR for salience score (%)
Biology	64.6	15.6	54.2	19.9
Chemistry	61.1	8.1	48.6	14.8
Physics	73.2	8.6	60.6	11.3

One of the reasons for the relatively low scores was that the student teachers did not always write explicit links between the concepts in the concept maps.   This automatically meant that they could not receive full marks for an incomplete proposition.   The lack of links between the concepts may have occurred because the

student teachers were more familiar with mind maps, which do not require explicit links between concepts.

Discussion and conclusion

Overall, there was no statistically significant difference between the concept maps for the different groups of student teachers.   The lack of statistically significant differences between the groups of student teachers contradicted the initial assumption that the student teachers of physics would show a greater understanding of electricity than the student teachers of chemistry or biology.   There were several possible reasons for the lack of statistically significant differences between the groups.

Very few of the student teachers had previous experience drawing concept maps. The assumption that as experienced learners, student teachers would have been able to draw detailed concept maps after a brief introduction was incorrect.   The student teachers also showed more awareness of mind maps which do not require explicit links to be made between concepts.   The lack of explicit links automatically lowered the proposition accuracy score if there was no proposition to score.

More detailed information about the physics student teachers' understanding of basic electricity was sought using the DIRECT 1.2 diagnostic instrument.   This is discussed in the next section.

DIRECT 1.2

Several instruments are available to investigate learners' conceptions in physics. An early example developed by Hestenes, Wells, & Swackhamer (1992b) was the Forces Concept Inventory (FCI).   There are also several tests available to investigate advanced electrical concepts, for example Ding, et al. (2006), but tests of basic electrical concepts are less common.   One such test is DIRECT 1.0 which is available in the public domain (Engelhardt & Beichner, 2004).   The version of the DIRECT test used with the students was DIRECT 1.2, which is not in the public domain and was obtained through information on the NCSU Physics Education R &

D Group (2007) "Assessment Instrument Information Page." The DIRECT 1.2 instrument was designed as a diagnostic instrument to allow teachers to target misconceptions about electricity at high school and university level. It was chosen for this research because it is a validated instrument which covers basic electrical concepts.

In contrast to the concept mapping task which was carried out with the cohort of PGDE science students, the DIRECT 1.2 instrument was administered to the physics student teachers only by another physics tutor. The second tutor used the instrument as an introduction to an input about teaching electricity and found that it stimulated considerable discussion in class. However, two issues were noted with the instrument. The first was that DIRECT 1.2 used the American rather than the international symbols for resistors and lamps which may have been unfamiliar to the Scottish student teachers. In practice, this was not a problem for the student teachers. The second was that the instrument asked questions about cells in parallel and the structure of a typical MES lamp ("torch bulb"), Engelhardt, Gray, & Rebello (2004), which do not feature strongly in the Scottish electrical syllabus and may also have been unfamiliar to the student teachers. The student teachers' results for the test were not normally distributed, so the discussion below is focused on qualitative features of the results.

Problematic questions

Six of the 29 questions in the instrument were problematic in the sense that fewer than half of the student teachers answered these questions correctly. Four of these questions were even more problematic in the further sense that more of the respondents chose one of the incorrect answers than chose the correct answer.

Question 10 required respondents to notice that one lamp had been short circuited and consequently would be off while the other two lamps would have equal brightness. The most popular answer (12 out of 21 respondents) was that one of the lamps was the brightest of the three rather than the correct response that two of the

lamps had equal brightness.   A likely explanation is that it was assumed that the extra wire in the circuit had no effect rather than it acted to short circuit one of the lamps.

Questions 11 and 20 were answered correctly by five and eight of the 21 respondents respectively.   The questions were linked conceptually in that they dealt with the detailed effect and interaction of charges and electric fields in simple circuits which are typically covered at university level rather than school level in Scotland.   For Question 11, only five of the respondents chose the correct answer, with the most common wrong answer being chosen by nine of the respondents. The incorrect answer more correctly applied to current flow rather than the transfer of energy. The point about the rearrangement of charges causing an electric field is addressed explicitly in Question 20.   One respondent did not answer Question 20, but the remainder correctly remembered that there is an electric field inside a current carrying conductor, but only eight out of 20 respondents remembered that the electric field is caused by a rearrangement of the charges rather than by the flow of current. It is likely that the reason for the non-zero electric field was not called immediately to mind by the 12 respondents who chose the incorrect answer.

For Question 25, 11 respondents chose one of the incorrect answers and only eight chose the correct answer.   This provided a contrast to Question 2 which used a similar circuit, but with resistors instead of lamps.   Although only 10 of the 21 respondents chose the correct answer, this was still the most popular answer.   In Question Two, 10 of the respondents calculated the power in the components correctly, which meant that they must have calculated the current correctly. However, in Question 25, only six of the respondents who correctly answered Question Two related this correctly to the brightness of the lamps.   However, Question 21 which was answered correctly by 17 out of 21 respondents dealt with *energy* in the same circuit as Question 25.   This suggested that the respondents may not have *calculated* their answers based on the current flow or linked current flow, brightness and power correctly in lamps.

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The final question, which was poorly answered, asked about the potential difference across an open switch. Only 10 of the 21 respondents answered correctly, with most of the rest (seven respondents) stating that the answer was zero volts, which is a common misconception among learners.

Unproblematic questions

An arbitrary cut-off of 80% of student teachers (more than 17 of the 21 respondents) answering correctly was used to select unproblematic questions. As a result, 12 of the 29 questions in the DIRECT 1.2 instrument were unproblematic for this group of student teachers. This is twice as many questions as the student teachers found problematic as a group. Setting the cut-off at 16 student teachers would result in another four questions being considered, which would have been more than half of the questions.

One of the basic skills of working with electric circuits is moving from a physical circuit to a schematic circuit and back again. Two of the questions which were answered well dealt with this skill. A third question dealt with whether or not a lamp would light when connected in various ways to a cell.

Other questions dealing with basic conceptual properties of circuits such as current, potential difference, resistance and energy were answered well in nine of the questions. Included in these nine questions were two questions about connecting cells in series and parallel which were answered well – which meant that the initial concern about type of questions was unfounded.

Discussion about DIRECT 1.2 results

The student teachers had not been told that they would be asked to answer questions about basic electrical concepts and so had not had a chance to prepare, although most answered most of the questions correctly. The problematic questions may have been

answered better if the student teachers had had a chance to prepare or if they had been answered after the class discussion rather than before.

Interviews

Much of the analysis of the (student) teachers' content knowledge derived from the repeated interviews is contained in a later section in this Chapter in the section about transforming content knowledge.   However, this section discusses a relevant interview passage about the link between current and brightness in lamps which was discussed in the previous section and also one of the teachers' apparent misconceptions.

Lamps and brightness

The analysis of the DIRECT 1.2 instrument showed that the student teachers as a group were unsure about the relationship between current and brightness and lamps. Although they could calculate the current through the lamps and the power rating of the lamps, as would be expected of physics graduates, in practice there was only one piece of knowledge they did not have: the relationships between current / power and the brightness of the lamp.

This was illustrated in a discussion with one of the teachers about what happened to the brightness of lamps when the current through them halved during Interview 3. In this case the teacher has deliberately not been identified.

> *So if you've got half the current passing through it and half the*
> *current passing through it to the top one – what do you think the*
> *brightness is going to be compared to the bulbs connected in series? –*
> *I'm assuming by the way that these are half as bright?   For goodness*
> *sake tell me I'm right!*

Although many of the teachers initially shared this misconception, it was the result of not knowing or recalling a specific piece of information, not the result of a fundamental misunderstanding of the physics.

Electrical concepts

Overall, the impact of ITE was seen most clearly in approaches to teaching and learning rather than content knowledge. However, one or two of the student teachers referred to a specific electricity input at the beginning of the ITE year. During this input, introductory series and parallel circuits were discussed in terms of energy.

> *As [tutor's name] was talking [about] yesterday and we were all*
> *getting informed [about electricity] yesterday. Because he was trying*
> *to make us think about different [electrical] concepts and stuff*
>
> *[T1.1.1]*

Table 5.4 summarises the explanatory electrical concepts used by Teachers 1 – 8 and 10 – 15 in Interview 1. The columns in Table 5.4 record the electrical concepts used by the student teachers to answer questions 1, 2 and 3a. (See Appendix 4.1)

Table 5.4 shows the wide variety of explanatory concepts used by the student teachers during Interview 1. At the time of Interview the student teachers had received an input about teaching electricity which focused on energy as the main explanatory concept. Questions 1, 2 and 3 dealt with the early, pre-mathematical stages of teaching about electricity in series and parallel circuits where energy-based approaches would be appropriate. Despite the focus on energy as the main explanatory concept, six out of the 14 student teachers did not mention energy in their replies; three teachers mentioned energy once; four teachers mentioned energy twice and one teacher mentioned it three times. A possible explanation for the wide range of electrical concepts used to explain what happened in the simple circuits is that before the student teachers took part in the first block of school experience, they were drawing on their own memories of learning electricity.

Table 5.4   Summary of concepts used to answer Q1, Q2 and Q3a in Interview 1

Teacher Number	Interview 1, Question 1	Interview 1, Question 2	Interview 1, Question 3
T1	Electricity	Voltage	Current and voltage
T2	Energy and voltage	Voltage and current	Current, voltage and power
T3	Current and voltage	Electricity	Current and voltage
T4	Voltage	Voltage	Current, voltage and energy
T5	Energy	Energy	Voltage and current
T6	Power /electricity	Power	PD /power
T7	Current, voltage	Voltage, energy, charge	Voltage, energy
T8	Energy, voltage, current	Voltage, potential difference	Electricity, energy, voltage, potential difference
T9	Did not participate in Interview 1	Did not participate in Interview 1	Did not participate in Interview 1
T10	Resistance, current and voltage	Resistance, current and voltage, Ohm's law	Current, resistance
T11	Voltage	Voltage	Current and voltage
T12	Resistance, current, electricity, energy, power, voltage	Electricity, current	Electricity, energy
T13	Energy, power, current	Current, energy	Current, resistance
T14	Voltage, energy, power, current	Power, energy, current, voltage	Power, voltage, current, resistance, energy
T15	Voltage	Voltage	Voltage / potential difference

Changes in electrical concepts were investigated using the teachers' changing responses to interview questions 1, 2 and 3a which dealt with introductory series and parallel circuits in S1 and S2.   Figure 5.3 is a change diagram which summarises the ways in which Teacher 1 changed the concepts he used to explain Questions 1, 2 and 3a.   The horizontal axis shows the times when the interviews were carried out.   The four circles in a horizontal line show any changes in the explanatory concepts.   The arrows connecting the circles show how many changes took place.   For example, the markings "+ + -" show that two new concepts were added to the explanation and one previous concept was no longer used.   Detailed results, including change diagrams for Teachers 2 to 6 can be found in Appendix 5.2.
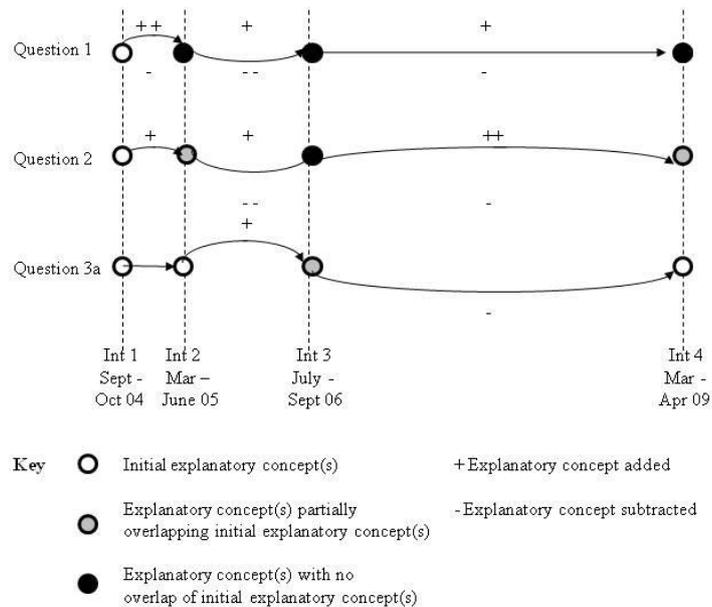
Figure 5.3   Change diagram showing Teacher 1's changing explanatory concepts for questions 1, 2 and 3a.

Table 5.5 below summarises the number of changes of explanatory concepts in each change diagram and the number of net changes of explanatory concept between Interview 1 and Interviews 3 or 4. For example, in Figure 5.3 above, Teacher 1 changed the explanatory concepts he used eight out of a possible nine times (recorded as 8 / 9 in Table 5.4). Teacher 1 also changed the explanatory concept used for two of the three questions asked over the course of the interviews. This is recorded as a net change of 2 / 3 in Table 5.4.

Table 5.5 shows that all the teachers, except Teachers 4 and 5, changed all or all but one of their explanations over the course of the interviews. Teacher 5's explanations for questions 1 and 2 were consistent across all the interviews. In most of the explanations the teachers used energy, voltage and current to explain what was happening in series and parallel circuits.

Table 5.5   Comparison of concepts used to answer Questions 1, 2 and 3a

Teacher number	Number of changes of explanatory concept	Net changes of explanatory concept
T1	8 / 9	2 / 3
T2	9 / 9	3 / 3
T3	6 / 6	3 / 3
T4	6 / 6	1 / 3
T5	3 / 9	1 / 3
T6	5 / 6	3 / 3

The circuits discussed all used the brightness of the lamps as a surrogate measurement for current. Despite this, only Teacher 3 used current as one of the concepts to explain what was happening in a series circuit in Interview 1. Teacher 3 still used current as one of his explanatory concepts for series circuits in his third and final interview. Teacher 1 was the only other teacher to use current to explain what happened in series circuits in his final interview. This is probably because the

current in a series circuit remains the same around the circuit and the voltage varies. Voltage was used to explain what happens in a series circuit by most of the teachers, except Teacher 5. Teacher 5 adopted a consistently energy based approach to teaching about series circuits.

Question 3a dealt with introductory parallel circuits. All of the teachers except Teacher 6 used current as an initial concept to explain what happens in a parallel circuit. A combination of current, voltage and energy were consistently used to explain what happens in a parallel circuit. Power was used by two teachers in the first interview and not after that. It is possible that by the time that the teachers were discussing parallel circuits, they had had an opportunity to clarify their thoughts about teaching electricity and so were clearer about how they would approach teaching parallel circuits than series circuits.

Apparent misconceptions

Teachers on occasion reported making apparently incorrect statements to pupils. Generally speaking, there was not sufficient evidence to decide if the misconceptions were genuinely believed by the teachers or if they had made pedagogical choices to deliberately use misconceptions in their teaching. In view of the lack of evidence, it was decided to assume that the teachers had made a pedagogical choice to use the misconception as part of teaching rather than that the teachers genuinely held the misconception, unless there was evidence to the contrary. However, the interviews were presented to the teachers as a professional discussion between colleagues, so it was possible that some of the looser use of language should be understood as a form of professional shorthand which would not have been used with pupils. In view of this, no examples of these apparent misconceptions have been included.

Analogies and metaphors

The constructivism and electricity literature review Chapters discussed the role of analogies and metaphors in teaching. The methodology Chapter discussed the role

of analogies and metaphors as a component of PCK.   This section examines how the teachers used analogies and metaphors in their teaching about electricity.

Teachers 1 to 6 all used some analogies in their teaching.   The analogies tended not to be used consistently, except by Teacher 2.   However, Teacher 2 used analogies selectively with different classes.

Fluid analogies

Fluid analogies such as water flowing in a pipe were used by all the teachers, except Teacher 6.   Teachers 4 and 5 used fluid analogies once; Teacher 1 used fluid analogies four times; Teacher 3 used fluid analogies six times and Teacher 2 used fluid analogies 9 times.   Overall, the six teachers reported using fluid analogies 21 times over the course of the interviews.

All of the teachers used a dormant metaphor (Sutton, 1992) when they talked about the flow of current.   Teachers 1, 2 and 3 could be considered to have brought this metaphor to life when they used water based analogies and talked about the flow of electric current being like a flow of water in a river or in a hose or pipe.   Developing this metaphor to introduce water pressure, possibly with the intention of linking this to voltage was not regarded as successful by the teachers.

In summary, the teachers used the common metaphor for the flow of current repeatedly throughout the interviews.   Three out of the six teachers reported using water analogies more than once in their teaching.

Anthropomorphic analogies

Anthropomorphic analogies were used slightly more often than fluid analogies, with the six teachers reporting 26 uses of anthropomorphic analogies compared with 21 reported uses of fluid analogies.   However, Teachers 1 and 3 did not report any uses of anthropomorphic analogies.

Teacher 2 reported using anthropomorphic analogies more often than the other three teachers put together. Teacher 2 used anthropomorphic analogies 14 times; Teacher 4, three times; Teacher 5 four times and Teacher 6 five times.

The anthropomorphic analogies were divided into four groups: thinking about electrons as people; thinking about the current as people; thinking about roads, paths or obstacle courses; and less commonly food analogies.

Other analogies

A total of seven analogies were placed into the "other" category. Teacher 1 reported three uses of other types of analogy. Teachers 2, 3, 4 and 5 reported one use each of another type of analogy and Teacher 6 only used anthropomorphic analogies.

Three of the analogies considered voltage to be some form of push or driving force. Two compared voltage to energy directly, with a third use reported as a transport analogy with coal trucks, which had links to an energy analogy. The final analogy was more specific and compared the behaviour of voltage in parallel circuits to the behaviour of current in series circuits.

Individual use of analogies

The use of analogies for teaching electricity varied considerably among the teachers. Teacher 2 referred to the use of analogies 24 times which was more than three times as often as the other teachers. Teacher 2 referred to using fluid analogies nine times, which was more than the total number of analogies referred to by any of the other teachers. Teacher 2 used anthropomorphic analogies 14 times, but only mentioned one analogy in the "other" category.

Discussion

Shulman (1987) discussed the important role of analogies and metaphors in teaching. It was therefore expected that the teachers would use a range of electrical analogies

and metaphors in their teaching. However, the use of analogies varied among the teachers. Teacher 2 used three times as many analogies as the rest of the teachers put together. His use of analogies is discussed in more detail in section 5.4.1. The teachers tended to emphasize the role of "knowing the rules" for pupils' understanding, see section 5.2.2 for further discussion of the rules. This may link to Gunstone et al.'s 2009 discussion about the level of confusion among Australian physics teachers about how to teach aspects of electricity.

5.1.2 Curricular knowledge

Physics curriculum

The teachers had all taught a range of classes. This information is summarised in Table 5.6. The columns show the number of each teacher and whether or not they had taught First and Second Year Science classes (S1/S2), Access 3 or Intermediate 1 physics, Intermediate 2, Standard Grade, Higher or Advanced Higher Physics.

Table 5.6   Level of classes taught by teachers

Teacher number	S1/S2	Acc 3 / Int 1	Int 2	SG	H	AH
T1	✓	✓	✓	✓	✓	✗
T2	✓	✓	✓	✓	✓	✓
T3	✓	✗	✗	✓	✗	✗
T4	✓	✓	✓	✓	✓	✗
T5	✓	✗	✓	✓	✗	✗
T6	✓	✓	✓	✓	✗	✗

All of the teachers had taught First and Second Year Science classes and Standard Grade Physics. The National Qualifications Access 3 and Intermediate 1 and 2 Physics were being taught in schools, although these teachers mainly taught at Intermediate 2 level. Only half of the teachers were teaching a Higher Physics

class.   Teachers 2 and 4 taught in smaller rural schools and therefore had the opportunity to take Higher Physics classes.   Teacher 1 had taught Higher Physics but was not doing so at the time of Interview 4.   The smaller number of teachers teaching Higher and Advanced Higher Physics classes is probably explained by the reluctance of Principal Teachers to allow less experienced teachers to take these classes.

Despite the fact that the teachers had taken a range of science and physics classes, the official Arrangements Documents which contained the school curriculum were not often mentioned by the teachers.   The teachers were more likely to refer to "my pupils" who were working at a particular level:

> *… another thing I've been showing my pupils…*   *[T2.2.5c]*

> *… with my Intermediate 1 class…*   *[T2.4.8b]*

> *My first year class were coming in at level 3, the grade – they've done science courses at level E and level F*   *[T4.3.8]*

> *I did it with my credit work and would have done it for general work as well …*   *[T4.3.3a]*

> *I got out this book for the Standard Grade and my Intermediate 2 pupils…*   *[T6.2.4c]*

Teacher 2 in particular had clear ideas about what would be taught in particular classes.   There was no specific reference to the Arrangements Documents, perhaps because they had been internalised by the teachers.

Other curricular areas

There is a close link between physics teaching and mathematics teaching in secondary schools.   Other sections of this Chapter deal with some of the mathematical issues the teachers identified when teaching electricity, particularly in relation to fractions when teaching about adding resistors in parallel, see section

5.2.2, and using ratios when teaching about voltage dividers, see section 5.2.4. This link may have been closer for Teachers 2, 3 and 6 who had also qualified as teachers of mathematics during their PGDE year.

5.1.3 Pedagogical knowledge

In the initial analytical framework, pedagogical knowledge had four components: context, values, learners and reflection. The initial analysis of these four components is discussed in this section.

Context

During the course of this research, all of the teachers spent time teaching in at least three schools. All of the teachers had placements in two schools as student teachers and were placed in a third school for their Probationary Year. The four teachers who participated in Interview 4 had different experiences after the Probationary Year. Teacher 1 worked as a supply teacher in different schools until he gained a permanent post by the time of Interview 4. Teacher 2 remained in his Probationary School until at least the time of Interview 4. Teacher 4 had recently moved to a second post-probation school at the time of Interview 4. Teacher 5 was teaching in his second post-probation Residential School at the time of Interview 4.

Over the course of the interviews, the teachers' experiences of the different schools seemed to be most directly affected by the different pupils in the schools rather than contact with colleagues.

Values

This section about the teachers' values is constructed around a discussion of one long quotation and several shorter supporting quotations dealing with classroom ethos.

Ethos, or classroom atmosphere, plays an important part in learning. The teachers were committed to involving pupils in their learning through the use of practical work to create a pupil-centred rather than a teacher-centred classroom. This is discussed in more detail in section 5.2.2. Although the teachers did not appear to regard practical work as a part of creating a classroom ethos, this approach probably did contribute to a positive classroom ethos. An explicit method some of the teachers used to create a positive ethos was to encourage pupils to learn from their mistakes.

One of the most common features of the teachers was that they wanted pupils to learn from their mistakes rather than to worry about making mistakes. Teacher 6 used one of his own old jotters to achieve this aim:

> *I got out this book for the Standard Grade and my Intermediate 2*
> *pupils, and I said look at this pupil – this is a Higher jotter … look at*
> *the equation they use – 1 over R1 plus 1 over R2 – they didn't put one*
> *over RT equals – I could really lose my rag with this – that means*
> *nothing, nothing at all … nonsense. Then I would say to them – do*
> *you want to turn over this jotter and see who it belongs to and see if*
> *anyway knows them, and it was my old jotter and they would ------ so*
> *I'm telling you, the best of us make mistakes – it's wrong - my physics*
> *teacher didn't pick me up on that and that story often sticks in their*
> *mind - when people get it right, it was often quite good when you see*
> *their face lightening up – that's his jotter – who's got a first then, so*
> *just a wee story to lighten it up to show the importance of it – it*
> *worked in just about every class.*   *[T6.2.4d]*

Teacher 6's approach was to apply the standard he expected of his pupils to his own work as a pupil. Using the surprising fact that the poor work was actually the teacher's work and that making mistakes at school did not mean failure reinforced the point in a way that the pupils would remember.

A similar approach to learning from mistakes was adopted by Teacher 1:

> *So I think if you can sort of say that it's all right and you can learn*
> *from those [mistakes], I think it's that kind of ethos I would like to try*
> *and instil in my class.* [T1.3.3a]

Teacher 5 took a different approach to building a positive ethos. When looking at a complicated circuit, he was honest with the pupils about the obvious difficulties and then worked through the circuit with them. Guiding the pupils through the circuit allowed Teacher 5 to discuss with the class how they would tackle the circuit – and how they would not tackle the circuit. In the course of this dialogue, Teacher 5 was building a rapport with the class and establishing an ethos where difficult circuits could be attempted.

> *This, at first sight folks, this is quite a scary circuit …. do it one step*
> *at a time, don't make silly mistakes, don't try and be too smart – kids*
> *laugh* [T5.3.4d]

All the teachers showed that they took their pupils seriously and wanted to do their best for them.

Learners

The earlier quotations in the curriculum section see section 5.1.2, revealed the teachers talking about "my pupils" and "my class". This may have been because the teachers were modelling language that they had heard from more experienced teachers and also because the teachers were building a rapport with the pupils they were teaching.

As well as talking about pupils in particular classes or particular years, one of the ways the teachers often talked about pupils was on the basis of ability. In an earlier discussion about practical work, Teacher 1 referred to more able pupils as "the good ones", T1.3.3a. In a residential context, Teacher 5 referred to some of the pupils as being "mainstream capable", T5.4.7a Nevertheless, Teacher 5 noticed differences in ability between pupils in different schools:

What you would be able to take for granted, in terms of kids being
able to do in mainstream ... you have to re-state that, and re-state that
and re-state it again and just hope it sticks.   *[T5.4.7a]*

These differences also occurred between pupils in the same class in a mainstream
school:

... there were a couple of kids in the second year class who were
special needs in terms of reading and writing and they actually took to
it more readily than a lot of the kids who were nominally brighter kids
because they had some kind of affinity to the whole thing and then it
just clicked and that was some of the more rewarding parts of the
course because you find something that the little lads could do and
they were quite happy because they saw they were getting on [T5.3.8]

Or between pupils in an earlier (independent) school:

The smarter ones did, particularly in the second placement, the
independent school – most of the kids the first time I did it – it's not
slapdash – it's just they were quicker about it – there were one or two,
particularly girls for some reason [who] were very fastidious – they
were looking for anything and they were superb to work with – yes,
they were noticing that, yes that was brighter   *[T5.2.3a]*

Teacher 5's discussion of these very different pupils in very different schools
nevertheless shows a number of common features in all the teachers' reactions to
pupils.   Teacher 5 showed a genuine interest in the pupils and was delighted in the
progress they had made at the level which was appropriate to them.   He also
encouraged some pupils to make observations that most pupils had not made and
used these pupils' observations to develop their understanding. During the
interviews, he showed personal knowledge of the pupils and their capabilities and
how teaching was adapted to different pupils.   The quotations also displayed a
realization that ability is only one of the factors affecting pupils' progress: interest
and application also made a difference.

Teacher 5 enjoyed working with pupils who were obviously making progress, but took pleasure in the progress of the pupils regardless of their likely levels of attainment, which again makes this an expression of his values. It was also likely that Teacher 5's pleasure in the pupils' progress communicated itself to the pupils and would also have contributed to building a rapport with the pupils.

The teachers also viewed pupils in terms of the pupils' perceived ability. Most of the explicit discussions about ability were about more able pupils. References to less able pupils were often inferred from comments made about adapting teaching for the needs of different pupils or discussion about pupils working on General / Intermediate 1 courses.

The teachers sometimes expressed a level of frustration with the pupils' attitudes or the level of the pupils' mathematical skills. Most of the expressed frustration about the pupils' mathematical skills occurred when the pupils were dealing with adding resistors in parallel, which required an understanding of the reciprocal of numbers and of fractions, see Equation 5.1 in section 5.2.2.

> *When I've introduced this formula, … the one thing I want to stress is every time they're putting in the figures write one over RT. Write that down on each line, just because you can get that sum. You can say, Oh, right, okay it's say naught point 5. You've not finished. They've not finished. And I think it's a case of being able to flip it over*
>
> *[T1.3.4a]*

> *… a lot of the kids just couldn't handle fractions … and the thing that always caught them is they would say is RP = 0.5 ohms - every flipping time, and you'd have to say no. What is it? – 1 over RP.*
>
> *[T5.3.4a]*

In the earlier section about ethos, Teacher 6 expressed the same frustration about this equation as Teacher 1, using an old jotter to show that even teachers have made mistakes when using this equation (and equations in general).

Another frustration was pupils not being willing to attempt calculations:

> *I had a 3rd year test, the credit test, which actually I felt was fairly*
> *straightforward, calculations based, and there were even some people*
> *who had not even attempted the questions which was really annoying.*
>
> *[T1.4.8]*

Reflection

In one sense, all the interviews gave the teachers the opportunity to discuss and reflect on their teaching. Nevertheless, within that sense of global reflection, the teachers also indicated that they had explicitly reflected on their teaching by using phrases such as "I think …" or "I wonder …" about particular aspects of teaching. In addition to this, the teachers also discussed how they would teach particular aspects of electricity which suggested that they had considered the impact of several episodes of teaching and had developed a more considered approach to those aspects. On other occasions the teachers reflected on the impact of individuals or groups of pupils on how they approached a topic.

After Interview 1, the other interviews explicitly asked the teachers if they had changed their approach to teaching electricity as a result of their experiences at the beginning of the subsequent interviews. If there was time at the end of these interviews, the teachers were asked what the important points were to get across about teaching electricity.

When the teachers were given the chance to reflect on the general points they wanted to make about teaching electricity, they concentrated on three issues: the practical problems the pupils had dealing with the apparatus; the important ideas for the pupils to understand and particular difficulties the pupils had. Two of the teachers also talked about their feelings about teaching electricity.

Only two of the teachers discussed their feelings about teaching electricity.   Teacher 4 was initially unsure about teaching electricity, because it had not been covered in detail during her undergraduate degree:

> *At university, I didn't do a lot of electricity, or anything to do with*
> *electronics really.*   *[T4.3.6a]*

However, by the time of interview 3, Teacher 4 felt more confident about teaching electricity:

> *I definitely feel more confident now, than I did before. I feel my*
> *knowledge of Physics in the Standard Grade courses has improved.*
> *[T4.3.7a]*

Teacher 4's confidence had increased because she had been able to internalise the electrical knowledge needed for teaching and adapt it for use with the pupils:

> *I think you learn as the kids learn as well, which helps.   Although you*
> *may be one step ahead of them, but only that one step and you're fine.*
> *[T4.3.6c]*

Teacher 6 was the only teacher who talked about not liking electricity as a pupil himself:

> *I think it's not a topic I enjoy*   *[T6.1.6a]*

> *but I think the electricity was just complicated and I really struggled*
> *in my mind to picture why it would happen*   *[T6.2.7b]*

However, in Interview 2, he also talked about making electricity more enjoyable for pupils:

> *I think it will be good to teach a subject which I didn't enjoy myself, to*
> *try and make it more enjoyable over the next couple of years.*
> *[T6.2.6c]*

Teacher 6 intended to make a subject that he had found difficult and did not enjoy into a subject that would be interesting and enjoyable to the teacher, and by implication to the pupils. This could also be interpreted as an expression of his professional values.

Overall, when the teachers were given the opportunity to reflect on their approaches to teaching electricity, they related the discussion to the impact teaching the pupils had on them. This could be interpreted as the teachers learning about how to teach from the pupils. This is discussed in more detail in section 5.2.7.

5.2 EMERGENT FRAMEWORK

5.2.1 Emergent components

Section 4.4.2 discussed the conclusion that the initial analytical framework, shown in Table 4.3, was too broad to allow detailed analysis of the interview results. Analysis of the data showed that a number of emergent codes could be developed inductively from the data. The emergent codes were shown in Table 4.4 in the previous Chapter. As a result of the development of the new codes, the initial analytical concepts were all reconceptualised as top level concepts which were associated with emergent codes.

Comparison of the initial analytical framework and the emergent analytical framework showed that there is a degree of overlap in the concepts in the two frameworks. Consequently, concepts which have the same analysis in the two frameworks are not discussed further at this stage.

5.2.2 Content knowledge

A common theme running through the interviews with all the teachers was the need to transform the teacher's subject content knowledge into a format that was accessible to the pupils.

> *This is where you get me confused [laughs] now because I know how things work myself, but then obviously how do you explain? How do you pass that information on?*
> *...*
> *Because I know it and it's dead easy for me, but how do I take it and explain in such a way [that the pupils will understand]* [T1.1.3a]

> *This is where you know it's interesting because I understand it, but how do I explain it in a logical fashion that the kids'll understand because we know that they'll... learn in different ways. So it's something you're going to have to try because as we've talked before*

> *some kid might look at that and go, oh yeah I understand it and other*
> *children, their learning styles are different, so you have to try and*
> *attack it at different set of viewpoints to try to get the information*
> *across and hopefully [help to] consolidate ones who understood it*
> *earlier as well.*   *[T1.1.3b]*

This transformation was approached in a number of different ways, some of which are discussed below.

Doing practical work

All the teachers regarded practical work as the foundation of understanding in physics. This was perhaps not so evident in the first interview before the student teachers had gained much experience teaching in schools, but was evident in the second and subsequent interviews when the teachers had gained experience. Indeed, Teachers 1 and 4 suggested approaching some of the theoretical problems by starting with practical work.

During the course of the third interview at the end of the Probationary Year, Teacher 1 gave a coherent rationale for the role of practical work in science teaching. In the course of giving this rationale, he also outlined some of the pressures which may act on teachers to curtail the amount of practical work in science teaching. The rest of this section outlines Teacher 1's rationale for the role of practical work in science and brings in supporting statements from some of the other teachers.

For the secondary science teachers interviewed, practical work in science was at the core of their professional practice. A common way to plan a lesson, which was reflected by the teachers interviewed for this research, was for the teacher to introduce a new idea or to revise one that had recently been considered before the class carried out an experiment. The lesson then concluded with a discussion of what the pupils had found and what the pupils thought it meant. Practical work provided a way for pupils to actively engage in their own learning and meet some of the requirements of the Curriculum for Excellence.

However, practical work in a school laboratory did not happen automatically. The teachers planned how to conduct the practical work and informed the pupils what to do. One method Teacher 1 used to achieve this, which is congruent with CfE, was to train the pupils how to collect and return equipment so that the teacher's focus was on the experiment being carried out rather than ad hoc arrangements for distributing and collecting equipment. Once the pupils were engaged in practical work, supervising them could be challenging because "this is where you need eyes in the back of your head," T1.3.3a, to ensure that the teachers were aware of what pupils were doing and to ensure safe practice in the laboratory. However, it seemed that the teachers interviewed thought that their pupils found practical work enjoyable and engaging.

Most of teachers interviewed had a strong personal commitment to practical work which partly arose from their own experience as pupils. In common with many of their pupils, some of these teachers found that they learned best by carrying out practical work rather than written work.

The teachers' strong personal commitment to practical work meant that they were more likely to resist the pressures which they perceived may exist in schools not to carry out practical work or to reduce the amount of practical work which is done. The pressures of curriculum coverage and lack of time meant that teachers often felt that they wanted to tell pupils what the results of an experiment would have been rather than allowing the pupils to carry out the experiment for themselves or guiding the pupils to the correct result.

The teachers linked the role of practical work to creating a classroom ethos where pupils were able to say that they did not understand something because there was no stigma attached to saying that they do not understand. One of the ways used to encourage this sort of open ethos was to point out that other pupils would also not understand but would not have the "brass neck," T1.3.3a, to admit this. The teachers also wanted to encourage the same ethos of openness around problem solving.

<u>Difficulties with practical work</u>

There were a number of common difficulties found when carrying out practical work. It was often the case that pupils did not find the "right answer" or rather did not find what the teacher would expect them to find. These difficulties can arise because of problems with the equipment itself or because of pupils' poor experimental technique.

One of the common problems discussed with the equipment used in experiments with pupils in S1/S2 was that the "identical" lamps (bulbs) used were not identical in practice. Pupils focused on the differences between the brightness of the lamps and assumed that this meant that the current flowing was different in series circuits where a fuller understanding would be that the current was in fact the same but that the lamps were not identical. This meant that pupils were then likely to make incorrect deductions about the theoretical concepts the experiment was designed to illustrate.

Know the rules

All the teachers referred to the rules that pupils need to know and be able to apply when answering questions. Initially, pupils were asked to practice using the rules to find missing values in straightforward questions. As pupils gained increasing facility with the rules, they were expected to apply the rules in less straightforward problem solving situations.

The basic electrical content knowledge for simple circuits depends on knowledge about charge, current, voltage and resistance in series and parallel circuits:

- Rules for current in series and parallel circuits;
- Rules for voltage in series and parallel circuits;
- Rules for adding resistors in series and parallel;
- Ohm's law in the form, voltage equals current multiplied by resistance or $V = IR$.

Adding resistors in parallel

A helpful rule of thumb for adding resistors in parallel is that the total resistance is always *smaller* than the resistance of the smallest resistor. This was mentioned by several teachers.

The formula used to calculate the total resistance, R_p or R_t of two resistors R_1 and R_2 in parallel is to use the formula

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$
Equation 5.1

To find R_p, pupils must remember to take the reciprocal of the number they have found. Several teachers mentioned that pupils often forget this last step.

In discussion with Teacher 1, the interviewer mentioned that it was possible to use the word equation "the total resistance of two resistors in parallel equals product over sum" or the total resistance of two resistors in parallel is equal to the product of their values divided by the sum of their values.

$$R_p = \frac{Product}{Sum} = \frac{R_1 \times R_2}{R_1 + R_2}$$
Equation 5.2

In practice, several teachers mentioned simply "banging the numbers into a calculator" to find the answer. The difficultly often mentioned with this method was that the pupils forgot to take the reciprocal of the number displayed on the calculator to reach the final answer.

Adding two identical resistors in parallel

In practice, it can be difficult for pupils to remember either the formula or the word equation. One way to find the answer is to remember that when two identical resistors are added in parallel, the total resistance is *half* the initial value. Choosing numbers which can be calculated easily mentally is the next step. To find the resistance of two 10 ohm resistors in parallel using the heuristic gives (10 times 10)

divided by (10 plus 10) or 100 divided by 20 giving a final value of five ohms.   This example was given by Teacher 1.

5.2.3 Curricular knowledge

School materials

In the course of the interviews, the teachers did not tend to mention written materials, whether textbooks or worksheets.   Again, this was possibly because the interview schedule used a broad approach to teaching electricity which focused on how the teachers interacted with classes.   Teacher 4 referred to using "Starting Science" textbooks, Fraser & Coppock (2002) and Fraser, et al. (2003), in Interview 4.

Worksheets were mentioned in relation to some of the younger rather than the older classes in discussion about introducing electrical concepts to some of the younger pupils.   The teachers who did mention worksheets had pedagogical justifications for doing so.

> *In 2nd year I was taking a step back and allowing the more able ones*
> *to work through the sheets at their pace.*   *[T1.4.1b]*

This was an expression of a pedagogical choice to allow the more able pupils to stretch themselves, and to provide teacher support where appropriate.   A consequence of this choice would have been to allow Teacher 4 to spend more time with the other pupils in the class.   Teacher 2 adopted a similar approach for some units too, with an explicit pedagogical justification in those terms:

> *with the units that we use … the kids who do get it will move on and*
> *it's self explanatory and they can work their way through the*
> *experiments on their own, but the kids who are struggling, you can*
> *spend a bit more time with*   *[T2.3.3a]*

<u>Apparatus</u>

A constant source of frustration for the teachers was the lamps that were available in schools. Lamps which had the same rating and therefore would have been expected to have the same brightness were not in fact identical. These differences in brightness could lead pupils to draw incorrect conclusions. The physics teachers tended to prevent this problem by selecting sets of bulbs which had the same brightness, although other teachers may not have done this as discussed in the previous section as well as below:

> *It depends how carefully we pick the bulbs to be honest. If I am doing*
> *it, I will try and find three bulbs which will light up very close to the*
> *same brightness.* *[T2.4.2]*

The problem of having to carefully select "identical" lamps to ensure that they have the same brightness is one which was mentioned by a number of teachers.

Another source of frustration was the cells (batteries) used in schools which did not necessarily behave as expected:

> *I have a personal aversion to batteries because the voltage varies, the*
> *internal resistance has all sorts of effects and it just messes lot of*
> *things up so I tend to use power packs more than batteries, and I say*
> *pretend this is one big battery* *[T2.3.6a]*

As well as identifying a problem with the apparatus, Teacher 2 had also decided on a physical solution and an appropriate pedagogical approach to explain the solution to the pupils.

5.2.4 Pedagogical knowledge

In the emergent framework, pedagogical knowledge covered a different range of concepts than in section 5.1.3 which used the initial analytical framework.

Pupils' misconceptions

Question 6b in the interview schedule offered the teachers the opportunity to comment about any misconceptions that pupils had used. Few conceptual misconceptions were suggested in answer to this question. The teachers tended to comment on practical issues about connecting circuits or the problems pupils had when using supposedly identical lamps (bulbs) which were not identical. There was also little discussion of possible pupil misconceptions in the bulk of the interviews.

A few teachers did mention conceptual problems faced by pupils. When discussing the introduction of the idea of charge and current, Teacher 1 avoided using the terminology of a flow of electrons [T1.4.1c] because he felt that pupils found this confusing (Arons, 1997). Teacher 2 [T2.3.3a] stated that a number of pupils regarded a battery as a fixed source of energy and did not realise that the rate at which energy is drawn from a battery varies. Teacher 3 [T3.3.4a] discussed the problems pupils had in reading digital meters. To the pupils, a reading of 1.49 units is not the same as a reading of 1.50 units. However, to a physics teacher, these two numbers would indicate the same reading. The same point was made by Teacher 6 in an earlier interview [T6.2.4a].

The teachers commented on a number of practical difficulties pupils had when asked to connect circuit components. Connecting the components with leads (wires) often resulted in a tangle of wires which obscured the underlying circuit for pupils. Another problem discussed was when pupils were using lamps to indicate current and were confused by bulbs with the same power rating which did not look equally bright.

Pedagogical choices for classes

Overall, the teachers tended to favour a particular approach to teaching, but did not restrict themselves to their favoured approach.   The approaches to teaching which were discussed in the interviews are summarised in Table 5.7.   The headings in Table 5.7 are derived from the analysis of the interview data.   A double tick shows a teacher's most commonly mentioned approaches to teaching and a single tick shows other teaching approaches which were mentioned less often.

Table 5.7   Summary of teachers' preferred teaching approaches.

| Teacher | Preferred teaching approach | | | | | |
	Doing practical work	Know the rules	Use of analogies	Question-ing	Predict – observe – explain	This is what you need to know
Teacher 1	✓✓	✓✓	✓	✓		
Teacher 2	✓	✓✓	✓✓	✓	✓	
Teacher 3	✓	✓✓	✓	✓	✓	
Teacher 4	✓	✓	✓	✓		✓✓
Teacher 5	✓	✓	✓	✓✓	✓✓	
Teacher 6	✓	✓✓	✓	✓		

✓✓   Preferred teaching approach
✓   Other teaching approach used

Analysis of Table 5.7 showed that Teachers 3, 4 and 6 used one main approach to teaching, while Teachers 1, 2 and 6 combined the use of two main approaches. However, all of the teachers used a variety of approaches to teaching classes.

All of the teachers viewed practical work as an important part of their practice, particularly Teacher 1 who gave a clear rationale for the role of practical work in teaching.   This was discussed in section 5.2.2, see above.   The importance of pupils knowing the rules for electricity was also discussed in section 5.2.2.   Analogies played an important part in the teaching of Teacher 2.   The role of analogies was

discussed in section 5.1.1.   All of the teachers mentioned questioning as part of their teaching.   Teacher 5 developed the use of questioning further by using a predict – observe – explain (POE) approach to teaching, which is discussed below.

Teacher 4's interviews showed a clear focus on telling the pupils what they needed to know about electricity.   This was explicitly mentioned in Interviews 3 and 4, but not Interview 1.   (Teacher 4 did not take part in Interview 2.)

> *... a lot of them[pupils] want to be electricians.   A lot of them want to work as mechanics as well, so they need to know about things like that [electricity]*   *[T4.4.6a]*

> *Just that they know the difference between current, resistance and voltage and the main concept that I think they need to know if they are going to build on [that] is what happens to voltage and current in series circuits and voltage and current in parallel circuits because they tend to get them mixed up.*   *[T4.4.7a]*

Over the course of the interviews, Teacher 4 was the respondent with the shortest length of interview of Teachers 1 to 6 for Interviews 3 and 4, see Table 4.2a.   The relatively short length of her interviews may support the suggestion that the focus of the discussion in the interviews was on what the pupils needed to know.

Commonsense approaches

A number of teachers adopted a "commonsense" approach to teaching tricky topics in S1 and S2.   The commonsense approach was adopted when the correct scientific explanation would have been too difficult for the pupils to understand, often because they had not yet learned the concepts needed for the explanation.

Pedagogical choices for individuals

The previous section about pedagogical choices for classes discussed the approaches the teachers used to teaching classes. However, several teachers also discussed adapting the approach used with a class to help individual pupils to progress.

Questioning

The role of dialogic questioning was based around discussions with Teacher 5 who discussed routine uses of dialogic questioning, Alexander (2008), in practical work during Interview 2, at the end of the second of three blocks of Teaching Practice, and also Interview 3 at the end of the Probationary Year.

In the course of Interviews 2 and 3, Teacher 5 frequently described an approach to teaching which appeared to be implicitly organised around an expanded Predict - Observe - Explain structure using questioning to encourage a pupil dialogue about practical work. The five steps in this approach were identified to be:

- Visual stimulus – demonstration to focus attention
- Initial observation / reminder of prior knowledge
- Pupils predict what will happen
- Observe / carry out experiment
- Discuss / explain what was observed

Initially Teacher 5 used either an overhead projector or a wall-mounted board to provide a visual stimulus for the class for practical activities or demonstrated the apparatus to be used to carry out an experiment. The initial stimulus either led directly to an observation or a reminder of relevant prior knowledge to allow the pupils to make reasoned predictions about what they expected to happen. On most occasions, the pupils carried out the experiments for themselves, but on some occasions they observed a demonstration. Once the practical work or demonstration had been carried out, the pupils engaged in a guided discussion or explanation about what had been observed and whether or not this agreed with their predictions. Teacher 5 also used this method as a way to engage classes in problem solving.

Problem solving

Once the pupils had understood the basic rules and were able to apply them in straightforward situations, the interview examined the ways in which teachers supported pupils in problem solving situations. Problem solving requires the pupils to apply their knowledge in more complicated and less familiar situations. To approach problem solving, the teachers all used a range of heuristic approaches, or "rules of thumb" which were based on their own experiences as learners in various settings.

Problem solving techniques

The teachers described a number of common problem solving approaches during the interviews. The approach selected depended on the particular problem. The problem solving approaches discussed included writing down what the pupils knew from the problem; redrawing, simplifying, using commonsense and finally tackling a theoretical problem practically by setting up a circuit.

Two of the approaches suggested were apparently contradictory: pupils were encouraged to focus on the big picture and also to go through the problem using "baby steps" or using a stepwise approach. Shifting the focus from the big picture to the small details was a feature of the way in which some of the teachers thought about finding some of the missing values requested in the various parts of question four. It is suggested that his may have been an instance of the teachers' tacit knowledge that changes to one part of a simple electric circuit have an effect on other parts of the circuit and therefore that it is necessary to consider the whole circuit as well as parts of the circuit.

Pupils were encouraged to write down the numerical information about the circuit contained in the problem. The teachers hoped that this would encourage the pupils to tackle the problem. If it did not, the pupils could try a commonsense approach where the pupils would calculate a quantity suggested by the information they had

written down.   A more focused technique was to redraw the circuit in a form which was more familiar to pupils and therefore easier for them to tackle.   The redrawing technique could be linked to simplifying the circuit, by, for example, replacing a number of resistors in series or parallel with one equivalent resistor.

If the pupils were unable to tackle a written problem by using any of the above techniques, a number of teachers suggested that the pupils tackled the problem practically by setting up a circuit to observe what happened.   Once the pupils had set up a circuit, they were in a position to try to understand what they observed rather than trying to imagine what would happen before they could try to explain.   This approach was often used with pupils in S1 and S2 and also lower ability pupils in older classes.

Content knowledge and problem solving with voltage dividers

The penultimate set of questions in the interviews dealt with voltage divider circuits in S3 and S4.   One of the reasons for asking questions about voltage dividers was to provide a context for the teachers to apply their content knowledge about circuits. Analysis of the interview data showed that the teachers used a number of different approaches as appropriate.

Several teachers stated that one of the problems with voltage divider circuits was the way that they were often drawn.   A simple series circuit with two resistors in series with a battery would frequently be drawn as shown in Figure 5.4.   A simple voltage divider circuit is often drawn as shown in Figure 5.5.   Although the two diagrams are conceptually identical, there are differences in the way that the circuits are drawn. These changes often confused pupils.
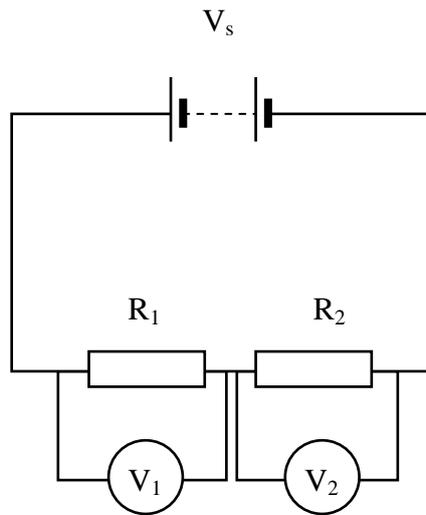
Figure 5.4   Simple series circuit, with two resistors in series with a battery.
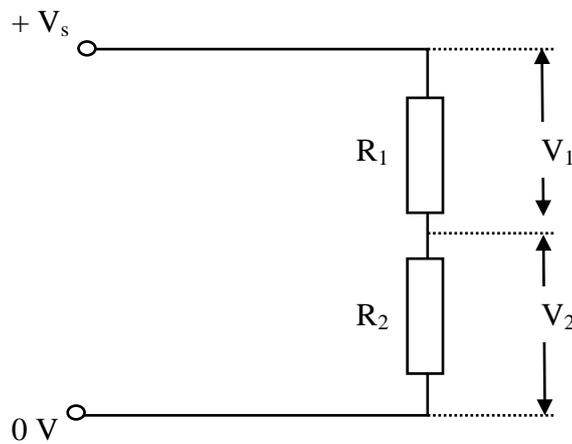
Figure 5.5   Simple voltage divider with two resistors in series with a voltage supply.

To go from the series circuit to the voltage divider circuit, the series circuit has been rotated through a quarter turn.   In addition, the battery symbol in the series circuit has been replaced by the symbol for a voltage rail, which appears to be a large gap in

the circuit. The apparent gap in the circuit can be confusing for pupils because the pupils have been taught that for a current to flow there must be a complete circuit with no gaps in it. Additionally, the symbol for a voltmeter is often replaced by a notional potential difference between two dotted lines.

Teacher 2 discussed the problems for pupils caused by simply rotating the circuit in Figure 5.4 through a quarter turn without changing any of the other symbols. Similarly, changing the voltmeter symbols in Figure 5.4 into symbols for potential difference in Figure 5.5 was also confusing for pupils. Finally, changing the battery sign into two power rails appeared to open a gap in the circuit, which in the pupils' understanding would have meant that there could be no current flowing and would cause even more confusion.

Calculations

Using Ohm's law, it can be shown that for the voltage divider shown in Figure 5.5, the ratio of the resistances is equal to the ratio of the voltages across them:

$$\frac{R_1}{R_2} \; = \; \frac{V_1}{V_2} \qquad\qquad \text{Equation 5.3}$$

Several teachers mentioned carrying out calculations about voltage or resistance in voltage dividers by using proportion rather than Equation 5.3 because some of the pupils found that method easier to use.

Equation 5.3 also leads to the heuristic that:

In a voltage divider, the bigger the resistor, the bigger the voltage across it

and, as a consequence in a voltage divider circuit:

If one resistor's share of the voltage goes up, the other resistor's share of the voltage goes down.

Several of the teachers mentioned that pupils had difficulty remembering what happened to the resistance of thermistors and LDRs when the temperature and light levels respectively changed. (A thermistor is a form of temperature dependent resistor also known as a **therm**al re**sistor**, hence thermistor. LDR is short for **l**ight **d**ependent **r**esistor.)

Teacher 2 and Teacher 4 mentioned a pair of linked mnemonics related to thermistors and LDRs:

> *When the temperature of a thermistor increases, the resistance of the thermistor decreases. This is often summarised as TURD – temperature up, resistance down.*

> *When the amount of light falling on an LDR increases, the resistance of the LDR decreases. This is often summarised as LURD – light up, resistance down.*

5.2.5 Context

Teachers' own experiences as pupils

As discussed by Kind & Taber (2005), a major resource beginning teachers draw upon is their own experience as learners. Most of the teachers did this at various points in the interviews.

One of the major resources the student teachers drew upon was their own experience as pupils. Teacher 1 in particular was influenced by his father when learning about electricity:

> *Well, the way that I actually learned Ohm's law from my dad, essentially because my dad was in the navy.*   *[T1.1.4c]*

> *I know about [it] because of my family. My dad had [electrical stuff in the house ...*   *[T1.2.7b]*

Teacher 1 discussed problems with Ohm's law and learning the formula to add resistors in parallel, which were solved with paternal involvement. Similarly, in Interview 2, the discussion about the way in which having multimeters at home meant a level of familiarity with them that was not evident with pupils. However, because Teacher 1 remembered the initial confusion when learning about the equipment, it was easier for him to help pupils with this:

> *... so you had to before you even start these experiments you had to explain to the pupils: this is the multimeter setting and that kind of thing.* [T1.2.7b]

Teacher 2 was also influenced by the approach adopted by his teachers:

> *... but a lot of it was just of matter of, this is how it works - go play with it until you figure it out sort of stuff. It actually worked quite well for me, but I don't think it works that well for everyone.* [T2.2.7b]

As a teacher, Teacher 2 allowed pupils to "go play", but was also aware that different approaches were needed for different pupils.

In contrast to the Scottish and British student teachers who accepted that electricity was taught from primary and then into secondary schools, a Canadian student teacher was surprised that British schools taught electricity at such a young age because electricity was not taught until high school level in Canada:

> *... you don't take it [physics] before what would be the equivalent of S6 because we go one year past that into S7 and so we did all of physics in two years ...* [T9.2.7b]

The Canadian student teacher had learned about electricity in high school using conventional current and found the change to using electron flow in Scottish schools challenging. This illustrated the important role that the curriculum plays in what is taught in schools and how teachers approach teaching.

<u>ITE</u>

Experience of ITE did not feature explicitly in the interviews.   However, when talking about how they structured classes and pedagogical approaches adopted, it is likely that some of this was at least influenced by ITE as well as by colleagues in school.

<u>Colleagues</u>

Teacher 1 did mention a discussion with a colleague which was related to values:

> *... as somebody said to me when I was a student, it's like why are we here as a classroom teacher? We're not here just to go home and get paid at the end of the month.   You're here to help these pupils attain whatever level they can attain.*   *[T1.3.3b]*

Teacher 1 also mentioned a discussion with a colleague about how to teach the mathematics associated with Equation 5.1

> *But I was talking with another physics teacher in the school and they were saying about how they teach it.*   *[T1.3.4a]*

Some of the conversations about colleagues related to the practicalities of teaching and the different areas of expertise of different subject teachers:

> *It depends how carefully we pick the bulbs to be honest. If I am doing it, I will try and find 3 bulbs which will light up very close to the same brightness.   I will make a conscious effort to do that, [but I'm] not sure our Biologist would bother to be honest.*   *[T2.4.2]*

The reference to "our Biologist" suggested that in this small school there was only one teacher of Biology, which would have had an influence on timetabling within the Science Department.

Discussions with colleagues were not often mentioned in the interviews.   This may be an effect of the focus of the interviews on how the teachers taught electricity

themselves rather than how they learned to teach electricity or interacted with colleagues more generally.

School Constraints

Some of the constraints the teachers dealt with were caused by the layout of the classrooms.   The result of the layout described below was that Teacher 1 developed ideas about how a science classroom could be laid out to allow the pupils to work in small groups.

> *I didn't like the class because there were fixed benches in my classroom with rows of five.   Which was really annoying because I'd like them to work in – depending on how much equipment there was – either pairs or groups of three.   Either way, the result was one person at the end of a row or somebody else was having to get added in.   So the seating in the class made it difficult to ... get the seating [right] from the start and I don't think I did it particularly well, but I know what it is I'd rather do.* [T1.3.3b]

In this example, Teacher 1 presumably found that small groups generally worked better than larger groups.   However, the awkward physical layout was actively managed to encourage learning.   Teacher 1 also reflected on the success of the management of the layout and had therefore decided what could be done differently. The teachers' use of reflection will be discussed in more detail in a subsequent section.

One of the constraints on the teachers was the structure of the timetable, which was different in different schools. Timetabling could cause problems for the pupils or for the teachers.   In some schools, electricity was only taught in S2 rather than in S1 and S2, which was not necessarily a problem:

> *... the electricity module is actually not taught in S1, they just have*
> *one large electrical module which they do ... about mid-way through*
> *second year*   *[T5.3.7a]*

A different kind of timetabling problem had occurred in the school where Teacher 4 was placed for the Probationary Year. The S3 physics class had not covered electricity in S1 or S2 because of a change to the structure of the course and found the introduction to electricity challenging:

> *The whole of electricity was actually hard for them to understand.*
> *Voltage, current and resistance. A lot of kids get confused with each*
> *of them and the symbols. And they always remember voltage and volts*
> *because they're both a V, but they couldn't really get current being an*
> *I and amps, again, because it's different.*   *[T4.3.4a]*

Apart from this class, most pupils had met the basic circuits using lamps in S1/S2 and therefore had time to assimilate some of the basic ideas and structures before meeting a mathematical approach to electricity in S3. In this class, the pupils had moved very quickly from the basic experiments to abstract concepts and equations which possibly did not allow time for them to assimilate the concepts.

At the time of Interview 4, Teacher 4 had moved to a smaller school and was teaching Standard Grade and Intermediate 2 physics in the same S3 class, with a view to deciding which examination it would be better for the pupils to sit in Fourth Year:

> *What I am doing is I am teaching the standard grade course and*
> *adding in the Int 2, the extra bit and I am trying to gather evidence to*
> *see which is going to be the best for the pupils, and I've got about six*
> *in the class who would be better to sit Intermediate 2 because they are*
> *more likely to get an A than a 1.*   *[T4.4.3b]*

Teacher 4 was the only teacher who mentioned teaching Standard Grade and Intermediate 2 work in the same class.

Other timetabling constraints affected the teachers more than the pupils:

> *Timetable this year is a bit disappointing.   I have 4th year physics*
> *class but nothing higher than that.* [T1.4.8]

Teacher 1 went on to discuss "trying to keep my knowledge up to date doing a bit of tutoring here and there" as personal professional development.   He also found the structure of the S2 timetable frustrating because it meant that there were no opportunities to teach other areas of the general science curriculum:

> *In S2 they do a rotation which I find frustrating because I am*
> *qualified to teach science and I quite enjoy teaching the other*
> *elements … The PT of Physics was saying it is the timetable they are*
> *issuing.* [T1.4.1a]

There was also a link to working with colleagues because Teacher 1 was also beginning to use the structures within the school, in this case the Science Department Meeting, to begin to put across a point of view and to ask for changes to the timetable within the Science Department.

A different perspective on the timetable was provided by Teacher 5 who worked in a residential school where:

> *Apart from two periods on a Monday afternoon, which are forty-five*
> *minutes, everything else is thirty-five minutes.   The rationale behind*
> *that is that really that's as long as they can stand.* [T5.4.7a]

Here the focus was on adapting all aspects of the timetable to the pupils' needs to enable their personal development.

Timetabling constraints were not mentioned by the student teachers during the first two interviews.   This was probably because the student teachers were allocated classes to help them to develop as teachers and so did not consider wider timetabling issues.   Interview 3 covered the Probationary Year and at this stage, the department's timetable started to have an impact on the classes the probationer

teachers were allocated, and in Teacher 4's case how electricity was taught to the Third Year Physics classes. Three years later at the time of Interview 4, three of the four teachers interviewed made comments about timetabling and had been influenced by the school timetable. Teacher 1 was frustrated by the limitations of his timetable. Teacher 3 who taught in a small school, had pupils in one class who would be entered for either Standard Grade or Intermediate 2 examinations depending on their progress. Teacher 5 who was teaching in a special school commented on the short length of the periods to accommodate the needs of the pupils. Teacher 2 who had remained in the same school since his Probationary Year did not make any comment about timetabling.

5.2.6 Values

Doing one's best for the pupils

The teachers were committed to doing their best for pupils from the beginning of the course. In the previous section about content knowledge, the first quotation was from Teacher 1's first interview and discussed how to change the teacher's knowledge into a form that would be suitable for pupils via explanation. This illustrated the teachers' wish to change and learn so that they could do the best for their pupils. The later discussion about the impact of pupils on teachers in the context section showed that the teachers often identified with particular classes when they talked about "my class" and were aware of the different needs of different pupils. This is illustrated by a quotation from Teacher 2's last interview:

> *I have been teaching almost 4 years now [and] I think the thing that*
> *has changed about the way I teach Electricity has probably been the*
> *number of different ways of doing it and I have found every kid's*
> *understanding of it is slightly different and what works for them is*
> *different.*   *[T2.4.6a]*

Teacher 2 tried different ways of teaching so that the teaching could be adapted to the needs of different pupils to allow them to do their best.

Doing one's best for pupils is sometimes discussed in formal terms of attainment (in the form of grades) but is often discussed in terms of what the pupils have achieved in class. However, the terms attainment and achievement were not used by the teachers, despite being part of the language of A Curriculum for Excellence, The Curriculum Review Group (2004). CfE also figured in Teacher 1's discussion of the role of practical work in the next section.

Teacher 4 explicitly considered the effect of choosing whether to attempt the Standard Grade or Intermediate 2 Physics course in the light of a number of different factors:

> *Yes, well it [Int 2] would give them better SCQF points and I think it links better to the Higher anyway ...*

> *What I am doing is I am teaching the Standard Grade course and adding in the Int 2, the extra bit, and I am trying to gather evidence to see which is going to be the best for the pupils* [T4.4.4a]

Teacher 4 worked in a school where pupils could be entered for either the Standard Grade or the Intermediate 2 Physics examination. The choice was pragmatically geared to ensuring the best result for each pupil based on evidence and presumably the pupil's aspirations.

Role of practical work

During Interview 3, after the end of the Probationary Year, while discussing introducing parallel circuits to Second Year, Teacher 1 was discussing what happened in parallel circuits when extra lamps are added. Pupils generally found it counter-intuitive that when the lamps were connected in parallel, all the lamps remained bright rather than becoming progressively dimmer as happened when the lamps were connected in series:

> *Again, you don't want to remove yourself too much. You say to them: There's the equipment. You know how to look after the equipment and*

set it up and let them do it for themselves: the whole Curriculum for
Excellence thing.   It's dead easy to say, Right this is what's
happening, and occasionally you feel yourself wanting to say, this is
how it is instead of letting them find it.   But if you've got the
worksheets that they can work from and the support, certain ideas that
they've got to [find].   Say right what happens there, what happens to
the lamp?   Using their own words, does it get dimmer or get duller?
However they want to describe [it], I think it is a good way for them.

The good ones, it's trying to ask what they think is going to happen
this time.   And a lot of them will think the same thing's going to
happen.   I don't want to demonstrate it.   Say this is how it is built, go
away and have a look and see what happens, and again they say, oh
right it's the same brightness, but obviously that energy thing doesn't
really work there.   So they say, how come now?   [T1.3.3a]

The extracts from the discussion above with Teacher 1 were used to illustrate the role
of practical work as well as a number of wider points.

Practical work lay at the heart of Teacher 1's practice.   Despite the pressure that he
felt to say "this is what is happening" because it saved time and because it may have
been easier, Teacher 1 displayed a commitment to helping the pupils to learn by
using their own words to talk and think about what they had observed.   Later in the
same part of the interview, he discussed extending the role of practical work with the
more able pupils, "the good ones", who were almost encouraged to use a Predict –
Observe – Explain structure.   In this instance, the POE activity challenged what the
pupils thought they knew about that "energy thing" even though the energy
explanation could have been extended to parallel circuits.   In this instance, Teacher
1 challenged the pupils to think more deeply.

<u>Wider points</u>

The discussion above also exemplified a number of wider points in relation to ITE and practical work. One of the expectations of the Standard for Initial Teacher Education, General Teaching Council for Scotland (2006b), is that pupils take responsibility for their own learning and this was also one of the expectations of the PGDE course. Teacher 1 had clearly given pupils responsibility for their learning, while still being available to help and guide the pupils as necessary.

In terms of understanding pupils' learning, the discussion about the more able pupils' learning also showed that he knew about the pupils' likely misconceptions about parallel circuits and therefore was in a position to deal with them.

Practical work was also used by a number of teachers to help pupils to solve some of the interview questions which were intended to probe how the teachers would have taught some of the theoretical concepts.

> *Basically we used the previous experiments and might stick in multi-meters at various points on the circuit*   [T3.3.4a]

> *If they can't get it, to look at it – I would go and get them to get equipment and set it up*   [T4.3.4a]

> *I would get them to build the circuit to see what happens*   [T4.4.3b]

> *I would certainly like them to try and predict before we started on an experiment.*   [T6.2.3b]

These teachers thought that in this case, the pupils would not be able to think their way through what would happen in the theoretical circuit without help. Practical work was used as a way to engage the pupils in what was happening in the circuits. Teacher 6 combined the practical work with asking the pupils to predict what would happen so that the pupils could then check it. All the teachers used practical work to advance the pupils' learning by providing observations for the pupils to consider.

Practical work was embedded in the practice of all the teachers interviewed after the end of the ITE year.   The student teachers who were interviewed once or twice during the ITE year had also begun to consider embedding practical work within their practice.

<u>Role of practical work</u>

Overall, practical work provided a way for teachers to organise their lessons and the pupils' thinking.   Abstract ideas and concepts which had to be derived from observing the relative brightness of lamps or numbers on meters were anchored in the pupils' own experiences.   The pupils' learning was hands on rather than relying on the words of the teacher or a textbook, although both may have been used. Practical work was embedded at the core of all the teachers' practice and for most was taken for granted.

5.2.7 Reflection

Teachers learning from pupils

All of the teachers discussed learning from pupils and using their reflection on the pupils' reactions to change and improve their teaching.   Teacher 6 discussed a situation where the pupils were struggling to cope with the role of different kinds of variable resistors in a voltage divider circuits, see below.   Other teachers also discussed this as an area of difficulty:

> *I think the point where they all struggled the most was the voltage*
> *divider circuit using [...] light dependent resistors and I struggled*
> *with that for a while and couldn't get the class to follow – they were*
> *all saying yes – but they weren't following.   I reflected on what I was*
> *doing and then started to build up the ideal answer – wrote out the*
> *ideal answer, got another example and then missed out all the key*
> *words – it starts to get dark therefore the resistance – leave a blank,*
> *let them decide, but then depending where it was on the circuit that*

means the voltage across the LDR – the resistance goes up therefore the voltage goes – leave a blank; therefore if the voltage goes above – leave a blank; the transistor switch turns – leave a blank – then built up and then started to miss out lines for them to see if they got it that way. I've used that a few times and I've had some really good successes with that, and that was something that wasn't working – went away – had a good think about it; think about how to improve the lesson   *[T6.2.8]*

Teacher 6 had realised that the pupils did not understand what was happening and were saying that they followed the explanation although they clearly did not.   After reflection and considering the best way to approach this subject with his pupils, he adapted his approach.   The new approach was logical and step-by-step.   If something happens, something else happens as a consequence.   Teacher 6 gradually reduced the amount of scaffolding he was providing in order to help the pupils to build up their understanding.

Teacher 3 noticed that pupils had a similar problem with understanding voltage divider circuits in one of his classes.   The solution the Principal Teacher suggested was to use bullet points:

the PT wanted them writing key phrases in bullet point style

                                      [T3.3.5c]

However Teacher 3 found that at least one pupil had problems using bullet points because different teachers had used different numbers of bullet points:

one kid got completely confused because she was taking supported study and she had a different number of bullet points for describing it and she had remembered it in a certain way   *[T3.3.5c]*

Teacher 3 found that this pupil was not the only one with difficulty remembering the number of bullet points.   Again, learning from the pupils, his solution was not to number the bullet points.

5.3 DISCUSSION OF RESEARCH QUESTIONS

Section 5.3 discusses the extent to which the two stage analysis described above answered the research questions given at the end of the literature review in Chapter 3. The rest of this Chapter goes on to discuss a new framework for teacher development derived from a reconceptualisation of the two stage analysis of the interview data.

5.3.1 Content knowledge

The student teachers content knowledge about electricity was discussed in section 5.1.1 and after re-analysis in the emergent framework, the teachers' content knowledge was discussed in section 5.2.2.

1.1   What did the student teachers know about basic (secondary school level) current electricity at the beginning of the PGDE course?

The student teachers' content knowledge about current electricity was explored using the DIRECT 1.2 questionnaire (Engelhardt and Beichner, 2004). The student teachers appeared to have a sound knowledge about most of the basic current electricity they would teach. They were unsure about some of the details about what happened when the current through a lamp was reduced. They correctly identified that the brightness of the lamp would be reduced, but did not apply their knowledge about power losses to correctly state the level of brightness reduction. They were also unsure about the effect of a short circuiting a lamp and the voltage across an open circuit. Nevertheless, these are relatively minor areas.

The student teachers' sound knowledge about basic electricity contrasted with reports in the literature, by R. Cohen, et al. (1983), Beichner (1994) and Gunstone, et al. (2009) among others, about the lack of understanding among physics students and teachers.

1.2   How was the student teachers' knowledge about basic current electricity organised?

Student teachers of physics, chemistry and biology were asked to draw a concept map of their electrical concepts to try to answer this question.   For the majority of the student teachers, this was the first time they had been asked to draw a concept map.   As a result, the maps did not show the interconnections between the concepts which are the hallmark of a well-developed concept map (Shavelson & Ruiz-Primo, 2005).   Statistical analysis showed that there was no statistically significant difference in the concept maps drawn by the three groups of student teachers.   As a result it was not possible to use concept maps to answer this research question.

A subsequent cohort of student teachers was introduced to concept mapping in a more structured way and were able to produce more structured concept maps.

1.3   Did the teachers' content knowledge about electricity change as they gained more experience?

Four of the six teachers who participated in Interview 3 after their Probationary Year did not report any change in their content knowledge about electricity.   Teacher 3 who had not studied much electricity in her undergraduate physics course and Teacher 6 who had studied Mechanical Engineering reported feeling more confident about their knowledge of electricity in Interview 3.

However, all the teachers were focused on transforming their high level content knowledge into a form that was appropriate for their pupils.   This was summed up by Teacher 6, who said:

> *I know I know it, but how do I get them to know that*   *[T6.2.5c]*

5.3.2 Curricular knowledge

The student teachers curricular knowledge about electricity was discussed in section 5.1.2 and after re-analysis in the emergent framework, the teachers' curricular knowledge was discussed in section 5.2.3.

2.1   Did the curricular knowledge of the beginning teachers develop over time, and if so, how?

There was no direct evidence that the teachers had increased in their curricular knowledge in the sense that they did not refer directly to the Arrangements Documents, SQA (2004e) for example.   However, the teachers did refer to particular school years, such as First Year, or examination courses, such as a Standard Grade class.   Two possible reasons are suggested for this.   One is that the teachers had internalised the syllabus and therefore did not refer to it explicitly.   The second possible reason is that the interview schedule was structured around different school years and therefore made it less likely that the teachers would refer to a particular curriculum document.

5.3.3 Pedagogical knowledge

The student teachers pedagogical knowledge about electricity was discussed in section 5.1.3 and after re-analysis in the emergent framework, the teachers' pedagogical knowledge was discussed in sections 5.2.4 to 5.2.7.   The emergent analysis of pedagogical knowledge was discussed in a greater number of sections than their content knowledge or curricular knowledge because subcomponents of the initial analysis became more important in the emergent analysis.

3.1.1   What types of explanations, including analogies and metaphors, did the teachers use to explain current electricity in the secondary school and did the types of explanation change over time?

The teachers' explanations of what was happening in electrical circuits tended to rely on the pupils' remembering the behaviour of current and voltage in series and parallel circuits. This resulted in a focus on the pupils remembering the rules which summarised this knowledge. The teachers all used the dormant metaphor of an electric current and a number of them developed the metaphor into a fluid or water analogy for electric current.

A number of electrical analogies were summarised in table 3.3. The teachers did not use any of the transport metaphors from table 3.3. (Teacher 2 did discuss using a coal truck analogy, but stated that it was not useful because the pupils did not use coal fires and therefore the analogy was not helpful to them.) They also did not use any of the gravitational analogies. However, five out of the six teachers did use one or more of the various forms of water analogy. Anthropomorphic analogies were mentioned most often, however, only four of the six teachers used this approach. Some of the anthropomorphic analogies overlapped with Harrison's (2008a and 2008b) discussions about analogies for electric fields, but were not used as analogies for the electric field.

Overall, the teachers seemed to be clear about what they wanted pupils to know. The general area of agreement was that the pupils had to "know the rules" for dealing with series and parallel circuits. Teacher 2 became more selective about the analogies he would use with particular classes. Apart from this, the explanations the teachers used did change with time, but this seemed to be a reaction to working with particular pupils or classes rather than a systematic development of their explanations.

3.1.2   What electrical models were adopted by the teachers and did the models change over time?

The student teachers had discussed electrical pedagogy in a class with the researcher's colleague. Therefore, it was assumed that they knew about the scientific model of electricity which was discussed in section 3.1.1 (Sefton, 2002).

However, as discussed in section 3.2.1 the concepts needed for this model are not included in the Scottish electricity curriculum, therefore the teachers needed to use curricular models rather than scientific models to explain electrical concepts.

During the data analysis, it was found that the teachers only used a current flow model to explain what was happening rather than using a number of complementary models. Overall, they preferred that the pupils "knew the rules" to explain what happened rather than using models.

Knowledge of Learners and Their Characteristics

3.2.1   What knowledge about the context did the teachers display and how does this change over time?

All of the teachers had taught in a number of schools: two schools as student teachers and at least two more schools as qualified teachers, except Teacher 2 who obtained a permanent post in his Probationary school.

During the first two interviews, when they were student teachers, the teachers were focused on learning to teach and not so much on wider issues. During Interview 3 at the end of the Probationary Year, the teachers showed that they were aware of some issues in the Science Department and some cross-curricular issues to do with mathematics and numeracy. The discussion of mathematics and numeracy was related to issues which arose in teaching electricity. These issues were the use of fractions and ratios.

Teachers 1 and 5 each mentioned Curriculum for Excellence on one occasion. This is a major cross-curricular initiative, which was perhaps not raised often by the teachers because the interviews were focused on teaching aspects of electricity rather than cross-curricular issues.

The teachers became more aware of the impact of their current context on their teaching. For example, at the classroom level, some of the teachers expressed

frustration with the layout of particular science laboratories.   Arguably, during Interview 4, Teachers 1 and 2 were aware of the role of the Science Department in determining what classes they would be timetabled to teach and the curricular areas they would cover.

3.2.2   What knowledge about pupils (learners) did the teachers display and how does this change over time?

The teachers knew their pupils as individuals and as classes.   They displayed this knowledge in Interviews 1 and 2 which took place in their PGDE year.   They displayed a greater depth of knowledge about classes and pupils in Interview 3 after the end of their Probationary Year when they had known the classes for a year rather than a few weeks.

At the time of Interview 4, one of the four teachers interviewed had stayed in his Probationary school, two teachers had taught in two other schools and the other teachers had taught in a number of schools before obtaining a permanent post. Nevertheless, all the teachers showed that they had a good knowledge of the classes and pupils they were teaching.   This commitment to learning about their pupils is an expression of the teachers' values which are discussed below.

3.2.3   Does knowledge about learners affect the way the teachers teach and if so how?

All of the teachers knew how they would teach particular topics to classes. Nevertheless, they adapted their teaching for individuals according to the responses they received.   This was easier when a class was working in small groups, particularly when the whole class was using worksheets or during practical work when some pupils worked more quickly than others.

During the initial stage of analysis, it was realised that the teachers were also adapting their approaches to teaching a topic as a result of the responses they had received from pupils. In this sense, the teachers were learning from the pupils.

3.2.4   What information about their values did the teachers reveal either implicitly or explicitly?

As discussed above, the teachers were committed to learning about their pupils. This was one of the factors leading to the development of the emergent theme, "doing the best for pupils."

All of the teachers were committed to the role of practical work as a fundamental part of their practice. Teacher 1 in particular felt strongly about the role of practical work. This was discussed in section 5.2.6.

Reflection

3.3.1   To what extent did the teachers reflect on their teaching?

In one sense all four interviews provided the teachers with opportunities to reflect on their teaching as they reported on approaches they could use or had used in the classroom. There was also an opportunity at the end of every interview to discuss their thinking about teaching electricity. After the first interview, the teachers were asked at the beginning of the interview if their approach to teaching electricity had changed.

The teachers were reflecting on their teaching from the very early stages of the PGDE year. During Interview 1, Teacher 1 mentioned the need to change his content knowledge into a form which would be suitable for pupils. He regarded this as an important aspect of teaching.

Some teachers discussed aspects of their own learning and used this as a way to consider how to approach their teaching.

5.4 EMERGENCE OF FRAMEWORK

Analysing the six teachers' interviews showed that all six teachers used a variety of approaches to teaching. However, over the course of the interviews, each of the teachers seemed to refer more to an individual approach to their own teaching. These approaches are described below. The teachers' approaches seemed to be more influenced by their craft knowledge of teaching, Leinhardt (1990) and Burney (2004), than theoretical considerations. An analysis combining the teachers' individual approaches and the emergent categories used in the analysis reported in section 5.2 led to the development of a new framework for teacher development which is described in section 5.5.

5.4.1 Individual approaches

The six teachers who took part in Interview 3 all described using a number of different approaches in their teaching, see Table 5.6 above. However, over the course of all their interviews, the six teachers described one or two main approaches to their teaching. This section examines the teachers' individual approaches.

Teacher 1 – role of practical work

An earlier section of this Chapter gave examples of Teacher 1's rationale for and approach to practical work. Teacher 1 used practical work to give the pupils some responsibility for their own learning and to help the pupils to develop their thinking by challenging what they thought they had already learned. In order to give pupils this freedom, Teacher 1 ensured that the pupils knew what was expected of them in terms of organising their use of equipment:

> *... but you get the idea of how you want the equipment setup, how they can set up this equipment up and how you want it put away. And then if you've got those things, it's like, this is what I want you to do today. I think, talk a bit about what we've done previously and let them, try*

and let them go for it and let them play around with the stuff as long

as it's done: this is where you need eyes in the back of your head.

[T1.3.3a]

As well as giving the pupils freedom to "play around with the stuff", Teacher 1 also provided the pupils with appropriate support by guiding their thinking at the beginning of the lesson and then carefully monitoring all the pupils while they were working, using "eyes in the back of your head".

Teacher 2 – the pragmatic use of analogies

Teacher 2 made the most systematic and thoughtful use of analogies when teaching. A range of different analogies were used. As Teacher 2 gained experience, different analogies were used with different class, depending on the age and ability of the pupils. During the Probationary Year, when discussing combing resistors in parallel with a Standard Grade class Teacher 2 described using analogies where 100 people walking down a road slowed down when they reached a narrow part of the road. However, this was immediately adapted to the effect of using one and then two turnstiles to allow a crowd of people to pass, T1.3.4c. However, in Interview 4, Teacher 2 initially discussed limitations and nuances of using analogies:

I use more analogies actually I don't tend to stick to a single one,

they change level to level as well as we get up towards the higher and

advanced higher some of the things I might use with my Intermediate

1 class go out the window they are not accurate enough. Some of the

analogies' start to fall apart when you start taking them any further.

[T2.4.8b]

This quotation showed that Teacher 2 discussed the range and limitations of analogies with pupils, as suggested by Harrison & Coll (2008). However, Teacher 2 seemed to have evolved this way of dealing with analogies rather than drawing on an

external knowledge base.   Teacher 2 did not use analogies with able examination classes, preferring that the pupils learned the rules:

> *... I tend to go straight with - this is how it works and go down the rules line for Standard Grade and the same for Higher. I do sometimes use water analogies for Higher because they're more able to visualise it.*   *[T2.3.4a]*

> *I think it is the variety of analogies for the different kids I don't teach a single analogy with the possible exception of current in Intermediate 1 after that it becomes I try and teach the electrical theory as true to original as I can and use analogies to explain why that works.*
> *[T2.4.6a]*

Learning the rules was preferred because that contributed more to the pupils' understanding in the long run than relying on the analogies.   Teacher 2 did use analogies with an Intermediate 1 class (considered to be of lower ability), but only with current and not voltage because the analogy being used probably broke down when used with voltage.   The analogy used was people standing on hosepipes, [T2.1.3b].

In Interview 3, Teacher 2 preferred the use of anthropomorphic, or people, analogies, such as the "smelly road" [T2.3.3b] which was rarely travelled.   According to Teacher 2, anthropomorphic analogies worked well for "people people" [T2.3.8] because these pupils found it easy to relate to this type of analogy.

Teacher 3 – pragmatic use of mathematics

As well as training to teach physics, Teacher 3 trained to teach mathematics, in common with Teachers 2 and 6.   However, Teacher 3 tended to take a more pragmatic and mathematical approach to teaching physics than the other teachers.

Probably electricity is quite a nasty concept to try and think of in a purist way about what's actually physically happening. The logic and maths for solving the circuits are actually not as difficult as the basic concept – things either add up – you've always got constant voltages and currents flowing through things in series and parallel, so you can always break things down into series and parallel circuits and build everything up from there ...   *[T3.2.6a]*

Teacher 3 tended to adopt this pragmatic mathematical approach throughout the three interviews he gave, even with respect to problem solving. In problem solving, the pupils wrote down what they knew and then followed a series of four steps:

you've now got the information for that resistor and then the equation, substitution, answer plus units – it was the four steps….

I think I would still use the four steps because it gets them into the habit of showing their working   *[T6.3.4a]*

Teacher 4 – this what you need to know

Teacher 4 initially felt somewhat insecure about teaching electricity as a result of the perceived lack of electrical content studied as an undergraduate. This was reflected in Interview 1 when Teacher 4 could not recall some of the salient information immediately, but did work out what pupils would need to know and a suitable approach by thinking through the question. Teacher 4 did not take part in Interview 2, but did take part in Interviews 3 and 4. By the time of these later interviews, Teacher 4 knew exactly what the pupils had to know at the different levels and how this content would be taught. This approach was reflected in the length of the interviews with Teacher 4 which tended to be the shortest interviews with Teachers 1-6.

When working through one of the more difficult questions in Interview 1, Teacher 4 applied basic principles to think through the answer to the problem and seemed to

find this difficult initially because electricity had not played a big part in undergraduate study, "I didn't do a lot of Electricity, or anything to do with Electronics really." [T4.3.6]

> *If the resistance goes down the voltage goes up, then the resistance... So I would get them to think about V=IR... so how as the voltage varies... So I would get them to think about V=IR, just like I'm thinking of it!*
>
> *Then so if V=IR, V must be proportional to the resistance, so the resistance, because I's staying constant, so if the resistance goes* <u>*down*</u>*, the voltage must therefore go... I'm not sure.*
>
> *So I'd have to think it through first and maybe give them numbers so that they thought about it themselves. So if that's maybe ten [long pause] So, if the resistance goes down, the voltage goes down.*
>
> *I had my doubts about that!* [T4.1.5d]

However, in Interviews 3 and 4 the response to this question was straightforward and to the point and showed clear understanding of the syllabus and the underlying physics and an approach to teaching physics which involved asking the pupils questions to guide their thinking:

> *What happens when you put it in the dark – is the light going up or is the light going down? And get them to think about what happens when the light....well it's been in the light, it's going in the dark so the light must be going down. So you know that light up resistance down, so if there's light down, resistance must go up.* [T4.3.5d]

This confirmed Teacher 4's statement early in Interview 3, where it was stated that:

> *I definitely feel more confident now than I did before. I feel my knowledge of the Standard Grade course has improved.* [T4.3.8]

Teacher 5 – predict, observe, explain

In Interviews 2 and 3, Teacher 5 developed an approach to teaching which could be described as a version of "Predict – Observe – Explain" or of dialogic teaching. This approach is discussed in more detail in section 5.2.4. Teacher 5 did not carry this approach on into Interview 4 when instead of working with pupils in mainstream schools, he was working with pupils in a residential school. However, this was a deliberate pedagogical decision, because the pupils in the residential school would not have responded well to this form of repeated questioning.

Teacher 6 – Know the rules

Teacher 6 had originally trained in Mechanical Engineering and did not like electricity when he was a pupil:

> T6.1.6c   *Electricity's probably going to be my second least favourite subject.*

> Interviewer   *And what's your least favourite?*

> T6.1.6c   *It's going to be electronics.*

However, he realised that he needed to teach electricity and to prepare to teach it:

> *I think it will be good to teach a subject which I didn't enjoy myself, to try and make it more enjoyable over the next couple of years.*
>
> *[T6.2.6c]*

Teacher 6's solution to teaching electricity was to concentrate on the rules that the pupils needed to know to be able to solve problems. He discussed the rules for current and voltage in series and parallel in all three of his interviews and summed them up at the end of Interview 3:

> *I would maybe just say what I said at the beginning – it's all about getting a clear circuit, or a clear set of rules and always apply that to*

> *all your teaching– always going back to them, rule 1, rule 2, rule 3, rule 4.* [T6.3.6a]

Using the set of rules gave a structure to his teaching and to the pupils' learning by reinforcing the importance of knowing the rules for current and voltage.

5.5   OVERVIEW OF CRAFT PEDAGOGY

The analysis of the six teachers' experiences contained in the previous section using an analytical framework which had been derived from an initial framework based on PCK, led to a reconsideration of the components of the derived analytical framework.   Reconceptualising the organisation of these components allowed the development of a new framework called Craft Pedagogy.   In this framework, teachers develop a Craft Pedagogy which based on a combination of individual and situational factors to transform their content knowledge into a form which is suitable for use with pupils and to develop their pedagogical approaches.

5.5.1 Craft Pedagogy framework

Figure 5.6 highlights the main aspects of the Craft Pedagogy framework.   The inputs to the teachers' developing Craft Pedagogy include individual and situational factors. The individual factors include the content knowledge and values the teachers had developed before beginning the PGDE course and which may continue to develop with experience.   The situational factors capture the ways in which the teachers' experiences in ITE and schools impact on their developing Craft Pedagogy.   The situational factors also capture the way in which the teachers were influenced by the pupils they taught.   The effect of the teachers' developing Craft Pedagogy is that their praxis also develops, which is reflected in the ways in which content their content knowledge is transformed and they develop their pedagogical approaches.

Although influenced by Shulman's conceptualisation of PCK, Craft Pedagogy differs from PCK in that it is based on examining the development of a small number of teachers in some detail and that it focuses on the continuing development of the teachers' praxis.   Craft Pedagogy also gives a major role to the way in which teachers learn from pupils and classes and how they use this learning to continue to develop as teachers.   Consequently, the main influence on Craft Pedagogy is the developing craft knowledge of teachers with a lesser role played by theoretical inputs.
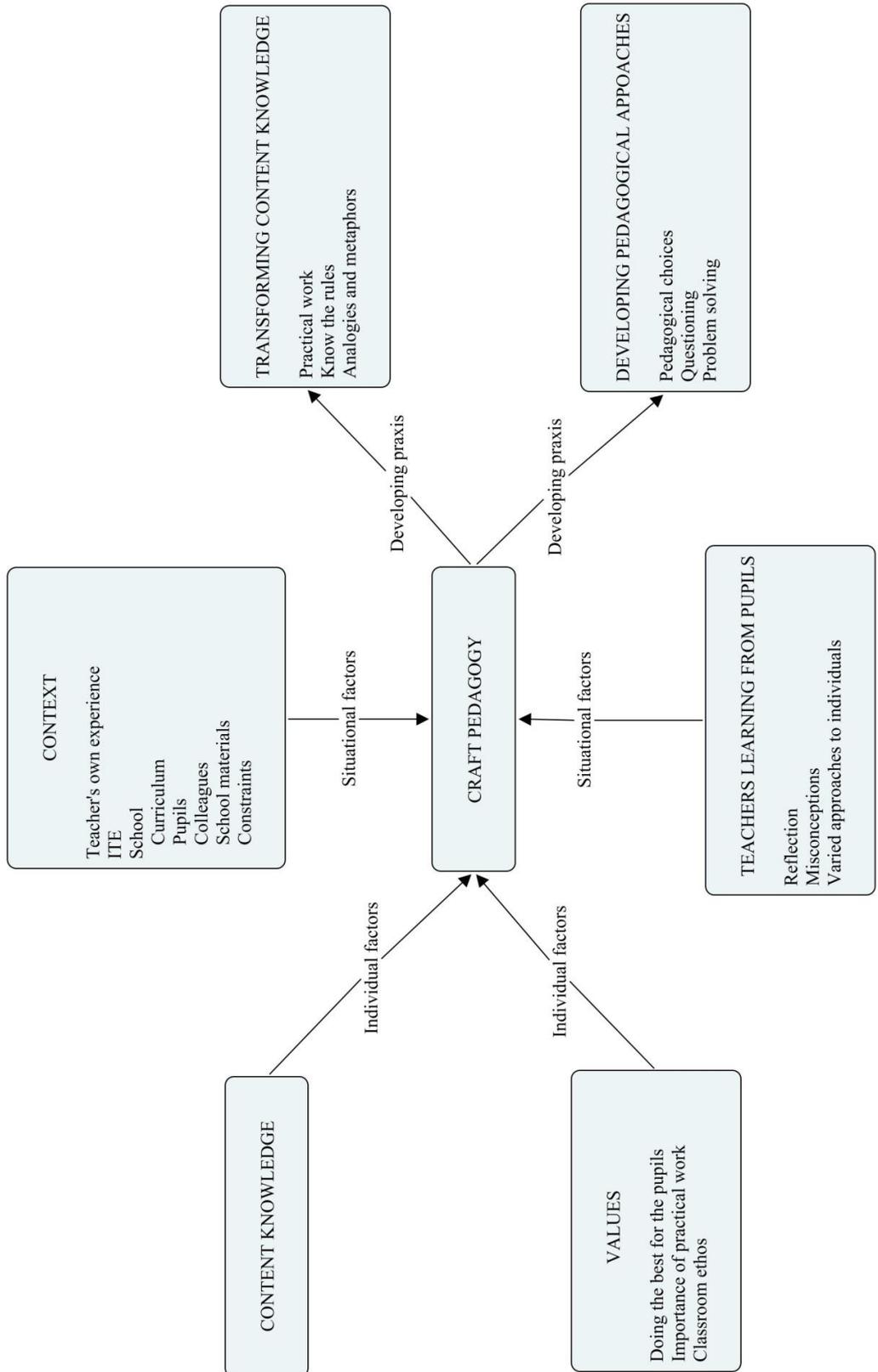
Figure 5.6   Components of the Craft Pedagogy framework.

The two main individual factors identified were the student teachers' initial content knowledge and their personal values as they began teaching. The three methods used to explore the student teachers' content knowledge were concept mapping; the pre-validated DIRECT 1.2 questionnaire; and the repeated interviews themselves. The main personal and developing professional values identified were doing the best for the pupils, the importance of practical work and the development of the classroom ethos.

The Craft Pedagogy framework contains two situational factors: the context of the teachers and teachers learning from pupils. The context deals with the teachers' own experiences as pupils; inputs from ITE; the influence of the school context including pupils, colleagues, school materials, the constraints of laboratories, equipment and timetabling as well as curriculum documents. The other major situational factor covers teachers learning from pupils and deals with reflection, how teachers deal with misconceptions and the varied approaches they take to different classes and pupils.

The second situational factor to be considered is the ways in which the teachers learned from the pupils rather than the ways in which pupils are expected to learn from teachers. The main ways in which the teachers learned from the pupils are discussed in the sections dealing with reflection, pupil misconceptions and the varied approaches the teachers adopted to teaching. One of the ways in which the teachers learned from the pupils occurred as the teachers reflected on how well a particular lesson had gone or the pupils' reactions to the lesson. As they gained experience, the teachers learned what the likely pupil misconceptions about particular topics or approaches were likely to be and used this information to adapt their teaching for those topics. The teachers all described a number of approaches to teaching, but each teacher also seemed to favour one or two approaches.

The craft pedagogies developed by the individual teachers are distinctive and based on a combination of individual and situational factors. Nevertheless, there are sufficient commonalities between the individual craft pedagogies to justify combining them to form one overarching framework called Craft Pedagogy.

The term framework has been used to describe Craft Pedagogy in this thesis to indicate the developing nature of the concept of Craft Pedagogy. At this stage, it is a concept based on the analysis of repeated semi-structured interviews which were carried out with six teachers of physics about one topic. The intention is to explore the further development of this idea by applying it to a wider range of topics and contexts to enable the development of a fully-developed substantive theory of Craft Pedagogy in the future.

5.5.2 Craft Pedagogy and physics teachers

The Craft Pedagogy framework arose from the analysis of the repeated interviews carried out with six physics teachers over the course of four-and-a-half years. This section discusses how the analysis of each teacher's interviews contributed to the development of the Craft Pedagogy framework.

The analysis of the interviews carried out with Teachers 1 – 6 during the PGDE year highlighted the main individual factors acting on the beginning teachers to be their content knowledge at the beginning of a PGDE course; their developing values and their growing awareness of their values as teachers. The individual factors affecting the beginning teachers interacted with the situational factors within the dual context of an ITE institution and the two schools where the teachers carried out three blocks of Teaching Practice. The interaction of these individual and situational factors gave rise to a transformation of the student teachers' individual content knowledge into a format which was suitable for use with the pupils. The interaction between factors also allowed the student teachers to begin to develop pedagogical approaches influenced by their own experiences and the classes they had taught during the PGDE year. This change was conceptualised as showing the student teachers' developing praxis and evidenced by their reflections in the interview transcripts. Analysis of the third and fourth interviews carried out at the end of the Probationary Year and near the end of the beginning teachers' fourth year of teaching showed the continuing influence of the individual and situational factors on the teachers' developing praxis. The teachers continued to transform their content knowledge in

the light of their interactions with students and continued to do their best for their pupils.   The constraints in the different schools where the teachers had taught affected their approaches to teaching as did continuing to learn from their pupils.

An effect of the small number of teachers in the study is that it was possible to analyse differences in the teachers' developing praxis.   Although the teachers shared many of the features described, they placed different amounts of emphasis on different features.

Teacher 1 articulated a strongly held position based on personal values.   He believed that practical work played a key part in the development of pupils' understanding. During Interview 3, Teacher 1 also expressed the strongly held belief that, rather than allowing pressure to cover the syllabus to dictate a didactic approach to teaching, the best way for pupils to learn was to be actively engaged in their own learning through practical work.

Teacher 2 was also committed to doing the best possible job for pupils, in part through the active use of practical work.   One of the main characteristics of his expressed approach to teaching was the pragmatic use of analogies.   Teacher 2 was the teacher who made the most use and the most considered use of them.   Different analogies were deliberately used with different classes at different stages and ability levels.   Teacher 2 was also aware that all analogies have limitations and that analogies can be extended too far (and were, on occasion, by some pupils.)   With examination classes, there was a preference for the pupils to use and come to understand the rules for current and voltage rather than to use analogies to structure their thinking.

Teacher 3 took part in Interviews 1, 2 and 3 but not Interview 4 because he had returned to work in industry at that time.   While he was teaching, he focused on the use of mathematics in teaching physics, possibly because he also trained to teach mathematics.

Teacher 4 initially found some of the interview questions about explaining electrical concepts challenging because there had not been much electrical content in her

undergraduate degree.   Indeed, this was discussed explicitly in the first interview. However, as Teacher 4 gained more experience and confidence in understanding how to explain the secondary school electricity curriculum, the focus of her approach changed to concentrate on the information that pupils needed to know.

Teacher 5's aim from the beginning of the PGDE year was on working with challenging pupils in a residential setting.   His aim was clearly an expression of deeply held values and had been achieved by the end of the Probationary Year. Beyond this, Teacher 5's pedagogical approach was based on a Predict – Observe – Explain (POE) model, White & Gunstone (1992), using questioning to encourage pupils to explain their thinking.   Teacher 5 adapted this initial POE approach to a residential setting where the pupils would have found such a potentially intensive approach threatening. Nevertheless, he used an adapted version of a questioning approach in the residential setting.

Teacher 6 did use analogies with younger First and Second Year classes, but tended to prefer a more mathematical approach focusing on the rules the pupils needed to know with examination classes.

Analysis of the repeated interviews with Teachers 1 to 6 showed that all six teachers had reflected on their experiences and as a result had changed their approaches to teaching.   All six teachers made repeated references to experiences with particular classes or particular pupils and had thought about how these experiences had caused them to adapt their approaches to teaching.   As well as reflecting on their experiences with pupils, the teachers reflected on the other contextual factors identified in Figure 5.6 to varying degrees.   Although all these teachers had developed their approaches to teaching in ways which are reflected in the Craft Pedagogy framework, they had all developed in different ways.

Chapter 6 Conclusion

This study was set within the context of a Professional Graduate Diploma in Education (PGDE) Physics course in a Scottish Teacher Education Institution. The analytical framework for the study was based on Shulman's 1987 version of pedagogical content knowledge. The aim of the study was to investigate if beginning physics teachers' pedagogical content knowledge about electricity changed as they gained experience of teaching. This Chapter will show how this aim was achieved by discussing how and to what extent the research questions were answered. The development of a new framework for teacher development, named Craft Pedagogy, is discussed and the implications for further research about teachers' practice and teacher education practice are explored.

6.1 RESEARCH QUESTIONS

The research questions were conceptualised using Shulman's (1987) version of PCK using Grossman's (1990) tripartite organisation of PCK, consisting of content knowledge, curricular knowledge and general pedagogical knowledge. The three research questions were based on each of these components. Research question 1 dealt with the teachers' content knowledge about basic current electricity. Research question 2 dealt with the four components of the teachers' pedagogical knowledge: context, values, learners and reflection. Research question 3 dealt with the teachers' curricular knowledge.

The research questions were addressed using a combination of qualitative and quantitative methods. The student teachers' content knowledge was investigated using the combination of the pre-existing DIRECT 1.2 electricity questionnaire and concept mapping. More information about the three aspects of the teachers' PCK, including temporal aspects of development, was collected using a series of four, repeated, semi-structured interviews over a period of four-and-a-half years. A unique interview schedule was developed and piloted for this purpose.

6.1.1 Research question 1

Does the teachers' content knowledge change over time?

The student teachers' content knowledge about electricity was investigated in three ways. The DIRECT 1.2 questionnaire was used to investigate the student teachers' of physics electrical knowledge directly. 21 out of 29 of the student teachers of physics completed the questionnaire in class. Overall, analysis of the questionnaire showed that the student teachers of physics had a good knowledge of basic electrical concepts. However, fewer than half of the respondents answered the questions about the role of the electric field in carrying energy in an electric circuit correctly. Although this is a university-level concept, understanding the role of the electric field in carrying energy underlies any explanation of why lamps light in simple circuits. The respondents were also unclear about the link between current, power and

brightness in lamps.   The respondents knew that having two bulbs in a series circuit rather than one would half the current flowing through the bulbs, but did not calculate that this would have resulted in the power, and therefore the brightness, being reduced by a factor of four.   If this issue arose during the interviews, the respondents discussed a reduction in brightness but did not mention a proportion.   It could be argued that these results contradict the findings reported by Engelhardt & Beichner (2004).

Concept mapping was used to investigate how student teachers of biology and chemistry as well as physics conceptualised electricity.   The analysis showed that a brief introduction to concept mapping did not allow the student teachers to develop their concept mapping skills to a stage where they were able to draw concept maps that reflected their understanding of the topic.   A longer introduction to concept mapping was given to the next cohort of PGDE physics student teachers in October 2005.   Giving the student teachers the opportunity to construct a group concept map produced more thoughtful concept maps.   The two approaches discussed to using concept mapping with student teachers suggested that concept mapping is a useful approach to use, but that like any learners, the students teachers required practice to acquire this skill.   This suggested that concept mapping could be a useful technique to introduce to student teachers, whether in schools or in higher education, as suggested by Kinchin & Alias (2005) and Kinchin & Hay (2005).

In their answers to the interview questions, the physics teachers showed that their content knowledge of electricity enabled them to teach their pupils.   Two of the teachers discussed revising their content knowledge, but by Interview 3, both talked confidently about teaching electricity.   The teachers used a simple model of current flow and used a number of analogies to discuss this.   They all held the scientific view that current is a flow of electrons.   The teachers did use analogies to explain the flow of current, but they did not discuss using a well-defined curricular or teaching model of current flow.   The lack of use of different kinds of teaching model, Gilbert, et al. (1998b), may be a result of not having explicitly considered the role of models in science teaching during their PGDE course.

Overall, the interviews showed a good level of content knowledge, however, some teachers did make statements which are incorrect and could be considered to indicate misconceptions held by the teachers. However, similar statements are used in school textbooks, and professional experience suggests that this can be the result of a pedagogical choice by teachers rather than the expression of a misconception. Overall, the interview data suggested that these teachers had a good understanding of electricity. This contradicts the findings of much of the physics education literature, including the recent papers by Shen, Gibbons, Wiegers, & McMahon (2007) and Gunstone et al. (2009).

However, Teachers 1 – 6 all spontaneously expressed concern about how to change their content knowledge into a form that would be accessible to pupils. They had realised the need to transform their content knowledge. This may have happened as a result of a combination of an initial realisation of the need to adapt their subject knowledge for pupils and because of discussions about pedagogy during their ITE year. Kind (2009a) and (2009b) discussed the need for teachers to transform their content knowledge in the context of her work as an ITE tutor and her review article about the role of PCK in science education.

6.1.2 Research question 2

Does the teachers' pedagogical knowledge change over time?

The components of the teachers' pedagogical knowledge were investigated using repeated interviews. Over the course of the interviews, the teachers showed development in the components of their pedagogical knowledge: context, values, learners and reflection. These developments are discussed below.

Pedagogical knowledge

All of the teachers used a range of approaches to teaching electricity.   However, over the course of the interviews, they seemed to favour one or two of these approaches to explaining electricity.

Context

The student teachers interviewed during this research were typically placed in two schools during the PGDE year and in a third school for their Probationary Year. Three of the four teachers who participated in Interview 4 were employed in a different school and one was still employed in his Probationary school.   Therefore all of the teachers had taught in at least three or four schools by the time of Interview 4.   Despite this, the influence of the wider school context was not a prominent theme.   The teachers were more influenced by their experience of the school laboratories they taught in.   However, the most common contextual factors which the teachers discussed were particular classes or pupils.   The prominence of the pupils in the teachers' thinking was probably because the teachers were constantly interacting with pupils and seemed to accept the school context as a given.

The role of Initial Teacher Education did not often feature explicitly in the interviews.

Values

The teachers were all committed to developing as professionals.   This was seen in the interviews by the ways in which the teachers took working with the pupils seriously.   Their over-riding consideration was doing the best for the pupils and helping them to learn.

<u>Learners</u>

By the time of the second interview, the student teachers had taught in two different schools for a total of 14 or 18 weeks. Despite this short time in schools, they talked about the differences between classes and pupils. After a year as Probationary Teachers, the respondents talked about the different levels of classes they had taught and adapting their teaching to the needs of the classes and individual pupils. The same was found during Interview 4 three years later. The teachers all knew their pupils and adapted their teaching approaches to their pupils.

<u>Reflection</u>

The way in which the teachers adapted their teaching to different classes and pupils showed that the teachers were reflecting on their teaching, either during a lesson or later when they considered the best way to teach a difficult concept. This was interpreted to show that the teachers were learning how to teach from interacting with the pupils. The way in which the teachers learned from their pupils is a key element of Craft Pedagogy.

6.1.3 Research question 3

Does the curricular knowledge of beginning physics teachers develop with time?

The teachers' developing curricular knowledge was investigated using the repeated interviews. There were relatively few responses about this component of PCK. This was possibly a result of the design of the interview schedule. The interview schedule was designed to lead the teachers through the typical electricity curriculum in Scottish secondary schools from First Year to Fourth Year. The questions were framed to refer to the school year and examination course. This may have focused the teacher's attention on a particular curricular stage and made it less likely that they would refer to another curricular stage. Nevertheless, the teachers had all taught the physics curriculum from First Year to Fourth Year and half had taught Higher

Physics.   They showed that they had a good knowledge of the school physics curriculum and had probably internalised the curriculum for the different years.

6.2 REFLECTION ON METHODOLOGY

Like any doctorate, the professional Doctorate in Education (EdD) serves as an introduction to the research process. One of the aims of any doctoral process is to show that the doctoral student has progressed to the stage where he or she can carry out research independently. Section 6.2 provides a reflection on methodology to demonstrate some of the learning achieved over the course of this doctoral study, beginning with the research questions.

Research questions

The answers to the top level research questions were provided in Section 6.1 in an attempt to answer the questions originally posed in Section 1.5 and based on Shulman's PCK. Section 4.1.2 split each of the top-level research questions into a number of sub-questions. These sub-questions were based on the components of the analytical framework which had been identified for the research.

On reflection, it would have been better to have referred to only the three top-level questions posed in Section 1.5 as the research questions. Subdividing them into 11 sub-questions may have given the impression that the research itself was too fragmentary. However, the sub-questions were a useful way to guide the research to ensure that the concepts which had been identified within PCK were addressed.

Qualitative paradigm

The research reported here is predominantly based on the analysis and interpretation of interview data and therefore sits within the qualitative paradigm. This may be considered problematic because of the debate about the status of interview research as a 'method' or a 'methodology' reported in section 4.1.3.

The resolution suggested here is that interview research can be considered to be a methodology in its own right. Section 4.1.3 discussed a number of research methodologies and some researchers use interviewing as a 'method' to carry out their

research.   In the present report, the research interviews carried out with the student teachers and teachers were used as a methodology within a social constructivist approach to research.

Strengths and limitations of data collection methods used

The research and data collection were conducted by a new ITE tutor researching her own practice.   This context contributed to the strengths and limitations of the research.   The main strength of the research is that it was a four-and-a-half-year longitudinal study which used repeated interviews with the same teachers.   The main limitation related to the way in which student teachers elected to take part in the research interviews and the way in which the other research instruments were used. One of the consequences of being a new lecturer was that the researcher was unwilling to place additional requirements on the student teachers above and beyond the course requirements.   As a result, student teachers were asked to volunteer to take part in this research.   Ethically, it was felt that the tasks the student teachers were asked to undertake should be beneficial to the student teachers as well as the researcher.   One outcome of the results and reflecting on the process of researching one's own professional practice, is that the researcher would now take a more proactive stance with student teachers in relation to future research of this kind.   The interviewing process placed demands on the teachers' time, which they were willing to provide.   Given that they were willing to help without gaining any explicit benefits, it would be possible to ask other student teachers to take part in research-orientated tasks which may take more time, provided that appropriate consideration is given to ethical issues.

The electricity concept mapping task and the DIRECT 1.2 questionnaire were attempts to provide additional information about how the student teachers conceptualised electricity.   In both cases, more information would have been gained if the instruments had been re-issued to the student teachers at the end of their PGDE course to investigate whether and how their ideas had developed.

As discussed below, more careful thought at the planning stage for researching one's own practice would allow for closer integration of teaching tasks and the research process for the benefit of the student teachers and the researcher.

The interview sample was an opportunity sample, based on student teachers of physics who volunteered to be interviewed. One of the results of this was that the student teachers who took part were mainly based in West-Central Scotland and had a wide range of degrees. The four teachers who took part in the fourth interview were all based in and around the South-West of Scotland.

Recruiting student teachers from all of the TEIs in Scotland and using demographic data would have provided a wider range of interviews to investigate the validity of the Craft Pedagogy framework. A larger initial sample would also have reduced the problem of teachers dropping out: an inevitable factor in longitudinal research.

As part of the research planning process, further time would have to be allocated for transcription and analysis of interview transcripts at the time of the interviews.

Revised methodological approach

Another reflection on methodology has been the realisation that any further research carried out on Craft Pedagogy or in other areas should be approached more systematically at the planning stage. Designing a research project is an iterative process where the different parts of a plan interact with one another. For example, once the general area for research has been decided, the focus is narrowed to concentrate on a particular area. Selecting the aim and research questions has an impact on the methodology selected, which in turn impacts on the methods of data collection and analysis. The constraints on these may in turn have an impact on the research questions. Clarifying these issues at the planning stage should result in a greater chance of answering the research questions after data collection and analysis.

6.3   CRAFT PEDAGOGY

Over the course of the four-and-a-half years covered by this research, the teachers showed that their PCK had changed and developed.   This contrasted with Shulman's approach to PCK which did not include a time dimension.   However, there were similarities with Cochran et al.'s (1993) discussion of pedagogical content knowing which does include change over time.

The contribution of this research was the development of a substantive theory of Craft Pedagogy, discussed in Chapter 5.   The analysis of the interview data generated a new framework for teacher development, named Craft Pedagogy. During the interviews, the teachers discussed aspects of their developing craft knowledge.   Based on the interview data, it was hypothesised that the teachers' craft knowledge was based more on their own practice than educational theory. Therefore, the thesis presented here is that it is possible to synthesise a substantive theory of Craft Pedagogy for physics teaching that draws on individual physics teachers' craft knowledge of teaching electricity.

Currently, the theory of Craft Pedagogy is based on the research reported in this thesis, which was carried out with one cohort of PGDE physics students and dealt with the experiences of six teachers over four-and-a-half years.   Further research should be carried out to explore the applicability of this theory to larger numbers of physics students and teachers.   The theory as currently framed refers specifically to teaching electricity.   Further research should also be carried out to explore whether the theory can be adapted to teaching all aspects of physics and other subjects.

More recently, Kind (2009b) gave an overview of the origins of PCK and of how it has been developed and adapted for use in the science education research community.   She argued that while PCK is a useful concept in the science education research community, it is a pre-paradigmatic concept.   As a result, PCK has potential for use in the science education community in schools, but the lack of an agreed definition of PCK means that it is not yet ready to be used in ITE or with school science teachers.   Kind (2009b) also argued that PCK is a useful model to

conceptualise teachers' development, but that there is no mechanism to explain the development of PCK.

This thesis suggests that Craft Pedagogy could provide the missing mechanism to explain the development of teachers' PCK.

6.4 FURTHER RESEARCH

This thesis suggests that the theory of Craft Pedagogy can explain some aspects of beginning physics teachers' development. The theory is currently based on the analysis of sets of interviews with six teachers who were interviewed over four-and-a-half years. Data from interviews with nine other student teachers of physics were also used to develop the theory. Further research could be carried out to include:

- larger numbers of physics teachers over a wider range of physics topics;
- a range of different subjects;
- teachers in different sectors of education.

The theory of Craft Pedagogy was developed using interviews with supporting evidence from a questionnaire and concept mapping. A possible next step could be to record classroom teaching. These recordings could be used to develop the theory of Craft Pedagogy in a number of ways. The recordings could be analysed using Craft Pedagogy as the analytical framework.

The interviews collected from the 15 participants were analysed using manual methods. This provided me with experience of coding and analysing interview data. The possibilities for research discussed above would result in carrying out research with many participants. Analysing a potentially large volume of data would suggest the use of computer aided qualitative data analysis software to facilitate the coding and analysis of the data.

6.5   IMPLICATIONS FOR PRACTICE

The development of student teachers' PCK is an implicit part of practice in the host institution's approach to ITE.   In particular, the implicit development of PCK plays an important role in the approach to physics teacher education.   Having carried out this research and considered approaches to developing aspects of PCK like those described by Kind (2009a) and Kind (2009b), it appears that PCK would be a useful theoretical concept to introduce to PGDE physics student teachers.   The introduction of an explicit rather than implicit focus on PCK would provide the student teachers with a theoretical framework to guide their reflective practice despite Kind's (2009b) reservations about the pre-paradigmatic state of PCK.

In addition to introducing the student teachers to PCK, they could also be introduced to the idea of Craft Pedagogy.   This would enable the role that learning from their pupils plays in their development as teachers to be made more explicit and therefore potentially more effective.

It is current practice in physics teacher education in the host institution to discuss the role of misconceptions in teaching science and physics as part of a constructivist approach to teaching.   There is also some discussion about the role of models and explanations and how these could be taught effectively.   A more explicit approach to helping student teachers to develop a pedagogy for using models in science education would also help pupils to develop their understanding about the role of models in science and the limitations of models and analogies in science, along the lines suggested by Harrison & Coll (2008).   This suggestion was implemented with the 2009/2010 cohort of student teachers of physics.

Both of these suggestions would give student teachers an explicit theoretical basis to help them to develop their own understanding of teaching and their pupils' understanding about science.   This explicit concentration on the role of theory in teaching would have several benefits for the student teachers.   The host institution will start offering Masters-level credits within the PGDE course in session 2010/11. Providing student teachers with an explicit theoretical framework will help to prepare

them to work at Masters Level.   Increasing the student teachers' awareness of their PCK should enable them to work more effectively with pupils and therefore potentially to enhance the pupils' learning.   In addition, experience working at Masters Level during the PGDE course would help to prepare the student teachers for possible entry to the Chartered Teacher Programme, Scottish Executive (2001), at a later date.

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Appendices

APPENDIX 4.1 ELECTRICITY INTERVIEW SCHEDULE

Interview 1:　　　Pre-School Experience 1

I'd like to talk to you about how you could go about introducing electricity to first and second year classes and then talk about how these ideas could be developed in third and fourth year classes and possibly in higher classes too.

Experiment 1 S1 and S2

1a.　　A series of experiments often carried out in first year classes involves the following sequence of experiments.　As more lamps are added in series, the lamps get dimmer.
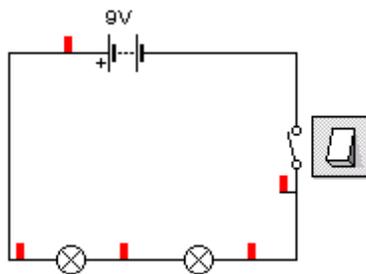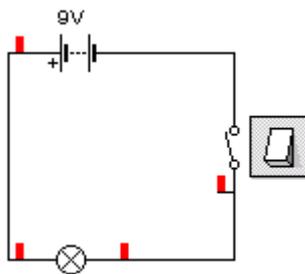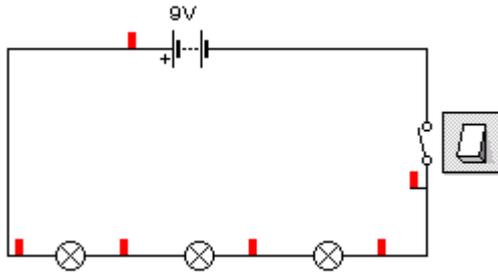
How would you use this sequence of experiments to help pupils to begin to understand electricity?

- What electrical concepts would you introduce?
- Why did you choose to introduce these concepts?
- Would you use any models to help pupils to understand what is happening?

1b. In the second diagram, pupils often ask:-

  o why do the lamps get dimmer?

  o Why are the lamps equally bright?

How would your explanation answer these questions?

1c. Why did you decided to explain this in this way?

Experiment 2 S1 and S2

2. Another experiment which is often carried out in first and second year is adding

   more cells to the circuit to increase the brightness of the bulb.
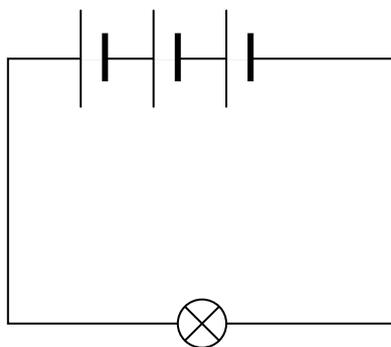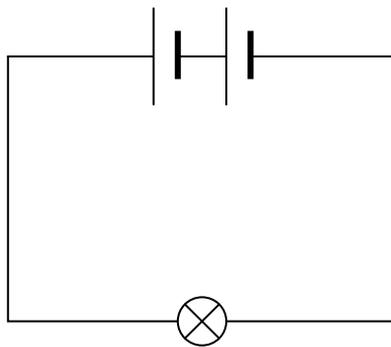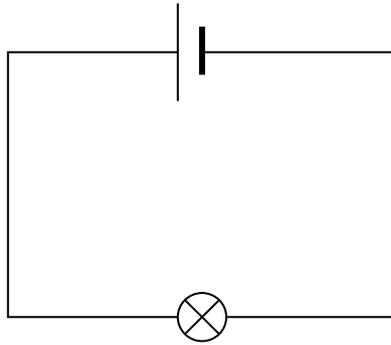
Experiment 3: **Parallel Circuits in S1 and S2**

Up to now we've been thinking about series circuits.   Lets start to think about

parallel circuits.

3a.   We know that in an ideal world, the bulbs in all 3 experiments are equally

bright.
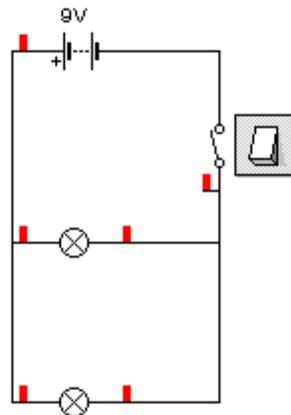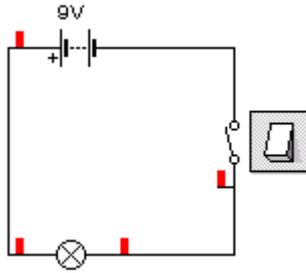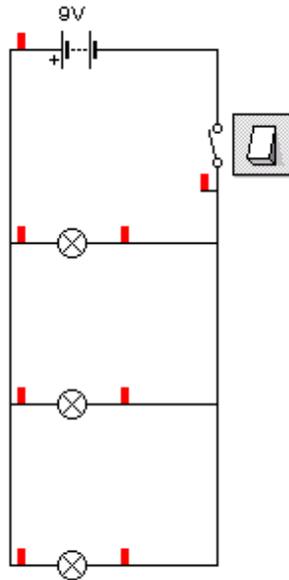
How would you get pupils to start thinking about this result?

3b. Pupils are often asked to compare the brightness of bulbs in more complicated circuits.   What sort of reasoning do you hope pupils would use in this case?
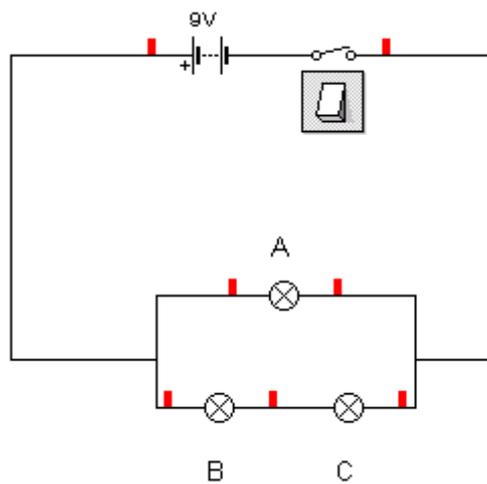
How would you help a pupil who was struggling with the answer?

3c.   What sort of reasoning do you hope pupils would use in this case?
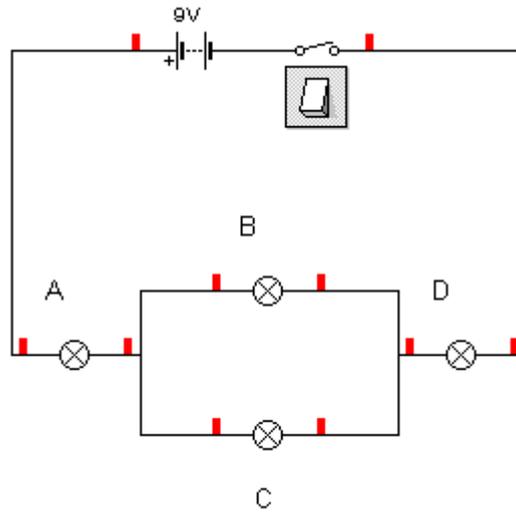
Section 4   Series and Parallel Circuits Again in S3 and S4 and Higher

4a.   Series and parallel circuits are met again in third and fourth year in a more

mathematical way.

How would you begin to get pupils to solve problems like this?

4b

4c

12 V

4d

12 V
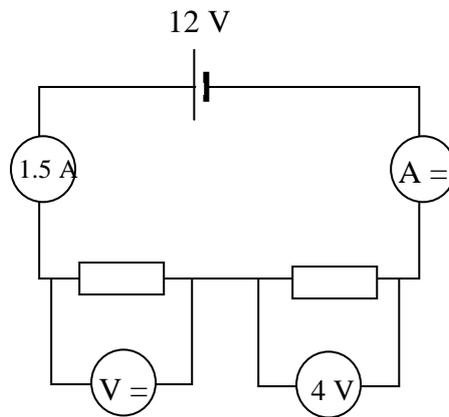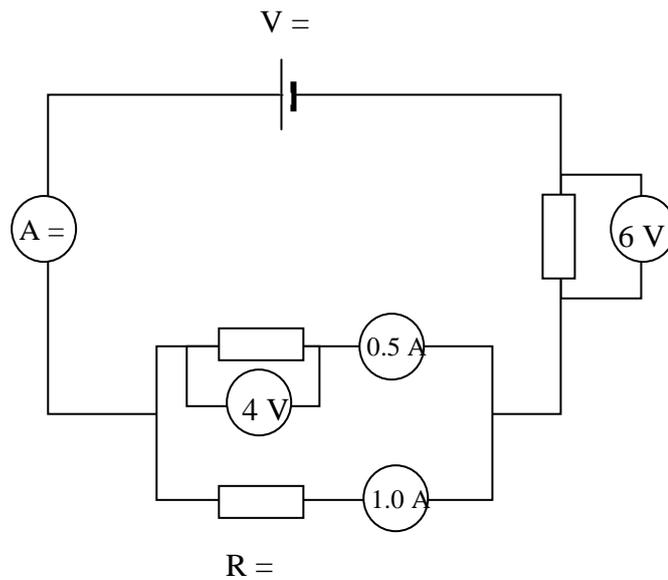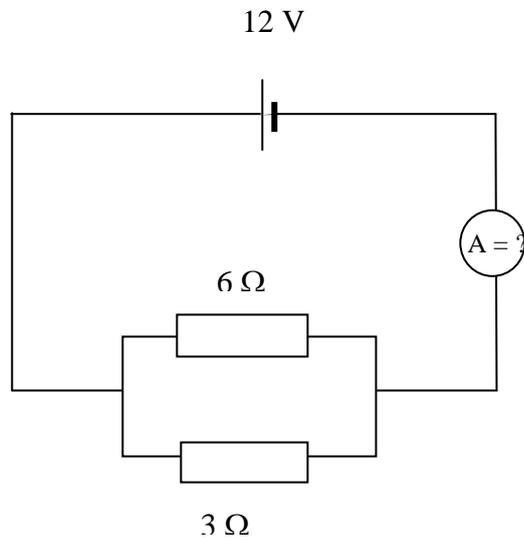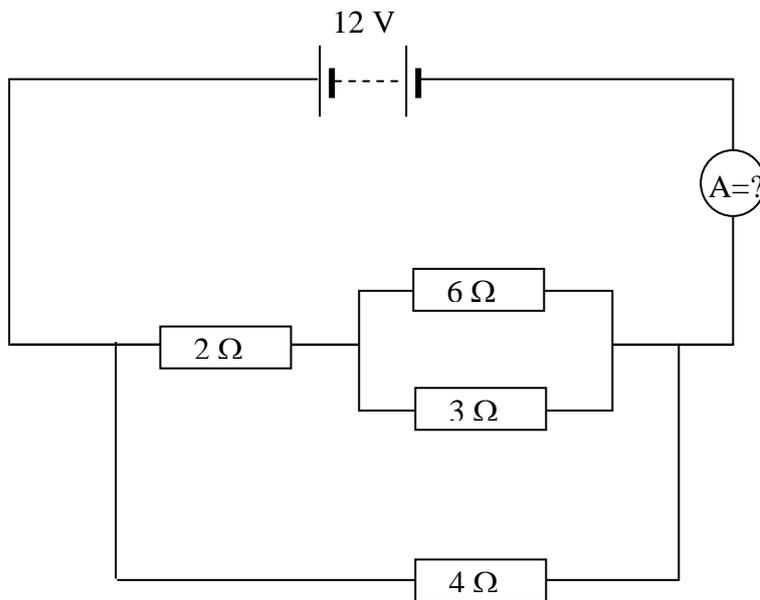
5a.   How would you start to get pupils to understand this sort of circuit?

5 V $\circ$ ────────────────┐
                           ▢ V_1
                           │
                           ▢ V_2
 $\circ$ ───────────────────┘

5b.

5 V $\circ$ ────────────────┐
                           ▢
                           │
                           ▢
 $\circ$ ───────────────────┘

5c.

5 V
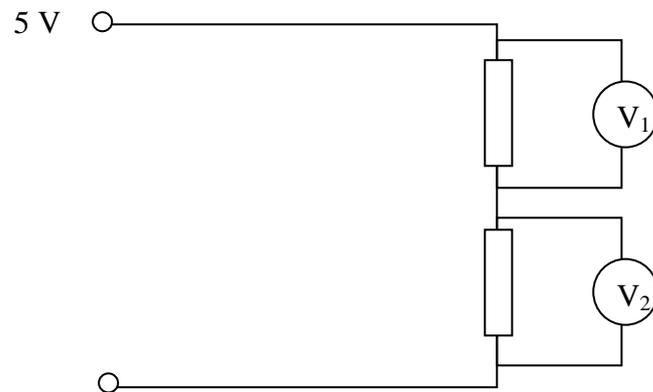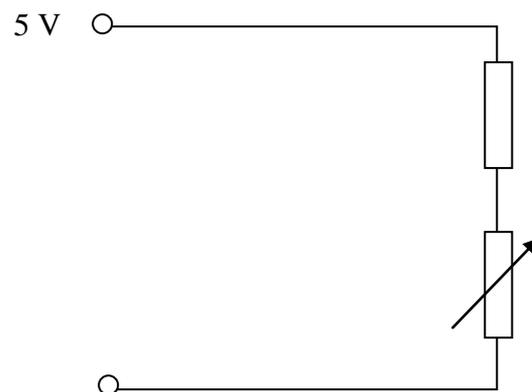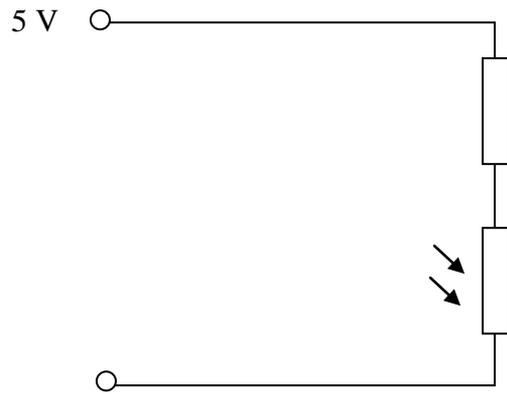
5d. Ideas like this are followed through to Higher physics. Eg a multiple choice question from 1998.

V
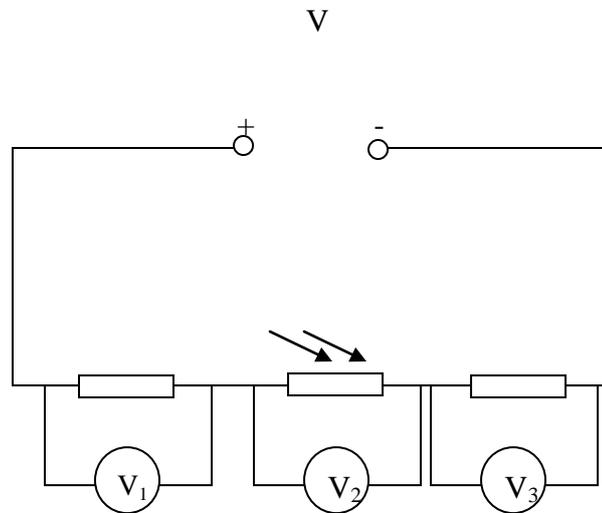
Section 6   General Questions

1.   What are the important ideas to get across when pupils are learning about electricity?

2.   In your experience up until now, what problems or difficulties do you think pupils do / might have when they are learning about electricity?

3.   Are there any other points you would like to add?

Interview 2:   Preliminary Questions after School Experience 2 or School Experience 3

Question 7

7a.   What experience did you have teaching electricity on placement?

7b.   Do you remember much about how you were taught electricity as a pupil?

7c.   Do you think that your ideas about teaching electricity have changed as a result of being in school?

Interview 3:   Preliminary Question Immediately Post-Probation

Question 8

8.   Did you have much experience teaching electricity during your Probationary Year?

Interview 4:   Preliminary Question Three Years Post-Probation
Question 8

8.   Did you have much experience teaching electricity during your Probationary Year?

APPENDIX 4.2 INTERVIEW DIAGRAMS

Diagrams for Electricity Questionnaire

Experiment 1 S1 and S2
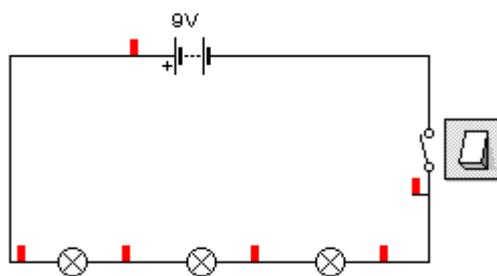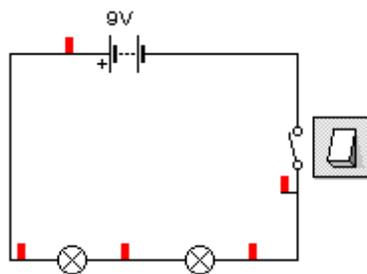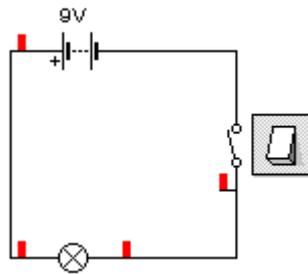
Experiment 2 S1 and S2
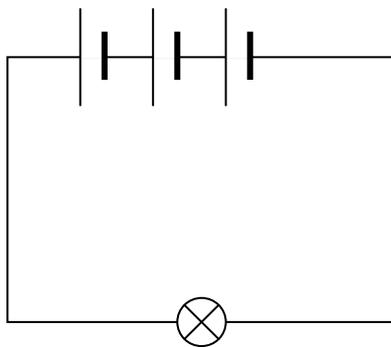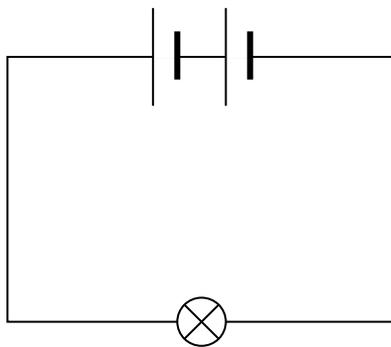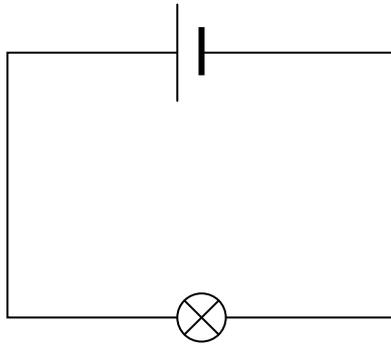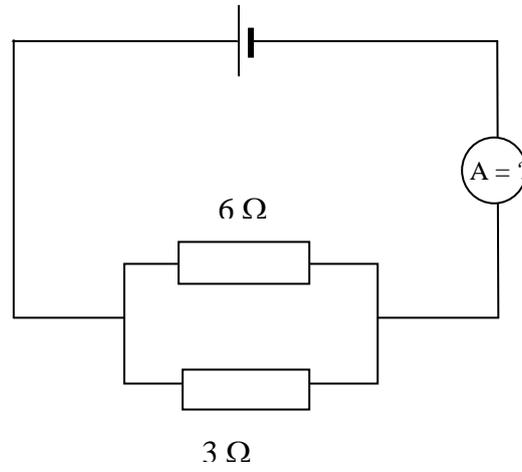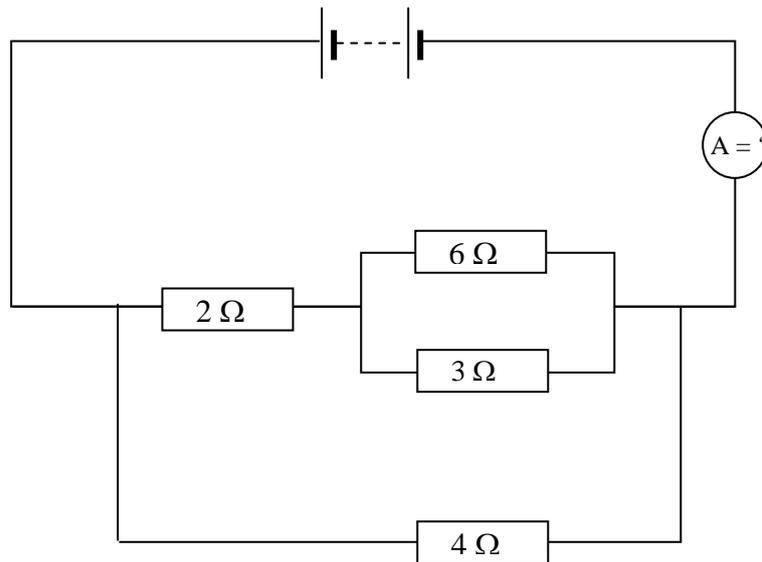
Experiment 3: **Parallel Circuits in S1 and S2**
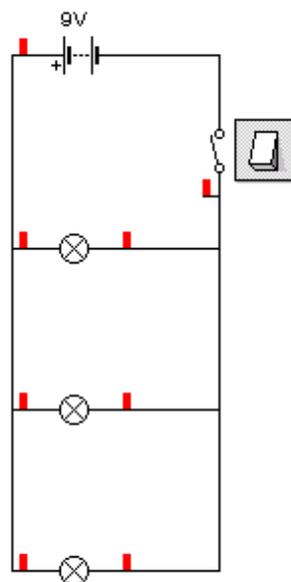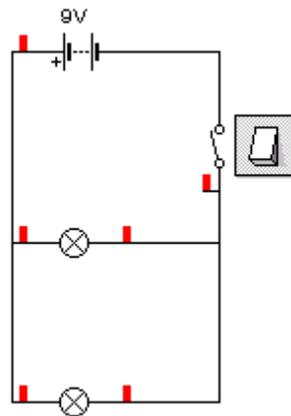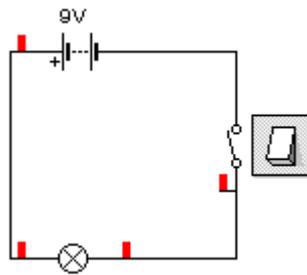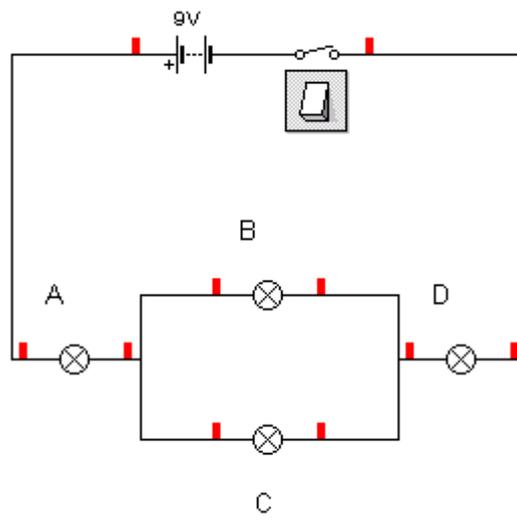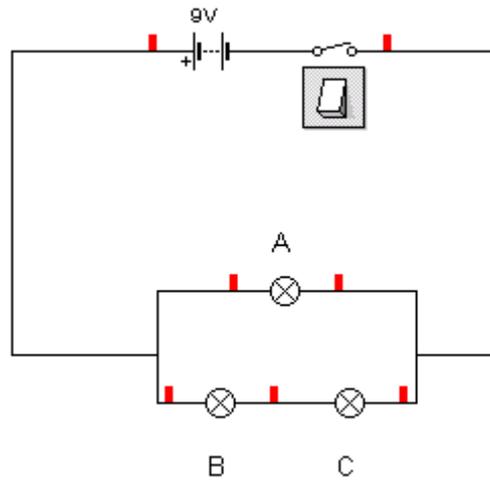
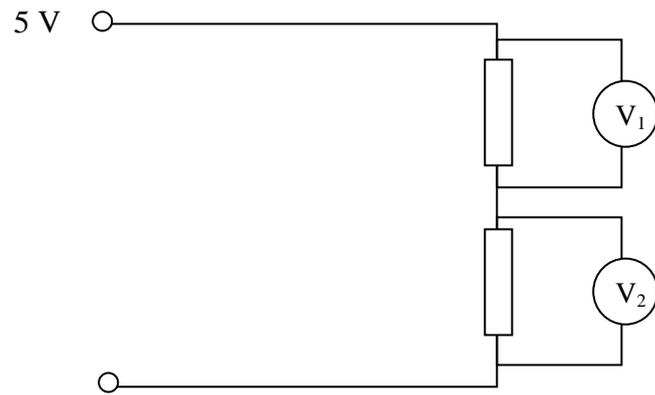## Experiment 4 Series and Parallel Circuits Again in S3 and S4 and Higher

12 V

1.5 A

A = ?

V = ?

4 V

V =

A = ?

6 V

0.5 A

4 V

1.0 A

R =

12 V

6 Ω

3 Ω

A = ?

12 V

2 Ω

6 Ω
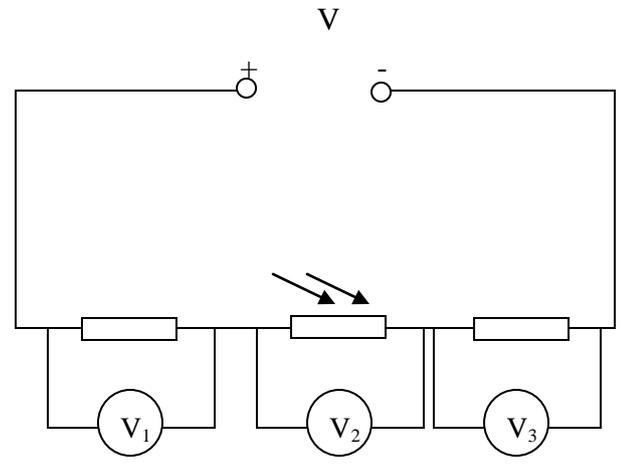
3 Ω

4 Ω

A = ?

1

2

3

5 V

V

4

V

+   -

V₁   V₂   V₃
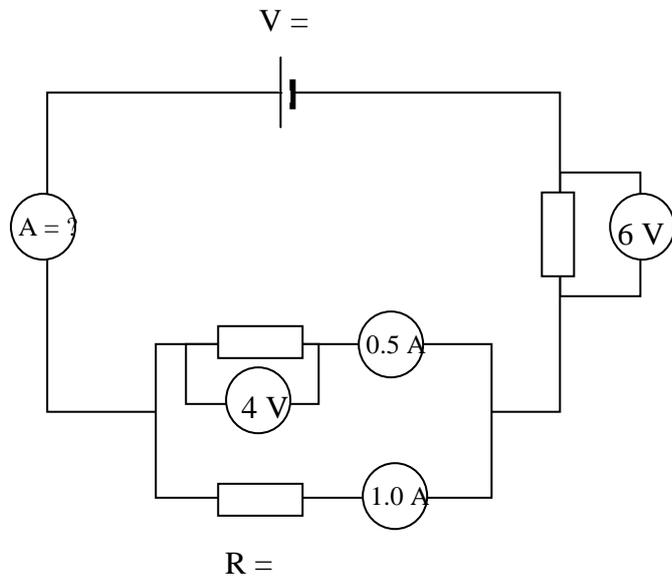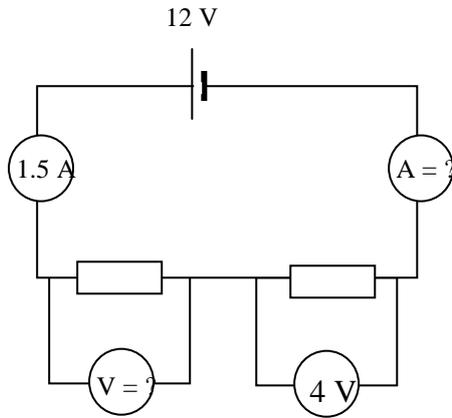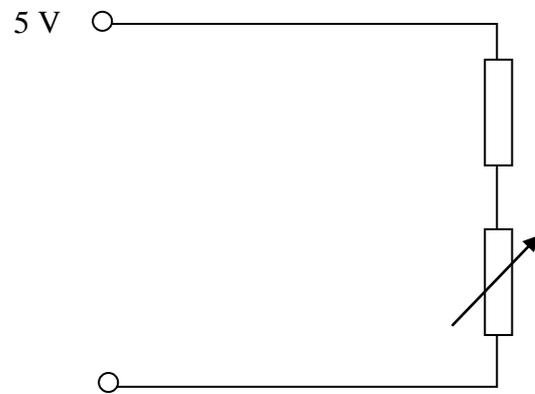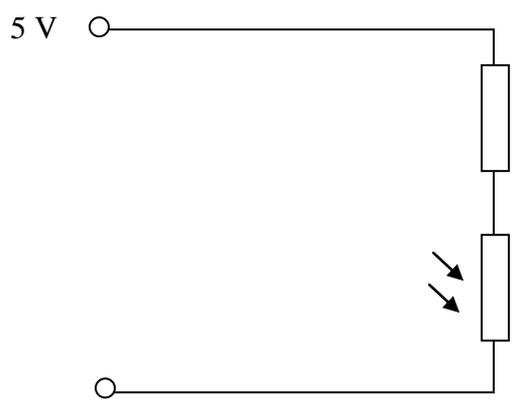
APPENDIX 4.3 INFORMATION SHEET

Background Information

As part of a Doctorate of Education (EdD) programme at the University of Strathclyde, I am carrying out research into how Physics Teachers teach Electricity throughout the secondary school. This is a follow up interview with teachers who were interviewed as student teachers and probationary teachers.

Interview

The research will be carried out by interviewing participants for a maximum of one hour. The interview will consist of a series of questions about teaching electricity and should take the form of a professional discussion.

Permission will be asked to make an audio recording of the interview and to make notes during the interview.

After the interview, the recording will be transcribed and you will be given a chance to correct the transcription. Your permission to use the transcript will be confirmed at that stage.

You are free to withdraw from the research at any stage, including during or after the interview.

Anonymity

Participants and their schools will not be identified in the EdD dissertation or any academic papers arising from the research.

APPENDIX 4.4 CONSENT FORM

As part of this project, I have made an audio recording of you.   I would like you to indicate which uses of the transcript are acceptable to you.   This is completely up to you.   I will only use the records in the ways you agree.   In any use of the transcript, names will not be identified.

The transcript can be used for the EdD dissertation

The transcript can be used for academic publications and / or meetings.

Remember, you are free to withdraw from the research at any time.

I consent to the following:-

The transcript can be used for the EdD dissertation   Agree / Disagree

The transcript can be used from academic publications and / or meetings.

Agree / Disagree

Signed   Date

Contact details removed.

APPENDIX 4.5 HEADTEACHER INTERVIEW PERMISSION REQUEST

<Insert School Address>

February 2009

Teaching Electricity

Dear <Headteacher Name>,

As part of my research as a physics tutor on the PGDE course at Strathclyde University I have been interviewing some of our previous students to discover how their thinking about teaching electricity has changed.

<Blank>, who is one of your physics teachers, had kindly agreed to help me with this research while s/he was a student at Strathclyde.   I have previously interviewed him/her on three separate occasions, including once at <Blank School>.   I wanted to ask you if you would agree to allow me to interview him/her at the school to find out if he has changed his ideas about teaching electricity. If this was agreeable to you I would like to interview <blank> on Friday 20th March at 13.35.

These interviews are wholly concerned with how the individuals involved have changed their ideas about teaching electricity.   No schools or individuals would be identifiable or referred to by name in any published or unpublished work arising from this research.

Thank you for considering this request.

Yours Sincerely

Morag Findlay

Lecturer in Physics

<Identifying information removed>

APPENDIX 5.1 CONCEPT MAPPING TASK

PGDE General Science Concept Mapping Task

You have been given an alphabetical list of electrical concepts from the 5-14 Environmental Studies Guidelines for Science.

Draw a concept map about electricity using as many or as few of these concepts as you want. You can also add any other concepts which would be helpful.

Label your concept map with your General Science section and Teaching Subject(s).

Hand in your concept map at the next General Science day, Friday October 8th 2004.

List of electrical concepts

|	
appliance	electrical insulator
battery	electricity
battery-operated circuit	electromagnet - function
bell	electromagnet - structure
buzzer	lamp
changing number of components	parallel circuit
circuit diagram	resistance
component	safe use of electricity
conventional symbols	series circuit
current	simple circuit
dangers of electricity	switch
electric motor	voltage
electrical circuit	wire
electrical conductor	

APPENDIX 5.2 CHANGE DIAGRAMS

Teacher 1

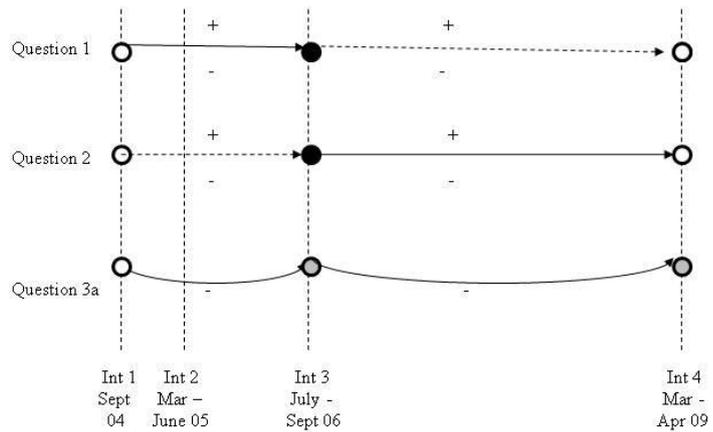| T1	Interview 1	Interview 2	Interview 3	Interview 4
Q1	Electricity	Power and voltage	Energy	Current
Q2	Voltage (driving force)	Power and voltage	Energy	Current and voltage
Q3a	Current and voltage	Current and voltage	Current, voltage and energy	Current and voltage
		+ + -	+ - -	+ -
		+	+ - -	+ + -
			+	-
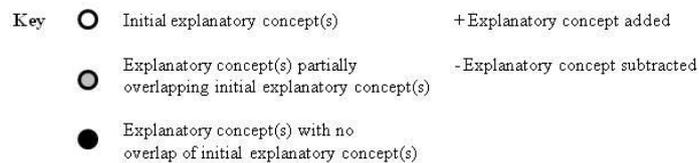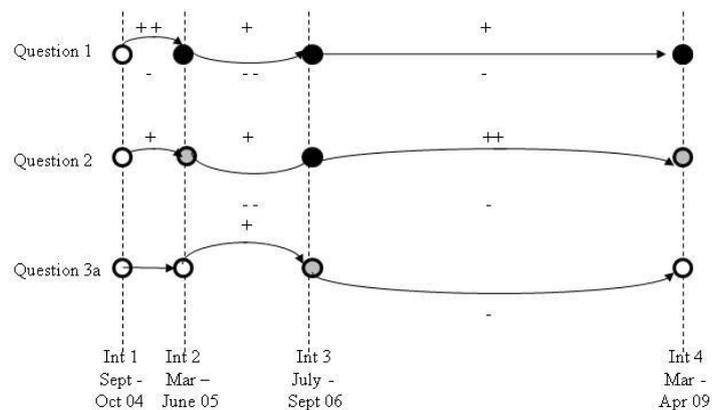
T2	Interview 1	Interview 2	Interview 3	Interview 4
Q1	Energy and voltage	Energy	Energy and voltage	Energy
Q2	Voltage and current	Power and energy	Energy (push)	Voltage
Q3a	Current, voltage and power	Current	Energy	Voltage
		-	+	-
		+ + - -	-	+ -
		- -	+ -	+ -
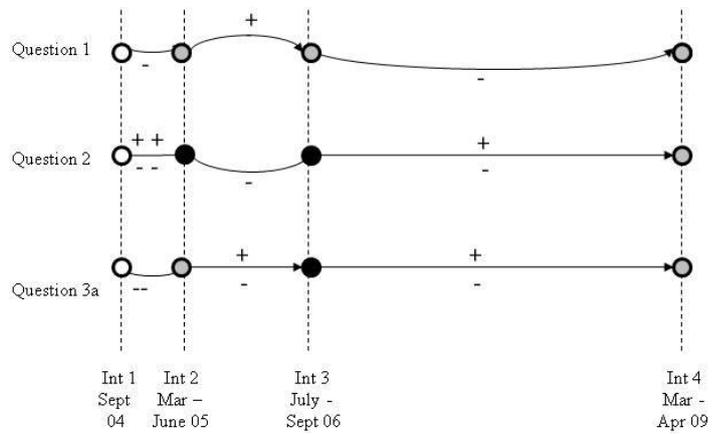
T3	Interview 1	Interview 2	Interview 3	Interview 4
Q1	Current and voltage	Resistance	Current and voltage	-
Q2	Electricity	Water analogy	Energy and current	-
Q3a	Current and voltage	Water analogy	Voltage	-
		+ - -	+ - -	
		+ -	+ + -	
		+ - -	+ -	
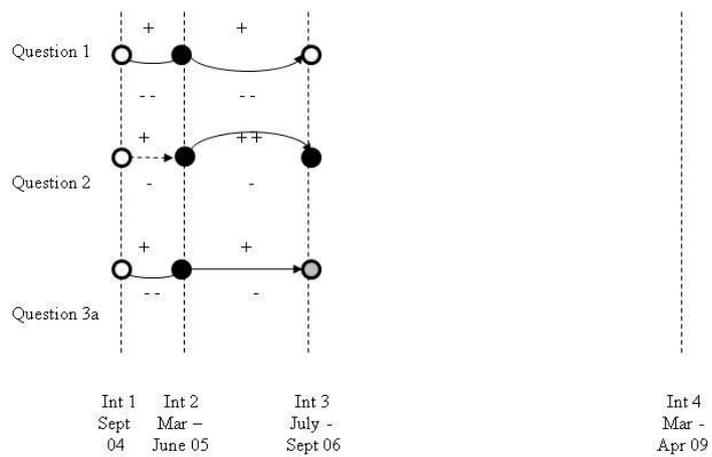
T4	Interview 1	Interview 2	Interview 3	Interview 4
Q1	Voltage	-	Energy	Voltage
Q2	Voltage	-	Energy	Voltage
Q3a	Current, voltage and energy	-	Voltage and energy	Energy
			+ -	+ -
			+ -	+ -
			-	-

T5	Interview 1	Interview 2	Interview 3	Interview 4
Q1	Energy	Energy	Energy	Energy
Q2	Energy	Energy	Energy	Energy
Q3a	Voltage and current	Current and energy	Voltage and current	Current
		0	0	0
		0	0	0
		+ -	+ -	-
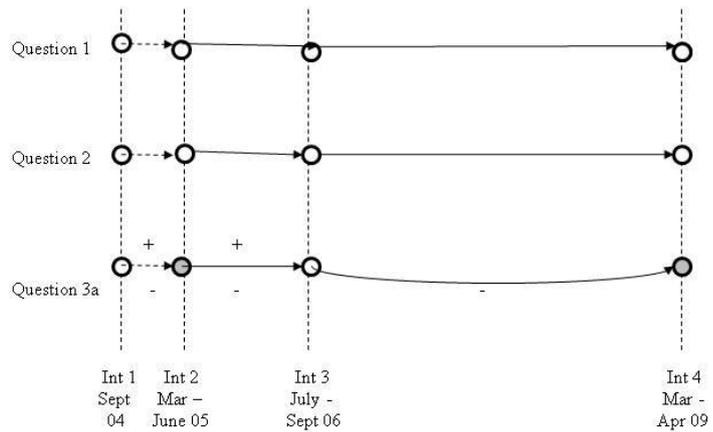
T6	Interview 1	Interview 2	Interview 3	Interview 4
Q1	Power /electricity	Muddy pool	Obstacle course	-
Q2	Power	Energy	Good meal	-
Q3a	PD /power	Voltage	Voltage	-
		+ - -	+ -	
		+ -	+ -	
		-	0	