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Methodological issues in science education research: a perspective from HPS

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Abstract

This chapter offers an overview of methodological issues within science education research, and considers the extent to which this area of scholarship can be understood to (actually, and potentially) be scientific. The chapter considers the nature of education and educational research; how methodological issues are discussed in educational research; and the range of major methodological strategies commonly used. It is suggested that the way research is discussed, undertaken and reported seems quite different in science education from research in the natural sciences as science education studies are informed by quite diverse paradigmatic commitments. The nature of educational phenomena is such that it is unlikely that science education could adopt the kind of disciplinary matrix that can guide researchers in the natural sciences (by allowing much methodological thinking to be implicit and taken for granted within a field). However, Lakatos's 'scientific research programmes' (SRP) offers a view of research traditions that can encompass social science research. From this perspective it is possible for progressive SRP to operate in science education.

Introduction

Science education as an academic field occupies an interesting position as there can be something of a tension between its location within one type of academic setting (education, often considered a social science, but also drawing upon the humanities) and its strong links with the disciplines that are the target for that educational activity (i.e., the natural sciences). For one thing, education is primarily about teaching, which is a practical and professional activity, often considered to be as much a craft as a science (Adams, 2011; Grimmett & MacKinnon, 1992). So Education as an academic discipline, has strong links with education *as practiced* in schools and other institutions 'of' education, and seeks to learn about and inform educational activity in such formal learning contexts, as well as increasingly in various informal contexts where learners may be self-taught, or learn through informal interactions that may not be primarily intended to bring about teaching.

For the purposes of this chapter education will be considered to be centrally about the processes of teaching and learning (Pring, 2000), acknowledging that the teaching may sometimes be in the form of self-direction of learning (Taber, 2009a). So science education is a field that is centrally concerned with the teaching and learning of, and about, science and the scientific disciplines. Science education encompasses both teaching for the general population – science for citizenship, scientific literary – and for the preparation of future professional scientists (Aikenhead, 2006; Hodson, 2009; Holbrook & Rannikmae, 2007; Laugksch, 2000; Millar & Osborne, 1998).

The nature of the work of teaching has raised interesting issues about the relationship between educational research and practice: issues about outsider versus participant research (Taber, 2012b), and about the challenges of translating research that is often necessarily framed for the academic community into a form that can inform practitioners (de Jong, 2000; Russell & Osborne, 1993) - or alternatively, seeking to find ways to draw generalisable findings from local highly-contextualised studies (Taber, 2000).

In addition, educational research is usually undertaken with human participants, and so is subject to ethical considerations that do not apply in the natural sciences (e.g.`, British Educational Research Association, 2004). A common metaphor for science is along the lines of wrestling nature's secrets from her (Pesic, 1999), but researchers are discouraged from seeing the collection of educational research data in this way. Indeed, objectifying the learner (or teacher) as a source of data, rather than considering them as a person participating in research, is usually considered inappropriate in educational work. (Ethical issues are considered further later in the chapter.)

These generic issues, which need to be faced by educational researchers wishing to influence educational practice, are often supplemented for science education researchers by questions raised by the juxtaposition of mindsets and commitments of two somewhat different disciplinary backgrounds. Education as an academic subject is often seen as a social science, and research training in education reflects this, with a major focus on the paradigmatic concerns and tensions that operate in social research. (Indeed this is over-simplistic as some scholarship undertaken within education faculties fits within the behavioural sciences, and some educational scholarship is best seen as located in the humanities.) Yet science education, as a field, tends not to be populated exclusively (or even primarily) by social scientists choosing to focus on science education for their research topic. There are certainly fair numbers of those, but many (and in at least some national contexts, most) of those who undertake research in science education have a background in natural sciences, and often experience of teaching natural science subjects at school or a higher level.

Even when such a researcher takes on an identity as a social science researcher, this is often secondary to their established identity as scientist and/or science educator (Kind & Taber, 2005). Yet, as will be discussed below, research training in the natural sciences is often somewhat different to research training in education and other social sciences. A further complication is that many of those undertaking research in science education who do not have a background of studying and teaching in the natural sciences actually have a background in Psychology: a subject that itself straddles the disciplinary divide between natural and social science (Barrett, 2009). This chapter will explore a range of issues about the nature of educational research (and the consequent implications for methodology), with a particular concern with whether research in science education can be considered scientific.

This focus is of interest for a number of reasons. The question of what can be encompassed within science, the demarcation question, has been of concern to some philosophers of science who have wished to distinguish science from pseudoscience (Lakatos, 1970; Popper, 1934/1959). The very adoption of the term 'social sciences' reflects an attempt to model disciplines like sociology on the natural sciences, leading to the questions of to what extent, and in what ways, are social sciences and natural sciences part of a larger 'science' (Kagan, 2009). In addition are two complications referred to above; the diversity of educational scholarship, and the professional identities of science educators.

Within education faculties, research and scholarship may take a wide range of forms, from completely non-empirical philosophical analyses, and literary analysis of texts for children, to experimental studies carried out by educational psychologists following established 'paradigms' (which in that context in effect means an experiment design) and considering participants as inter-changeable subjects from particular populations (normal 12 year olds, dyslexic 9 year olds, autistic secondary age boys, etc). In some national contexts science educators will be working as part of such diverse communities, whereas in other national contexts it is more common for science educators to be working as part of science faculty – within a physics department for example. Many science educators move into research in science education with a well established professional identify as a scientist (or more specifically chemist, etc) and/or science teacher and therefore bring expectations of what kind of activity 'research' is: expectations that will inform their understanding of the particular institutional context in which they are working.

The programme for this chapter

The present chapter will first consider the particular nature of educational research, and the nature of the field of science education, before considering the question of whether induction into science education research reflects the process of induction into research in the natural sciences. The chapter then considers the logic of developing a research project, and how in educational enquiry this involves a justifiable choice of methodology, which may have to moderated to some extent by ethical considerations, and which informs the construction of a specific research design drawing from a range of particular research techniques used in educational work.

The chapter then considers how best to understand the range of methodologies commonly applied in education in terms of the different ontological and epistemological commitments that may apply when enquiring into different kinds of research foci. This leads to the conclusion that science education is unlikely to develop the kinds of neat and somewhat self-contained research traditions often associated with research in the natural sciences, but rather that principled choices from a diverse repertoire of methods is likely to reflect the inherent nature of the research area – and that indeed such choices will be expected to shift as knowledge is developed in any particular area of research.

The chapter finally considers how despite the apparently 'aparadigmatic' nature of research in science education, conceptualising research traditions within the field in terms of Lakatosian research programmes is likely to support the research community in organising research in ways that can be seen as scientific, in terms of allowing judgements about progress, and offering researchers more heuristic guidance about fruitful directions for research.

The Nature of Education and Educational Research

The philosopher of education, Richard Pring, has highlighted how educational research should focus on the core activities of education, that is teaching and learning, suggesting that "the distinctive focus of educational research must be upon the quality of learning and thereby of teaching" (Pring, 2000, p. 27). However, Pring also acknowledged that this would go beyond the immediate classroom context to include research undertaken to "make sense of the activities, policies and institutions" which were set up to organise learning (p.17). That is, educational research commonly focuses on classrooms and learners, but also encompasses studies exploring the policies that inform classroom teaching, and how these are derived, developed and (often imperfectly) enacted. Research may also consider the governance and management of institutions such as schools, as well the way that education, teaching and learning are understood in particular cultural contexts.

Education is the context for directed learning, and in formal educational institutions (such as schools and colleges) structures are put in place to encourage and channel learning. A key type of activity in such institutions is teaching, which I suggest is best understood as *deliberate actions intended to bring about particular learning*. The conditional 'intentional' is important here, because as the vast literature in science education testifies, what students learn is not necessary what the teacher intended to teach (Duit, 2009), and may sometimes be quite idiosyncratic. Not only is much learning spontaneous, in the sense of occurring without any specific intention to learn, but, as learning is a highly iterative process, it is strongly channeled by existing ways of understanding the world.

I am aware that there is an interesting question of the relationship between terms such as teaching, pedagogy and Didaktik (Fischler, 2011) – the latter being a common term in continental Europe, but used less in the Anglophone countries. Teaching is here used to refer to the activity, where pedagogy can either be used to refer to the general theoretical body of knowledge about how to go about teaching or to refer to a specific strategy adopted in a particular teaching context (an interesting parallel with the way 'methodology' is used both in a general abstract sense, and to describe the specific strategy employed in a particular research study).

Learning is here understood as a change in the potential for behaviour, that is a change in the behavioural repertoire of the learner (Taber, 2009b), assumed to be underpinned by changes in the way the learners' experience of the world is represented in some form of cognitive structure. It is widely accepted that 'circuits' within the brain provide the material substrate that supports cognition, although the precise correlation between the synaptic level and experience of 'having an idea' is much less clear. Despite this, it seems clear that people do represent aspects of their experience of the external world internally, and that as Vygotsky (1934/1986) long ago noted these representations are organised into structures rather than being like discrete 'peas in a pod'.

The nature (e.g. coherence) and extent of such structuring is a theme of empirical research in science education (Fellows, 1994; Ganaras, Dumon, & Larcher, 2008; Taber, 2008), and it is clear that the ways individuals relate and integrate their conceptions of the natural world is often quite different from the way concepts are related in professional science or in formal science curricula. However, such conclusions are indirect inferences made in research, because an individual's cognitive structure is not directly observable (Phillips, 1983). Rather, we rely on the learner's behaviour in representing their ideas in the 'public space' where it can be observed as the basis for modelling their thinking (Taber, Forthcoming-b). In science education we are often concerned with developing students' knowledge and understanding (key concepts that are themselves not easy to operationalise in research), so commonly the 'behaviour' we are interested in is of the form of speech or inscriptions – such as involved in answering a teacher's questions in class or completing a test paper or assignment.

Although some commentators consider informal learning, and the spontaneous mechanisms that support it, to be distinct from learning processes in educational contexts where there is an intention to teach particular things (Laurillard, 2012), there is an increasing tendency for contexts for informal science learning (such as museums) to be planned according to pedagogic principles. So although informal science learning may often appear "haphazard and incoherent" (Stocklmayer, Rennie, & Gilbert, 2010, p. 11), the educational work of museums and science centres is informed by similar debates and principles as those informing the design of curriculum and teaching in schools and colleges (Pedretti, 2002).

As an academic area, Education is something of a recent addition to the Academy - despite scholarly periodicals such as *Science Education* (preceded by *General Science Quarterly*, which first appeared in 1916) and *School Science Review* (first appeared 1919) being long established - and this is reflected in the diverse disciplinary backgrounds of many education faculties as noted above. Traditionally education was seen as an applied subject which drew upon four 'foundation' disciplines: philosophy, psychology, sociology and history (McCulloch, 2002). However, in recent decades education has become more firmly established as an academic subject in its own right.

There would seem to be a generational effect here, in that the first holders of PhDs 'in education' were necessarily supervised and advised by faculty who themselves originally trained in other disciplines; but that first generation of education PhDs could then start supervising their own research students from within the 'discipline' of education.

The Nature of Science Education in the Academy

Certainly in science education this transition occurred within living memory of some of those currently still working in the field, so the most senior professors of science education active today, undertook their own post-graduate studies in other subjects. Fensham (2004) has provided a very readable account of the origins of science education through this process. This means that early researchers in the field were trained in research methods of different disciplines, and for those who trained in the natural sciences their expertise was often not optimal for transferring to a context exploring educational problems.

Some of the early studies in science education adopted methodology that would seem crude and naive to a post-graduate student (and justified in terms that would be considered inadequate if submitted for publication) today, and there has been much borrowing of techniques from other fields. Such borrowing need not be a bad thing, providing the techniques concerned are not, in the process, decontextualised from the paradigmatic commitments which provided their justification as valid knowledge-seeking tools. To offer a crude analogy: a screwdriver can be used as a chisel, and a chisel can be used as a screwdriver: but in both cases one is likely to do a poor job, and risk the integrity of the tool itself. In the same manner, as will become clear below, research techniques have been designed with particular jobs in mind, and may provide a messy outcome when used without due care and attention.

The major journals in science education now publish work not only on a wide range of themes, but adopting a broad range of methodologies. Some of these methodologies reflect approaches common in the natural science, but others draw upon approaches less widely employed in the natural sciences, as they are intended to explore aspects of the human experience itself. Whilst the scope of the present chapter does not allow any detailed discussion of specific data collection or analysis techniques, the key considerations that have informed different paradigmatic stances will be considered below.

The methodological turn in science education

Early researchers in the field of science education were pioneers, and it is perhaps inevitable that some pioneering work seems crude or trite as a field becomes better established. However, recent decades have seen the development of an extensive literature focusing on educational research methodology, and a new researcher entering an educational field such as science education today can be introduced to a varied, if somewhat contested, range of reading setting out the nature of educational research, and how one should go about it. Often educational research is treated as a specialised area within social research (i.e., social science research) more generally, and sometimes it is grouped with other areas that relate to the professions (particularly areas such as social work and nursing). In effect, educational research has developed into a field of activity within education as a subject area, and research methodology has become the subject of primary journals (such as *Educational Researche*r, ISSN: 0013-189X; 1935-102X) as well as being an active area of textbook publishing.

This reification of educational research into a subject for study as well as a means to carry out studies, has led to much discussion about the diversity of methodological approaches used in educational studies, and the relationships between them (Bassey, 1992; Clark, 2005). Some of these issues are explored later in this chapter. With this diversification of methodological approaches being employed in educational research, it has become increasingly expected that empirical research reports should provide not only a description of the methodology employed, but also a justification of the approach used and acknowledgements of limitations inherent in the methodology or the specific design for a study.

These considerations might suggest that there seem to be two related key differences between methodology in education, including science education, and in the natural sciences:

1: research in science education as a field draws upon a wide menu of available methodological choices, whereas research in most particular fields within the natural sciences is limited to a much more (to mix metaphors) limited palette;

2: descriptions of research in science education often offer extensive justification of chosen methodology, commonly including explicit discussion of ontological and epistemological commitments underpinning research designs; whereas reports of research in the natural sciences often focus on specific technical details without extensive justification of the overall methodology.

This could be taken to suggest that research in science education, being unlike research in the natural sciences, should not be considered scientific in nature. To consider why these differences exist, it is useful to consider Kuhn's account of how researchers are inducted into the natural sciences.

Normal Science, Revolutionary Science and another 'Sort of Scientific Research'

Thomas Kuhn has been highly influential in both science studies, and discourse about the nature of work in the social sciences, largely based upon reaction to his essay on *The Structure of Scientific Revolutions* (Kuhn, 1970), and the adoption of the notion of working within a 'paradigm'. In that work, Kuhn argued that scientific revolutions were rare, and that most scientists spent their careers doing what he termed 'normal science'. Although key aspects of this work have been much criticised (and some of this criticism will be discussed briefly below), Kuhn's description of how scientists are trained and inducted into traditions of research is especially relevant to the present chapter, and is considered here to offer very fruitful insights when considering the way methodology is discussed and understood in educational research.

Kuhn described normal science as working within a paradigm, or a 'disciplinary matrix' (Kuhn, 1974/1977). In Kuhn's model, most science occurs within an established tradition, and these traditions are occasionally interrupted when a niggling anomaly leads to an individual (a) forming a revolutionary re-conceptualisation of the field and then (b) persuading the scientific community to shift allegiance such that a new tradition is formed and the old one abandoned. For Kuhn such a revolution changes both the meaning of terms and ways of seeing and understanding the world to such an extent that those working within the new paradigm should be considered to speak a different language (such that the two paradigms become incommensurable) and in effect work in a different world (Kuhn, 1996).

Aspects of this thesis have been widely discussed and critiqued (Masterman, 1970; Popper, 1994), especially the notion of incommensurability and the potential implication that there can be no objective way of judging progress in science - i.e. it could be argued from Kuhn's analysis that a revolution makes a field different, but not necessarily further advanced - although Kuhn himself would argue that his analysis suggests judging progress is problematic rather than impossible (Kuhn, 1973/1977).

Induction into scientific research

However the aspect of Kuhn's work most relevant for the present chapter is his description of how a new scientist prepares for work in, and becomes accepted within, a research field. For Kuhn, the process of becoming a professional scientist is in effect an induction into a particular tradition (or paradigm, in one of the senses in which Kuhn used the term) through a kind of intellectual apprenticeship. By the completion of this training process the new scientist has adopted the norms associated with the disciplinary matrix that in effect defines the current state of the particular subfield in which the scientist has completed research training (Kuhn, 1996). This disciplinary matrix provides the framework for scientific work "based firmly upon a settled consensus acquired from scientific education and reinforced by subsequent life in the profession" (Kuhn, 1959/1977, p. 227). Kuhn saw each such tradition as ultimately derived from a particular scientific achievement – such as Newton's work on mechanics, or Lavoisier's work on chemistry, but other examples might be Darwin's work on natural selection, or Crick and colleagues work on the structure of DNA and the 'central dogma' of molecular biology. Such achievements were revolutionary enough to initiate a new direction for scientific research; moreover, one which could provide a starting point for developing a whole new approach (Kuhn, 1996).

In his work, Kuhn argued strongly that a scientist needed to demonstrate a commitment to the tradition in which he or she was working; and that this was equally true for the few who would initiate scientific revolutions of their own, as it was for the majority that would work their entire careers on the 'mopping-up' work of normal science. Kuhn did not imply that such 'mopping-up' work lacked interest or excitement: it was routine in the sense of being within an established tradition, and therefore had a strong 'convergent' focus, compared with the divergent nature of the 'discoveries' that initiated the occasional scientific revolutions.

Kuhn recognised the ubiquity of imprecision and anomaly in scientific work, and considered that progress in science depended upon scientists being able to have enough commitment to accepted theory in the field not to be continuously distracted by attempts to explain non-significant discrepancies between theoretical predictions and results (Kuhn, 1961/1977). Michael Polanyi (1962/1969) also discussed how scientists need to be able to use personal judgement to ignore most of the multitude of apparent anomalies (in effect, *prima facie* refutations) met in the course of scientific work. Where Polanyi emphasised how such judgement depended upon tacit knowledge (which he related to the way an external reality becomes known through the complexity and subtlety of human perception/cognition), Kuhn stressed how the indoctrinating effect of scientific education could dull the ability to recognise a significant anomaly for what it was.

Whilst identification of a significant anomaly was central to initiating a scientific revolution in Kuhn' account, even the successful revolutionary has to make their argument for a paradigm-shift from within the existing tradition – that is they need to be recognised by others in the community working in the field as being a full legitimate participant (cf. Lave & Wenger, 1991) in that particular scientific tradition (Kuhn, 1996). This required a "thorough-going commitment" to the existing tradition (Kuhn, 1959/1977, p. 235).

The disciplinary matrix in which scientists worked, and in which they drew upon the commitments underpinning their scientific work, supported "relatively unproblematic…professional communication" and allowed "relative unanimity of professional judgment" and was "comprised of ordered elements of various sorts" (Kuhn, 1974/1977, p. 297). These included symbolic generalisations, models and exemplars (the latter providing the derivation of Kuhn's original choice of the term 'paradigm'). For Kuhn the set of models used within a scientific tradition range from heuristics offering analogical insight, to deeply held metaphysical commitments amounting to an ontology (Kuhn, 1974/1977). Indeed, within normal science "research is directed to the articulation of those phenomena and theories that the paradigm already supplies" (Kuhn, 1996, p. 24). Elsewhere Kuhn refers to how researchers within a shared paradigm "are committed to the same rules and standards for scientific practice" (Kuhn, 1996, p. 11), and how paradigmatic exemplification derives from how scientific practice involves "law, theory, application, and instrumentation together" (Kuhn, 1996, p. 10).

As suggested above, Kuhn's thesis has not been universally accepted. Indeed, whilst it may be welcomed as a useful challenge to models of the nature of science that relied on the logical structure of research and oversold an assumption that in principle sufficient careful research could provide a basis for unambiguously interpreting nature, it arguably encouraged views of science that in turn underplayed the role of logical argument and interrogation of evidence in reaching consensus in science. In particular, the suggestion that normal science is somewhat routine, pedestrian and almost a mater of following algorithms (which has perhaps been taken from Kuhn, rather than offered by him) has been challenged by those who consider controversy to be a common if not constant feature of science, rather than a sign of a rare major shift (Machamer, Pera, & Baltas, 2000). Indeed, Feyerabend (1988) countered the notion of normal science by suggesting that the history of science suggested there was no standard method or set of preferred approaches in science, but rather that scientists were much more pragmatic, adapting and inventing method to meet the needs of the problem at hand.

At first sight there appears to be a wide gulf here, but the present author's own personal reading is that perhaps such different accounts of science need not be as inconsistent as may appear initially to be the case. My basis for suggesting this (whilst acknowledging it may partly reflect a personal cognitive style of tending to prefer integration to fragmentation) links to notions of what might be termed 'grain' size in analyzing the nature of science. This reading would acknowledge both (i) that certainly controversy is certainly common in science, and indeed is probably an important part of the motivation for much research (Machamer et al., 2000), but many controversies concern issues that are not linked to core ontological commitments within a research tradition (and so can be accommodated in something like Kuhn's normal science); and (ii) that innovative techniques for data collection and analysis are indeed common in the history of science when taking the 'long' view, but that again major new approaches (rather than refinements to existing techniques) are relatively rare within the day-to-day career of the working scientist , and that 'standard' techniques do become and remain established within research traditions.

From this view, criticism of Kuhnian normal science as a description of most scientific activity would *not* undermine what Kuhn has to say about the research training of individual new scientists, which generally takes place over a matter of a few years, working in one area of science, and often within the context of one or two research teams and laboratories. Typically, then, according to Kuhn, a scientist trains within a particular research tradition that leads to embracing the research community's commitment to the kinds of phenomena that fall within the scope of the field, the kind of entities that are used in explanations, a theoretical apparatus within which predictions and explanations can be developed, standard forms of representation, and accepted techniques for undertaking research studies. However, despite this characterisation of normal science, Kuhn did not claim that scientific work necessarily *had* to take this form, but rather saw this as the nature of 'mature' sciences.

Indeed, Kuhn (1996, p. 11) acknowledged that in fields that had not achieved such maturity, "there can be a sort of scientific research without paradigms, or at least without … unequivocal and … binding" paradigms. That is, Kuhn was offering a descriptive account of science based on his historical scholarship, not a prescription for science. His description could be seen as providing demarcation criteria for mature sciences, but not for scientific enquiry *per se*. In 1983, Gilbert and Watts referred to how research into learning in science was in "a pre-paradigmatic phase" as there was "no general agreement on the aims of enquiry, the methods to be used, criteria for appraising data, the use to be made of the outcomes" (p. 61). Arguably, to some extent, this description could still be applied to science education as a field of research some thirty years later, and if we wish to see research in science education as a scientific activity, then we need to consider it as Kuhn's other, less mature, "sort of scientific research". However, there is an alternative argument, long recognised by Shulman (1986) for example, that suggests that research into such areas as teaching are unlikely to mature into something like Kuhnian normal science, because of the nature of the complexity of educational phenomena is such that no single perspective is likely to offer a full enough account of inform effective educational practice.

Characterising the Educational Research Project

In order to consider whether educational research is, is sometimes, or at least can be, a 'sort of scientific research', it is necessary to consider the nature of the work the educational researcher undertakes, and to reflect on how and why this might be different from research in the natural sciences.

The overall 'shape' of a discrete research study

The conceptualisation and development of an educational research project goes through two cycles during each of which there is a kind of expansion phase of exploring options and seeking sources of information, followed by a focusing (Taber, Forthcoming-a). Figure 1 uses the lemniscate as a visual metaphor to suggests that a study can be understood to ideally progress through three focal points (indicated on figure 1): the initial concern or interest, the specific research questions (RQ) and the conclusions. This model assumes, for the moment, that research is largely conceptualised on a study-by-study basis, which is clearly a major simplification (Lakatos, 1970).

The origin of the project is some kind of concern, issue or other focus that is seen worth investigating. The first cycle (see below) involves a process of developing the conceptual framework for the study - exploring relevant literature, and reviewing previous research that may be pertinent - 'setting the scheme' as it were for the new study. That is a phase that can be seen as supported by divergent thinking: allowing the recognition of relevance and forming links across diverse literature. This is followed by the framing of specific RQ for the study. This latter step involves a focusing in on the specifics of the research (a more convergent process), and setting out how variables and constructs will be understood. Reaching this point will involve identifying any axiological commitments, the values that inform why we do research and so how we should conduct ourselves as researchers, as well as the ontological nature of what is to be researched, and so the epistemological constraints and affordances which will inform the kind of knowledge that it is possible to develop about what we are interested in.

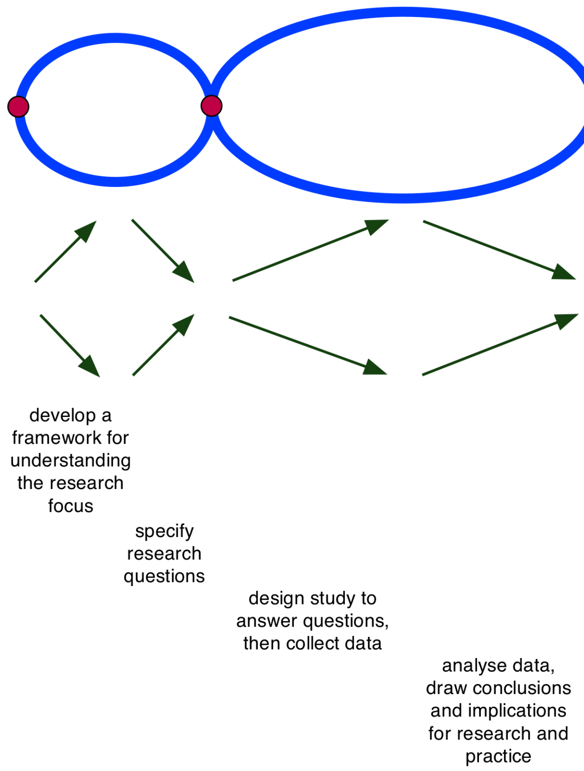

Figure 1: The research process as involving successive phases of expansive and focused thinking

The second 'cycle' of the project (Figure 1) involves another expansive stage, where a research design is developed which can facilitate the answering of the RQ, followed by the collection of data to build up the evidence base needed to answer the RQ. This is followed by a further convergent phase where analysis 'reduces' data to results, and leads to conclusions. The overall process therefore calls upon both divergent and convergent thinking; both creative and logical thought (Taber, 2011).

Owning the research problem in science and in science education

Formalising the process in these terms is often important in educational research because of the nature of existing literature. This reflects a difference between the common experiences of new researchers in education compared with natural sciences. A new doctoral student in one of the natural sciences will commonly be set a problem that is part of an ongoing programme within a wider research team in the laboratory, and the process of identifying the relevant literature and so conceptualising the 'gap' in existing knowledge the study is intended to 'fill' may be relatively straightforward. Indeed, it may be quite clear which techniques are to be adopted (perhaps those for which the lab is equipped with specialised apparatus), and how data will need to be analysed to produce knowledge claims acceptable to those working in the relevant field of science.

Arguably, the novice scientific researcher may be scaffolded to such an extent that they are only primarily responsible for the data collection and analysis stages, and much of the decision-making that leads up to this is largely channeled by the induction into an established way of understanding the ontology and epistemology adopted in that subfield of science. This would suggest that much of the thinking which informs such decision-making for a new researcher in education is in effect short-circuited in the natural sciences. This is in line the picture of 'normal' science (see above), described by Kuhn (1996), where the new scientist is inducted into the disciplinary matrix of the field by working through the standard paradigms. The result may often be someone who is very informed about the standard thinking and techniques in a specialised field, whilst having a much more limited knowledge of other fields within the discipline.

Yet the experience of a new doctoral student in education may be quite different in a number of ways. Whilst science education is now sufficiently theorised and staffed with expertise to support the natural science model outlined above, it is more likely that the research student will have greater latitude in selecting their project (if only because the apparatuses of research are less specialised and so less likely to be a constraint), and indeed within education the process of developing the project is seen as a key part of the education and training of the researcher.

Moreover, whilst it remains important that doctoral supervision provides specialist support in learning about the topic area and acquiring specific skills, the student may find no single clear picture of the research area in the literature that allows an obvious conceptualisation of a 'gap' in the knowledge or a single sensible approach to an issue or problem. The state of knowledge in many educational topics would not fit Kuhn's notion of normal science, with its paradigmatic norms.

Where Kuhn suggests that the primary mode of thinking in normal science is convergent, this is often less true in educational research. Rather than being expected to 'plug' a specific 'hole' assigned by a supervisor, the educational research student is often expected to demonstrate extensive divergent thinking in accessing, evaluating, and choosing between alternative potential ways of conceptualising their problem area. Within this context for undertaking research, the transition from an initial topic or issue of interest to the formation of specific RQ normally involves wide reading around a topic to appreciate and consider a range of possible ways of conceptualising the field, perhaps each based upon understanding the topic in quite distinct ways, and so suggesting different notions of how best to learn about the subject. It is seen as the part of the student's task to develop a conceptualisation of the field, and the justification for adopting (and if necessary adapting) a particular theoretical perspective (see below) for supporting the research. To caricature, the educational researcher 'owns' the research problem not because it has been 'given' (assigned) to them by the supervisor or lab director, but because they have 'built' (developed, discovered, constructed) it themselves.

Moreover, because of the lack of a clear disciplinary matrix that sets out particular tools for thinking about and doing research in the field, the research student is expected to learn about a wide range of methodologies so as to be able to comprehend and apply critical judgement in reading literature around the research topic, as it is quite likely that relevant knowledge claims in research journals will derive from a range of data collection and analytical techniques, potentially drawing upon very different (ontological and epistemological) assumptions informing different researchers' work.

The RQ themselves act as the point of transition in the flow of the study (see Figure 1), and just as the RQ should reflect the thinking that has come before, they should themselves be reflected in what is to follow. A research design must address the RQs, and be compatible with ontological assumptions informing the study (in terms of the nature of what is being studied), and epistemological considerations in terms of what it is reasonable to expect to be able to know about that kind of research focus. A methodology should therefore be selected (see below) which is suitable to answer the RQ taking into account the understood ontology of what is being studied and the kind of knowledge considered viable for such a focus; and data collection and analysis techniques are then selected which are coherent with that methodology. Data is collected (another 'expansive' stage, see Figure 1), then analysed to produce findings/results (another phase of concentration and reduction, see Figure 1) developing a logical case for making new knowledge claims.

Conceptualising the Research Project

Discussions of educational research often make references to such notions such as the 'theoretical perspectives' and 'conceptual frameworks' supporting particular research studies. The way these terms are understood, and will be used, in the present chapter (as unfortunately different authors do not always use a common terminology – see the comments below about phenomenography) is represented in Figure 2. As well as 'theoretical perspective' and 'conceptual framework', this figure also includes three other key terms: 'research questions' (as discussed above), 'research design', and 'methodology'.

RQ are the specific questions that a research study is intended to address. These may take the form of a formal hypothesis, but in educational studies they may be much more open-ended, and the degree of openness will often depend upon the current state of knowledge in the topic area (as will be discussed further below).

The RQ for a particular study derive from a conceptualisation of the topic area that sets out what is already known, and what is not yet known and might be worth finding out. The wording here, 'what is already known', is not intended to suggest absolute knowledge, but rather the set of knowledge claims currently considered robustly supported, and so suitable for taking as a starting point for further research. This conceptualisation, the 'conceptual framework' of a study, is often formalised in the literature review of a research report. The RQ are addressed through a 'research design' that sets out how the required data are to be collected, and how they will be analysed so as to answer the RQ. The essential logic of a research 'design' is such that it should in principle be prepared ahead of the empirical work taking place, and indeed doctoral students are commonly expected to have their research designs scrutinised and approved before commencing their ‘fieldwork’. However, as in the natural sciences, research may involve false starts and unproductive ‘cul-de-sacs’, and the design reported in published reports (and theses submitted for examination) may well – as in the natural sciences (Medawar, 1963/1990) - be a rational reconstruction in the light of experience, of what eventually ‘worked’.

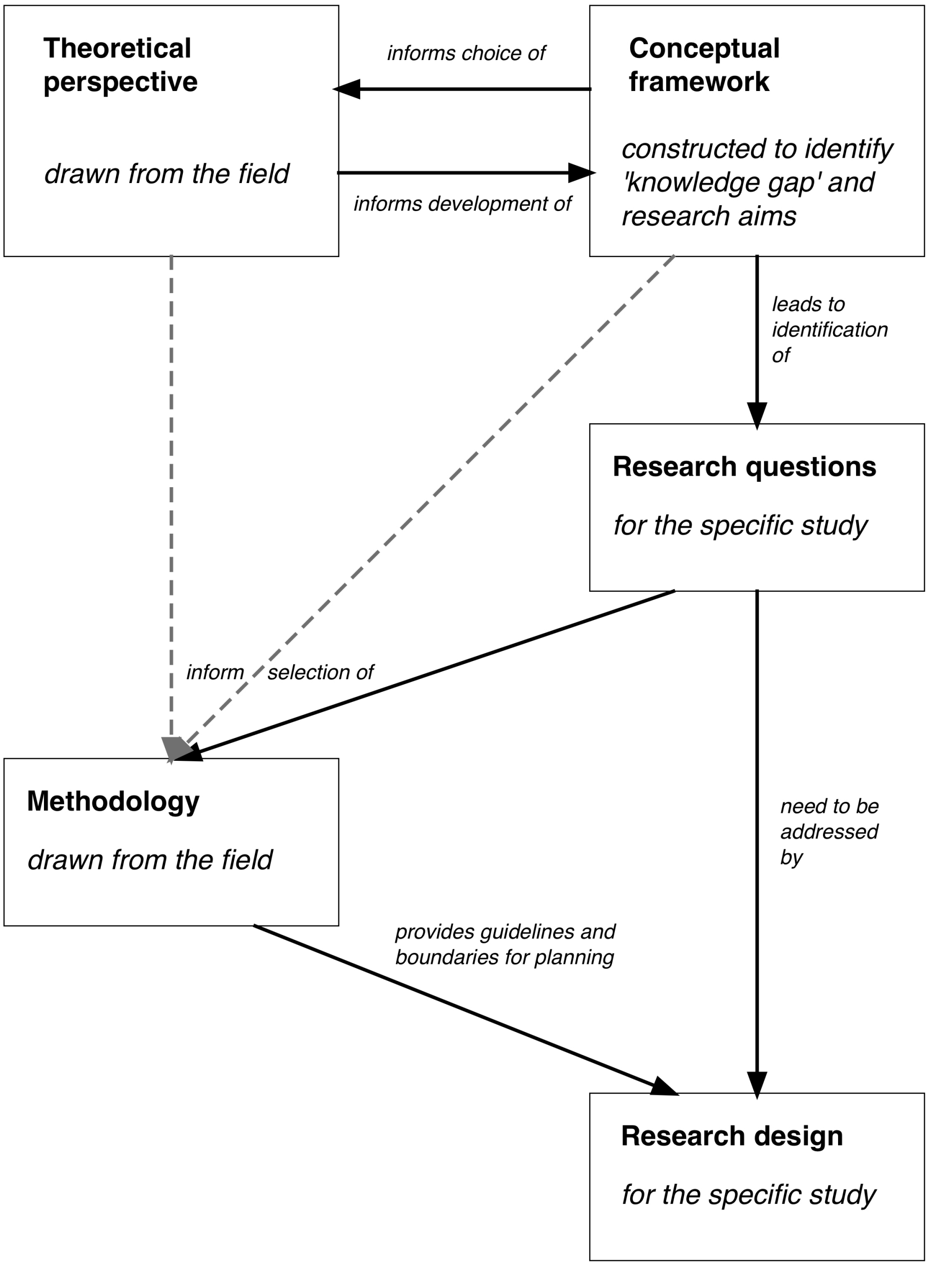

Figure 2: Some key terms used to describe educational research

In some forms of educational research, the research design might be synonymous with 'experimental design', but, as is discussed below, many educational research designs are not based on experimental methods. Moreover, some research designs are 'emergent' which means that only the initial stages of data collection are firmly established before the research begins, as further detail of the research design will be informed by ongoing data collection. This is a somewhat different issue to the previous point regarding false starts (where a pre-planned approach that it was anticipated would be suitable for answering RQ, is later found to be unproductive), as with an emergent design it is recognised in advance that an iterative process will be needed to refine the design.

In a grounded theory study, for example, it would be inappropriate and counterproductive to fully specify the data collection for the entire study in advance (as will be seen form the description later in the chapter, that would undermine the logic of the methodology), whereas in an experiment it is important to specify data collection and analysis carefully in advance – although the specification that is reported in a formal account may well have been preceded by earlier versions that were abandoned as the research was developed.

Not reporting the outcome of experimental studies because those outcomes are not welcome is unethical, but not reporting studies because they are judged to have methodological failures that undermine the credibility of the results is quite appropriate (and indeed journal referees may well judge studies in these terms even when the researchers consider the procedures employed adequate). Ultimately it is the researcher's judgement (and so their professional integrity) that has to be relied upon to discriminate between results that go unreported because they are not robustly supported and results that are robust but do not support conclusions the researcher hoped to draw. This issue is familiar enough from work in the natural sciences (Polanyi, 1962/1969).

The process of shifting from a conceptual framework to specific RQ, and then to a research design is clearly familiar from the natural sciences, although there it is more likely (although not always) that research design will imply experimental design, and that research designs will be specified in detail (precisely which data to collect, precisely how it will be analysed) before any data collection begins. The argument offered in this chapter is that there are necessary (essential) differences between educational research and research in the natural sciences; but that this need not exclude research in science education from being considered 'scientific'. In particular, the process of designing and justifying research is likely in science education, more than natural science, to require *explicit* consideration of ontological, axiological and epistemological considerations.

Theoretical perspectives

Educational phenomena, teaching and learning, and the social institutions intended to support teaching, can (as Shulman, 1986 recognised) be very complex, and there are often alternative ways of approaching the conceptualisation of a particular research focus (such as student learning about some science topic). Discussions of educational research often make references to the 'theoretical perspective' informing a study, as something other than the 'conceptual framework' underpinning the study.

Theoretical perspectives can be thought of as well-developed theoretical positions about some aspects of a social or educational phenomenon that can act as starting points for making sense of research topics. An important point is that in science education there is no 1:1 correspondence between theoretical perspective and specific topics. Rather there will often be several theoretical perspectives that might be relevant to a topic. These might sometimes be seen as based on competing theories, but often they might be better thought of as each illuminating some of the facets of a complex phenomenon.

There are parallels to both of these alternatives in the natural sciences. So we might consider theoretical perspectives as competing in the way that the oxygen theory of combustion competed with the phlogiston theory (Thagard, 1992); or the notion that species have an inherent essence that makes them absolutely distinct (as might be expected if each type was originally formed by an act of special creation) is at odds with the idea that all living things derive by descent from a common ancestor (in which case species are not absolute, but current loci of relatively stable forms at a particular historical moment, contingent upon a great many particulars of past events, with temporary salience against a background of constant slow modification and shifts).

But even in the natural sciences, alternative and apparently inconsistent perspectives need not be considered to be in direct competition. An analogy here might be the way interactions between colliding molecules might be conceptualised in terms of different theoretical models. One theoretical perspective that could be applied would be an ideal gas model, where molecules can be considered to behave as spheres that undergo perfectly elastic collisions. Here the molecules are stable entities, and their collective behaviour can be used in explanatory models of bulk behaviour of the gas. Another theoretical perspective that might be applied could be to consider molecules to be complex structures including electronic orbitals with associated energy levels, some of which are occupied and others unoccupied. Here descriptions in terms of potential overlap between occupied orbitals on one molecule and unoccupied orbitals on another may form the basis for explanatory models of reaction mechanisms (at the submicroscopic level) that help explain patterns of chemical reactivity at the bulk level. In this example, we might consider that both of these perspectives are potentially valid, and could contribute to a full understanding of gas properties, but that in relation to a particular scientific problem, one will be more productive than the other. So even within the natural sciences, the application of a concept may involve selecting an appropriate tool for a particular job, from a metaphorical conceptual 'toolkit' (Taber, 1995) offering alternatives that all have their own range of application. Indeed, this very feature of science appears to offer a major challenge to many learners, presumably because they often misconstrue the nature of the models presented in the curriculum (Taber, 2010c).

The difference between these two types of cases would seem to be whether the different perspectives can meaningfully be considered complementary. Whilst a model of molecules as like tiny billiard balls is clearly incomplete because it does not explain chemical reactions, it remains a useful analogy for some purposes, and can complement other models that explain particle behaviour under other circumstances. In other words, the apparently inconsistent models are not competing for the same 'explanatory space' in this example: one perspective explains physical properties that are commonly exhibited by gases and gas mixtures, and the other perspective can explain why chemical change sometimes occurs when gases mix. By contrast, the oxygen theory competed with the phlogiston theory to occupy the same explanatory space – of why combustion sometimes (but not always) occurs.

Similarly, descent with modification through natural selection (Darwin, 1859/1968), and the notion that organisms are members of a species because of some essence (Mayr, 1987), competed (and indeed for some still compete) in the 'explanatory space' for explaining how living things on earth appear to fit into a number of specific types that (although very large) is tiny compared with the number of individual organisms on earth. Theodosius Dobzhansky (1935, p. 345) enquired whether the notion of a species was "a purely artificial device employed for making the bewildering diversity of living beings intelligible, or corresponds to something tangible in the outside world…[that is, is] the species a part of the 'order of nature', or a part of the order-loving mind?". Indeed, it has been argued that the tendency to retain elements of essentialism long after the general tenets of Darwinian evolution were widely accepted, has been a major problem in biology (Hull, 1965), amounting to the kind of obstacle to scientific progress discussed by Bachelard (1940/1968).

These examples from the natural sciences give some sense of how theoretical perspectives might be drawn upon in particular research contexts. At first sight a difference between research in the natural sciences, and research in science education, is that in education it may not always be so clear whether alternative theoretical perspectives are competing or potentially complementary. This difference reflects the complexity of educational phenomena (discussed further below), and is brought into focus because of the use above of historical examples from the natural science (combustion, particle theory, the origin of species) where we are judging the issue with the benefit of many decades of 'hindsight'.

A wide range of theoretical perspectives have been drawn upon in research in science education, but some illustrative examples would be:

- Greca and Moreira (1997) explored college students thinking related to the concept of field drawing upon a particular theoretical perspective of the main types of mental representations people use;
- Verhoeff, Waarlo and Boersma (2008) explored teaching and learning of cell biology in upper secondary school, drawing upon a theoretical perspective based on general system theory;
- Davidsson and Jakobsson (2008) explored the value of a socio-cultural theoretical perspective in thinking about the learning that can occur when people visit science and technology centres.

Competing Theoretical Perspectives in Science Education

Space here only allows limited exemplification, but an example of where different theoretical perspectives have competed in science education concerns research into student thinking, understanding and learning in science. Two examples here concern flavours of 'personal constructivism', and the relationship between personal constructivism and socio-cultural perspectives on learning.

A very influential theoretical perspective from developmental psychology that informed work in science education was that due to Jean Piaget and his 'genetic epistemology' (Piaget, 1970/1972).

Within that programme of work, Piaget developed a stage theory of cognitive development which saw particular domain general structures of thought as associated with different developmental stages, and which put limits on the kind of learning possible for students at each stage (Piaget, 1929/1973). Although details of the Piagetian scheme, and how it is understood to relate to education, have faced criticism (Donaldson, 1978; Sutherland, 1992), this has been a very influential perspective in science education (Bliss, 1993, 1995). In particular, Piaget's work with its focus on structures posited in mind (Gardner, 1973) contrasted with work informed by the highly influential behaviorist school (largely in the United States) that had eschewed explanations relying upon non-observable constructs such as state of mind (Watson, 1924/1998, 1967).

However, in the 1970s an alternative perspective was developed in science education that focused less on general structures of thought (the complexity of thinking available to learners) and more on their particular meaning making in different scientific topics, leading eventually to an extensive research effort (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Duit, 2009). This research explored students' own ways of thinking and talking about various natural phenomena and scientific topics, such as force, plant nutrition, heat etc. The aim here was less to characterise student thinking at particular levels, but to allow teachers to be aware of typical conceptions students brought to (and or took away from) lessons, and to think about how to support students in developing understanding of the scientific models that were reflected in the school or college curriculum. This work was sometimes labelled as the alternative conceptions movement (ACM).

Both of these perspectives can be understood to be personal constructivist approaches, focused on how the individual comes to iteratively build up personal knowledge in the form of internal representations of the world (as directly experienced, and as heard about second-hand), but with rather different foci: one domain general (so learning in any topic is constrained by the general stage of development), and one very much on a topic-by-topic basis (where familiarity with a particular domain can lead to areas of expertise).

These two perspectives can certainly be seen to have competed for research attention and resources, although arguably they did not compete for the same explanatory space as they focused primarily on rather different aspects of science learning. That the ACM came to dominance within science education - although an important strand of research to inform teaching from the Piagetian perspective continued (Adey, 1999) - probably said less about the perceived *validity* of the Piagetian perspective, than the greater perceived *fruitfulness* of the ACM for actually informing teaching. It might also be tentatively suggested that the ACM was attractive to many of those setting out on research in science education because the terminology of early work (often conceptualised as being about identifying misconceptions) was more accessible than the rather specialised and perhaps seemingly esoteric language that had been developed within the Piagetian programme. That is not so suggest that the ACM was under-theorised, as that was not so (Driver & Erickson, 1983; Gilbert & Watts, 1983; Osborne & Wittrock, 1985). However, as a research programme developed from within education (rather than the developmental psychology base of the Piagetian work), there was always a strong impetus to report work in terms that would make sense to classroom teachers.

More recently, much discussion and some contention in science education has been the question of whether the adoption of a social constructivist perspective (Roth & Tobin, 2006; Smardon, 2009) should be seen as complementary to, or a potential replacement for, a personal constructivist perspective. That is, does the acknowledgement of the importance of social interaction in learning (directly through dialogue, or indirectly through institutions and cultural artifacts) imply that considering learning as the personal sense-making of individuals in order to construct personal knowledge in the form of mental models associated with the minds of individuals (and represented in the physical substrate of that individual's brain) is invalid (or at least, unproductive). One view would be that the personal constructivist perspective adopts notions of knowing and knowledge that are no longer viable in terms of what is commonly claimed about how learning needs to be understood as socially situated, and how knowledge-in-action depends upon social context (Hennessy, 1993).

However, from within the personal constructivist perspective it can be argued that learning is a very complex phenomenon, and that a sensible simplification for many purposes is to understand learning as due to processes that occur within the cognitive system of an individual learner who perceives their environment (in which other people and the signs of culture may be highly salient and relevant to learning); constructs internal models of it, and then acts according to the perceived reality provided by those models (action including making public representations of personal knowledge that can be perceived by others); and, where it seem appropriate, adjusts the internal models as indicated by feedback from the environment (including the public reactions of others to that behaviour). The present author has taken this more synthetic 'complementary' view of personal and social constructivism as useful perspectives that can both contribute to progressing science education (Taber, 2009b): a stance that is by no means a consensus view in the community.[1]

Selecting a Methodology for a Study

The term 'methodology' when used to describe research in education - or the social sciences more widely - is distinguished from 'methods' - which generally means the specific 'techniques' used to collect and analyse data. Methodologies are considered to be broader: to be principled approaches to undertaking research that can provide a framework for selecting particular component techniques. A simple analogy here is that methodology refers to an overall strategy to achieve research aims, within which specific tactics (techniques) may be employed to meet particular sub-goals (Taber, 2007) .

Although one might refer to the specific methodology used in a particular study, methodologies tend to be considered as general-purpose approaches that can be selected according to the nature of the RQ being addressed (as suggested by the analogy with pedagogy and pedagogies, above). One common methodology would be the experiment, but educational research commonly also draws on a range of other methodologies such as survey, case study, ethnography and grounded theory. It is worth reflecting briefly on the core characteristics of these common methodologies.

Experiment: the experimental 'method' is taken from work in the natural sciences, and is used to test a hypothesis by controlling variables to compare two sets of conditions that differ in one accord. In practice, true experiments are seldom possible in education, for reasons discussed later in this chapter.

[1] Just as there is a vast literature drawing upon and adopting (labels if not always principles) of constructivism, there have been a range of criticisms of constructivist work in science education. These include criticisms of: constructivist approaches that seem to support relativist stances on scientific knowledge (Coll & Taylor, 2001; Cromer, 1997; Matthews, 1993, 1994; Scerri, 2003); suggestions that constructivist teaching approaches undermine traditional ecological knowledge in indigenous communities (Bowers, 2007); the theoretical basis of constructivism in education (Matthews, 2002); the level of empirical support for knowledge claims (Claxton, 1993; Kuiper, 1994; Solomon, 1992); inappropriate focus on individuals (Coll & Taylor, 2001; Solomon, 1987, 1993b); limited linkage between result findings and implications for teaching (Harlen, 1999; Johnstone, 2000; Millar, 1989; Solomon, 1993a); associations with unstructured 'discovery' learning approaches (Cromer, 1997; Matthews, 2002); and diversion of resources from more productive areas of research (Johnstone, 2000; Solomon, 1994). An account of these criticisms and possible rebuttals is offered elsewhere (Taber, 2009b). Some of these issues reflect a wider debate in education about the nature and relative merits of constructivist and inquiry-based teaching compared with other pedagogies – especially what has been labelled as 'direct instruction' (Kirschner, Sweller, & Clark, 2006; Klahr, 2010; Taber, 2010a, 2010b; Tobias & Duffy, 2009)

Survey: a survey is used to find about the level of association of one type of element with a different type of element. So for example, a survey could be used to find how many fume cupboards school science laboratories are typically equipped with (i.e. reporting the proportion of such laboratories having no fume cupboard, one fume cupboard, etc.). Commonly surveys are used to seek self-report information from people, regarding such matters as their attitudes or behaviours. Surveys may be used to test hypotheses by comparing responses of different survey items - e.g. one could test the hypothesis that a higher proportion of male science teachers than female science teachers expect to be promoted to head of department.

Surveys may be applied within limited populations (the students in one school, for example), but are commonly used in relation to larger populations (e.g. secondary chemistry teachers in a national context) using sampling techniques, and inferential statistics to make inferences about the populations sampled. A survey that all, or nearly all, science teachers responded to could tell us whether or not a higher proportion of male science teachers expect to be promoted to head of department than female science teachers; but in practice a representative sample of modest size is likely to be sought from which inferences can be drawn about the broader population.

Case study is a methodology used to explore a particular instance in detail (Stake, 2000; Yin, 2003). The instance has to be identifiable as having clear boundaries and could be a lesson, the teaching of a scheme of work in a school department, a university teaching department, a group visit to a museum by one class of students, etc. For example, Duit and colleagues (Duit, Roth, Komorek, & Wilbers, 1998) report a classroom episode where one group of students undertake a discussion task relating to the magnetic pendulum. The authors of the report provide extensive context for making sense of the case in terms of the classroom and curriculum setting of the episode.

Although case study looks at an identifiable instance, it is normally naturalistic, exploring the case in its usual context, rather than attempting to set up a clinical setting - which would often not be viable even if considered useful, as often the case is embedded in its natural context in ways that influence its characteristics (so moving a teacher and a class from their normal setting, to a special research classroom in a university, for example, is likely to change behaviours that would be exhibited in the 'natural' setting).

Sometimes (instrumental) cases are chosen because they are considered reasonably typical of a class of instances, where the complexity of what is being studied suggests more can be learnt by detailed exploration of an instant than surveying a representative sample. Other (intrinsic) cases may be selected because they have been identified as special in some sense, and the researchers want to see if they can find out why: for example why one teacher gets especially impressive learning outcomes.

Ethnography is an approach drawing upon anthropology, which attempts to make sense of a particular culture or group in its own terms: that is to understand the meaning the individuals in that culture of group assign to certain rituals or cultural practices (Agar, 2001; Hammersley & Atkinson, 2007). Whilst, ethnographies, that is detailed accounts produced by ethnographic methodology, are relatively rare, if not excluded (Long, 2011; Reiss, 2000), in science education, studies which draw on ethnographic approaches and perspectives are quite common.

Grounded theory is a set of methods for developing theory using an inductive approach. Developed - or 'discovered' (Glaser & Strauss, 1967) - in sociology, grounded theory is an approach which attempts to provide methods to assure scientific rigour when researchers attempt to understand social phenomena and existing theoretical frameworks are considered inadequate. Grounded theory relies on a number of core principles (Taber, 2000), including emergent research designs that build upon 'theoretical sampling' (i.e. using the analysis of initial data to inform decisions about the next steps in data collection), constant comparison (an iterative approach to analysis that requires repeated revising of data coding intended to ensure analysis that provides best fit to all the data) and theoretical saturation (i.e. only ceasing data collection when further data adds nothing substantive to the theory being developed).

As this suggests, the complete grounded theory methodology is very demanding and is only viable when researchers are not under strict time pressures to complete a study. Despite this, grounded theory is commonly cited as a referent in educational studies, although often in practice such studies adopt the constant comparison method without substantive theoretical sampling or reaching theoretical saturation.

Other candidates for methodology

Sometimes *phenomenography* is considered a distinct methodology, although it is alternatively considered rather to be a particular perspective (e.g.`, Koballa, Graber, Coleman, & Kemp, 2000), an analytical framework (Ebenezer & Erickson, 1996), or even a field of enquiry (Marton, 1981). Phenomenography seeks to describe, explore and characterise people's experiences.

Approaches such as lesson study, and design research, may also be considered as methodologies. In lesson study (Allen, Donham, & Tanner, 2004), an approach to curriculum development that has been especially popular in Japan, a group of teachers work together to plan a lesson, which is then taught by one of the group and observed by others. This allows the lesson plan to be revised, before another member of the group teachers the revised lesson, allowing a further 'trial', and opportunity for further refinement.

Whilst such approaches might seem to be more about 'development' than 'pure' research; if educational research is intended to improve teaching, then such approaches certainly cannot be excluded form consideration. Some commentators on educational research see a major distinction between 'pure' and 'applied' research (Springer, 2010), but arguably all 'educational' research (as opposed to, say, psychological research into learning) should potentially have at least distal implications for informing educational activity, and the pure/applied division is not an especially helpful distinction. Arguably this presents a difference between research in science and research in education: perhaps because work exploring educational phenomena that could be considered as 'pure' would be likely to be considered not as educational research, but as research in another area such as educational psychology or sociology undertaken within educational contexts. Certainly if we adopt the steer offered by Pring (Pring, 2000, p. 27), then educational research is always in principle 'applied' research.

Rather, a more significant issue raised here is the role and nature of theory in research, and the extent to which curriculum development and lesson design need to be seen as idiographic activities depending upon the subject matter, curriculum setting, institution and cultural contexts, of teaching and learning. This is an issue where the science education community has not reached a strong consensus (Kortland & Klaassen, 2010; Tiberghien, Accepted for publication). There is an argument that the complexity of teaching and learning is such that iterative processes (such as that used in lesson-study) are needed within teaching, and should be institutionalised within the profession to make it a 'design science' (Laurillard, 2012).

This leads to consider another methodology that is often cited in educational research, i.e. '*action research*' (McNiff, 1992). Like many of the descriptors used in discussing education research, action research is understood differently by different authors, but usually means research that is carried out by practitioners to address a problem or issues in their own practice. A key feature of action research is its cyclic nature, with the practitioner-researcher implementing and evaluating an innovation intended to address the concern, and then modifying the innovation as indicated by the evaluation. There is then a similarity between the action research cycle and the learning cycle (Marek, 2009). The focus of action research is meant to be the improvement of the practical situation, rather than the development of generalisable theoretical knowledge, and so action research often lacks detailed documentation and formal reporting.

That said, published studies are sometimes said to be examples of action research, although generally to be considered worthy of publication, such studies are expected to demonstrate both a level of documentation, and a robustness of argument for knowledge claims, outside the typical characterisation of action research. That is, the logic of action research is that at the end of each cycle, decisions about the next cycle of action are based upon judgements 'on the balance of probability' rather than waiting to accumulate sufficient evidence to support formal knowledge claims made in an academic research journal.

Arguably, action research is less a methodology as such, than a mode of research that is context-driven, where the focus is on improving practice within a specific context, rather than developing abstract, generalisable, theoretical knowledge. This is in contrast to academic research that is theory-driven, but which might collect data in a limited specific context as a methodological choice (for example, if a case study seems most appropriate to answer RQ). From this perspective, true (context-driven) action research is unlikely to provide the basis for academic research reports, but there is no 'in principle' reason why *practitioner* research cannot contribute to the academic research literature as long as it is suitably theory-driven, and not exclusively concerned with addressing an immediate issue embedded within the practice context. Such practitioner research would need to apply suitable methodology to support theory-driven work (i.e. action research *per se* would not be such a methodology), but could still be initially motivated by a local problem or issue, and may well contribute to improving practice, as well as offering a more generalisable contribution. There is therefore a good reason to avoid conflating action research with practitioner research more generally.

The methodologies described here do not exhaust the methodologies claimed in research papers. As well as variations, refined and hybrid versions of the above methodologies, there are also references to quite different methodologies. However, what counts as a distinct methodology, is open to debate. It could be argued, for example, that so-called 'feminist methodologies', such as the feminist ethnography used by Basu (2008) in a paper reported in *Science Education*, are conflating a methodology (in this case ethnography) with a theoretical perspective (here, feminism) that is informing the choice of that methodology, and how research is designed based on that strategy (cf. Figure 2). A counter argument would be that the more specific feminist methodology is distinct because it is informed by a particular value position (in this case "the importance of research having benefit for research participants and their immediate community", p.256). Whilst this author is not convinced that feminist ethnography should be considered a distinct methodology in its own right, ultimately what is important is that methodological choices are carefully explained and justified, and as long as that is so, readers can draw their own conclusions about the worth of knowledge claims made, and the particular labels used as descriptors are secondary. However, this example raises the important point that methodological decisions in educational research are informed by axiological as well as ontological and epistemological considerations.

Ethical Considerations and their Methodological Consequences

All researchers should be informed by professional standards of ethics. In the natural sciences a focus on research ethics often concerns such issues as not inventing data, not selecting results for reporting based on their level of agreement with preferred ideas, giving full acknowledgement to the work of others, and so forth. These considerations also apply in educational research, of course, but there are additional ethical complications in educational work that do not tend to arise in most research in natural science. Often these issues are significant enough that methodological considerations may need to be compromised because of the ethical imperative.

The good

Researchers tend to feel that research is inherently a good thing because it produces knowledge, that allows us a better understanding of some aspect of the world, and so can inform our choices. Even in the natural sciences such a view might be challenged. Science provided knowledge to allow the development of explosives used in war as well as in engineering applications, poisons used in Nazi gas chambers, and the atomic bombs dropped on Hiroshima and Nagasaki. If such applications are considered inherently evil (and few would dispute that at least in the case of the gas chambers used as instrument of genocide), then questions may be raised about the wisdom of the science that provided the technology. However, there is a common argument that knowledge in itself cannot be evil, as it can only inform human actions, where there is a moral choice in how to apply such knowledge.

Costs and benefits of research

In areas such as medical science, there may be questions about the costs of the knowledge produced by research. Sometimes new treatments and procedures do more harm than good (as was the case with the use of thalidomide, which led to thousands of serious birth defects): but the medical profession is bound by an imperative to do no harm, and so puts in place various safeguards to avoid harming participants in studies. Sometimes there is a recognised substantial risk, and a participant may choose to take that risk in the hope of a possible benefit. In such a situation the notion of informed consent becomes very important: that the person agrees to take the risk based on an understanding of the available knowledge about possible risks and likely benefits of participation. Sometimes participation is altruistic in the sense that the participant may be aware that there is likely to be minimal benefit personally, but that knowledge obtained may contribution to developing treatments to benefit hypothetical others at some future time.

Informed consent

The medical research scenario offers a strong parallel to the situation regarding much educational research. Educational research may be carried our primarily to develop theories that might be applicable at some point in the future, and such research may potentially inconvenience teachers, learners and others who are asked to contribute through their participation. We might hope that people would welcome a chance to contribute to the development of educational knowledge through participation in studies, but a researcher cannot require or expect this. Therefore informed consent must be obtained from participants, and the wishes of those potential participants who decline involvement must be respected, regardless of the basis of their decisions, even if this weakens or undermines a research design – such a an experimental design

There are clearly complications with obtaining informed consent that relate to the ability of – especially young – children to understand what they are being asked to give consent to; regarding when parents as well as learners need to give consent; about when teachers, acting in *loco parentis*, are able to give consent on behalf of students. Teachers, head teachers (or school principals), area education officers and government ministers may act as 'gatekeepers' who decide whether a proposed study can be carried out in particular classrooms and schools. They may well reject requests for research that is judged to have potential for undermining normal order and procedures.

Innovations that seem promising to researchers, may be judged to make too heavy demands on potential participants; and even quite straightforward procedures such as administering simple questionnaires to classes may be unwelcome to busy teachers. This is often likely to lead to researchers compromising research design based on what might realistically be granted when permission is sought. Experimental designs that look to compare two different teaching and learning conditions can often apply inferential statistics providing that the learners are randomly assigned to conditions, However, in practice researchers are usually restricted to working with intact classes, where at best, whole classes can be randomly assigned to treatments - a much weaker design. Indeed, sometimes the choice of a 'treatment' group, rather tan a 'comparison' group, depends upon which teacher is prepared to adopt some innovative practice, immediately suggesting that teacher characteristic may well be a cofounding factor.

A particular issue that arises is that where some potential participants decline to be involved in a project, this may well bias any attempt at sampling. If a study seeks a representative sample, and reasons for granting or declining consent link to the issues being researched, then the final sample may well be skewed.

Openness and confidentiality

Another key issue that may lead to methodological compromises is the need to respect participants' desire for anonymity in research. Generally, with some exceptions, it is normally considered appropriate to assure potential research participants that their data - and it has been argued that the data is *theirs* to gift to the researcher (Limerick, Burgess-Limerick, & Grace, 1996) – will be kept confidential within the research team, and that any reports will be written such that individuals (and often institutions) can not be identified. This is more readily assured in some types of research than others. So reporting detailed case studies, where the expectation is to provide thick description to support reader generalisation, may be difficult without giving away information that would allow informants to be identified.

Indeed there are examples of research in the science education literature where the published details seem to make it very unlikely more than one person could match the description (see examples disucssed in Taber, Forthcoming-a). Sometimes it is suggested that it is appropriate for researchers to deliberately change some biographical or other details to assure anonymity of participants - but this clearly means providing a report which is known to be false in certain regards, and puts the onus on the researchers to know what details change be changed without undermining the authenticity of the published account.

Member-checking and rights to withdraw

A further complication of respecting the rights of individuals involved in educational research, is that it is often suggested that a participant should have the right to withdraw from at any stage in a study: "Researchers must recognize the right of any participant to withdraw from the research for any or no reason, and at any time, and they must inform them of this right" (British Educational Research Association, 2011, p. 6). This can clearly undermine research designs. In longitudinal studies it is quite common to experience attrition as participants leave the study for various reasons and this might modify the balance of participants sampled if decisions to continue participation or withdraw may be linked to issues being explored. To some extent this might be accommodated by building-in redundancy through enrolling more participants than are required for what is considered likely to be a sufficient data set – but that may well require additional resources.

In an interview study, for example, it is normal to advise participants that they may stop the interview at any time, or decline to answer any particular questions. If a sequence of interviews are planned the participant is invited to continue their participation on each occasion, i.e. the researcher cannot expect them to abide by commitments perhaps made months before. It is commonly also suggested that whilst a study is in progress, participants should not only have the right to decline further participation at any point, but also have the right to withdraw any data they have provided earlier in the study.

A related point concerns the right to comment on material written about a participant. In some forms of research, particularly interpretive studies claiming to report on the views, ideas and opinions of others, it is recommended that the participants should be invited to read, and comment on, and draft reports relating to their own cases. In itself this is as much a methodological as ethical safeguard, as it gives participants the chance to check the researchers' interpretations of their inputs are valid. Any feedback received from such 'member checking' should be treated as additional data that needs to be considered in drawing conclusions. Clearly at this point there might be potential for a participant to request particular changes (if perhaps they feel their comments are not presented in a favourable light) and seek to withdraw their data from the study otherwise. This has potential to undermine the integrity of a study.

There are clearly circumstances where member checking has less value methodologically. One case would be where students thinking is analysed in relation to canonical scientific thinking, where it is likely a student holding an alternative conceptual framework may not be in a strong position to confirm or otherwise the worth of the analysis. In such research there are techniques that can be adopted as part of interview procedures to ensure the validity of the interpretations being made by researchers during data collections (although it should be noted that further insight into students' thinking may emerge later during analysis): confirming responses by repeating or rephrasing questions; clarifying ideas by asking follow-up questions; paraphrasing what one believes to be the co-learner's argument, and seeking confirmation; returning to the same point in the same context later in the interview, to see if a consistent response is given by the co-learner; and approaching the same point through a different context later in the interview, to see if the co-learner gives a consistent response in the different contexts (Taber, 1993). Member checking may also be of limited value in studies looking at shifts in participants' opinions, as participants may not retain a clear and accurate recollection of their earlier stances once their thinking has moved on.

Particular challenges of teacher-research

Ethical issues may become especially problematic for teachers and lecturers undertaking research with their own classes (and colleagues). There are a number of complications here compared with research carried out by 'external' researchers. For one thing the usual 'gatekeepers' who normally need to approve a study before researchers approach students about being potential participants are bypassed. A second issue concerns obtaining informed consent, as students could feel that they are obliged to help their teacher who will often have a role in writing reports on them, or grading their work (Taber, 2002). Although the teacher may not seek coercion, safeguards are needed to assure students that participation is entirely voluntary, and that non-participation carries no penalty in regard of their study. Both of these issues can be dealt with effectively by recruiting a suitable senior colleague to act as a nominated person to check on the procedures being employed, and informing students that they may refer any concerns to that person.

A difficult issue is to decide when research goes beyond normal teaching practice. The fully professional teacher is expected to be research-informed, and able to develop their teaching through classroom research (Taber, Forthcoming-a). Teachers are expected to innovate, and to collect data so that they know how effective their teaching is. An innovative teacher, trying out new ideas to improve their teaching, and collecting classroom data to evaluate their work would *not* expect to have to seek permission from the learners in the class (and/or their parents for younger learners), nor to offer opportunities for some class members to decline to be involved in any lesson activities based on innovative approaches. Yet, in effect, this kind of evidence-based teaching practice is a form of research. This is indeed an area where it may not be clear when classroom enquiry and innovation should be considered primarily research rather than just good teaching practice.

However, what is clear is that the science education research journals contain many examples of studies based upon data collected and analysed by teachers working with their own classes, where the impression given is that the purpose of data collection was research (rather than as a normal part of teaching) and where often there is no mention of how the research was presented to learners, nor whether they were invited to contribute and given the choice to decline. That is, some of these studies are written as though the authors feel that they are entitled to set exercises to collect data without consideration of way they are using their students as data sources. Perhaps the researchers in such studies did follow appropriate ethical procedures, but if so they did not feel the need to report they had done so.

Increasingly, journals are expecting authors to make a declaration on submitting studies to the effect that appropriate ethical guidelines have been followed: although this relies on the researchers having a good understanding of the issues involved. It is suggested here that there are useful criteria that can be used to decide when evaluations of teaching innovation, or other examples of teacher research, should be considered to need informed consent from students (see Table 1). These concern the nature of the activity used to collect data, the purpose of the data collection, and the intended use of the results (Taber, Forthcoming-a).

Focus	Teacher-research should be considered part of normal classroom practice when	Teacher-research requires informed consent from learners when
Activity	It involves normal teaching and learning (including assessment) activities carried out within normal curriculum time	It goes beyond the normal range of teaching and learning (including assessment) activities and/or occurs outside of normal scheduled curriculum time
Purpose	It is intended to help understand better an aspect of the professional context, or solve problems arising within that context: i.e. knowledge is sought to inform educational practice in the institutional setting that will benefit the learners involved in the research	It is intended to answer general theoretical questions and support the development of abstract knowledge (i.e. the students concerned are just a convenient sample considered to represent a boarder population of learners)
Dissemination	Research results will inform the teacher-researcher, and may be shared will departmental or other colleagues working in the same institutional setting	It is intended that research results will be submitted for publication or disseminated through websites, conference, networks etc. (N.b. this would apply to research undertaken for an academic award)

Table 1: Determining when teacher-research requires informed consent from learners

So it is suggested that researchers should (i) should seek explicit consent from students they would like to be involved in studies; and (ii) acknowledge that informed consent was given in research reports, when the research

a) requires input from students outside of the normal classroom/curriculum schedule; and/or

b) is 'theory-directed' (i.e. looks to answer general questions, where learners involved stand for learners generally) rather than context-directed (where the research is aimed at specific issues relating to the teaching and learning in the particular research context); and/or

c) is intended for reporting and dissemination beyond the institutional context where the research is undertaken.

Following these guidelines will protect learners from being treated as research-fodder, and will protect researchers from suspicion of unethical practice.

Selecting Techniques in Educational Research

There is not a simple correspondence between methodology and particular techniques, but there are some clear patterns. Experiments require some form of quantification. Surveys tend to involve the use of questionnaires and/or structured observations. Case studies tend to use a range of techniques, commonly including interviews, observation, and document analysis.

Interviews can be used as data collection techniques in a range of methodologies, but the *type of* interview used may change from one methodology to another (and this is also true of observational techniques). So an interview used in a study employing survey methodology is likely to use a highly structured schedule of questions (in effect, an oral questionnaire) which the interviewer is not supposed to vary (i.e. to ensure comparability between respondents), whereas in an ethnographic study interviewing is likely to be based around a much more flexible interview schedule that allows the interviewer to probe for the participants' understandings and perceptions, and to use the interactive nature of conversation (Bruner, 1987) as a means to check and refine the researcher's interpretations of what they are being told. In effect these types of interview are rather *different techniques*, informed by rather different assumptions about what is methodologically appropriate in a particular study (see below). In the survey interview, it is assumed that (in principle) the interviewer could be replaced by another trained interviewer without influencing the responses of participants. Such objectivity may be more difficult to achieve in an ethnographic study where the sensitivity of the researcher to nuances in responses is much more significant.

A research design should include the ways in which data will be analysed, as well as how they will be collected, and again particular ways of analysing data are linked with particular methodologies. So, for example, formal hypotheses tested through experimental or survey approaches requires the deductive use of quantitative methods of inferential statistics, whereas grounded theory employs the 'constant comparison' method of ensuring theory is developed from data by an inductive approach. In some methodologies it is expected that triangulation (Oancea, 2005) from different data sources, or even different data collection techniques, is used to ensure the 'trustworthiness' of research (Guba & Lincoln, 2005). However, this is not considered necessary when research techniques are considered to unambiguously access ontologically clear research foci (as in a well designed experiment).

Whilst figure 2 does not show any direct link from the theoretical perspective (or the conceptual framework) to a research design, it is intended to imply an indirect influence occurs through the RQ. The formulation of RQ involves selecting terms and phrasing that reflect, and imply, particular meanings that have been developed through the formation of the conceptual framework, informed by the theoretical perspective identified as the starting point for building an understanding of a topic.

An interesting question is to what extent the process reflected in figure 2 would be recognised as relevant to research in the natural sciences. It is argued in this chapter that *in principle* the same kinds of consideration that apply in educational research also apply in research in the natural sciences, but much more can be taken taken-for-granted within 'normal science'.

Typologies of Educational Research Methodologies

A key analytical tool used in characterising educational research, is a description of several levels at which the research can be described. Commonly three or four levels are posited, that shift from a consideration of philosophical commitments underpinning the research, to identification of particular techniques to collect and analyse data. For example, one commonly cited model is that use by Crotty (1998), who describes social research at four levels: (i) epistemology, (ii) theoretical perspective, (iii) methodology, and (iv) methods. As one example within this scheme, *a questionnaire* (method, i.e. technique) might be used to carry out *a survey* (methodology), from a *positivistic* theoretical perspective drawing upon *objectivist* epistemology.

This is only one of the schemes recommended in textbooks on social and educational research, because it is very difficult to find a common analytical framework that readily fits all different forms of research in education. The present author prefers a model that is somewhat more simplistic (Taber, 2007), and works with three basic levels of analysis understood as philosophical (the level commonly called paradigm in the social sciences), strategic (methodology) and tactical (techniques).

Crotty discusses three epistemologies: objectivism, constructionism and subjectivism - depending on whether meaning is considered to be *inherent in* an object, to *arise from interactions with* an object, or to be *imposed upon* an object by a subject. Often in accounts of research such as Crotty's, the impression is given to novice researchers that they are expected to adopt one of these epistemological perspectives as a way of understanding the world. Yet this would seem to imply seeing the world as comprised of objects that at some fundamental level are of the same basic nature, at least in terms of what we might aspire to know about them. Such a perspective may be contrasted with pragmatism (Biesta & Burbules, 2003), which is unfortunately (and inappropriately) sometimes presented as having little time for philosophical issues, but rather simply looking for tools to do particular (research) jobs.

Neither the adoption of a blanket epistemology nor of a naive pragmatism offer a justifiable approach for educational researchers when considering methodologies to adopt for particular purposes. The position taken here is that the extent to which researchers can both (a) clarify the ontological status of foci of research; and (b) directly and unambiguously access the foci of research; varies considerably in educational work, and therefore the selection of epistemology must reflect the needs of a particular study. So, for example, it does not make sense to consider that the same assumptions will support research into the provision of Bunsen burners equipping school laboratories; student attitudes to practical work; and teacher understandings of socio-scientific issues.

Qualitative versus quantitative

In a book on research design, Creswell (1994) suggested that once a focus for a study was established, the next step was the choice of paradigm, and he presented two options: the quantitative (or positivist, experimental or empiricist) paradigm, and the qualitative (or constructivist or naturalist) paradigm. According to Creswell, particular methodologies (or as he called them methods) were appropriate for each of these paradigms:

Quantitative methodologies	Qualitative methodologies
Experiments Surveys	Ethnographies Grounded theory Case study Phenomenological studies

Table 2: A typology of research methodologies, after Creswell

The reference to paradigms here reflects the adoption of the term in the social sciences after the widespread influence of Thomas Kuhn's work (considered above). The identification of a paradigm which is considered positivist, experimental or empiricist might seem to some to imply a more 'scientific' paradigm. However, in the present Chapter, it is argued rather that a scientific approach involves a choice of methodology that is consistent with the aims of the particular study.

A major problem with the Creswell classification is the prominent use of the terms 'quantitative' and 'qualitative' as major labels, as these terms have come to be used in very different ways in educational research. One common way in which the terms quantitative research and qualitative research are understood is in terms of the type of data being collected and analysed. Certainly there is an important difference between quantitative *data*, which is suitable for certain types of analysis, and qualitative *data*, which needs to be treated with different analytical approaches.

However, even that distinction is not absolute, because there is a spectrum of approaches to the analysis of qualitative data (Robson, 2002). So, for example, it may well be that interview transcripts, providing text (qualitative data) may be analysed by counting specific words, or phrases, to test some hypotheses (i.e. quantitative analysis). It is also common for qualitative data to be initially analysed using interpretive approaches (qualitative analysis), leading to the assignment of coding which then leads to counts of the frequencies of certain codes, which again could be the basis of either descriptive statistics or hypotheses testing.

However, in other studies, qualitative data may be treated in much more thematic and narrative ways, with no frequency counts or other quantification. So even when we restrict our focus to data, the quantitative-qualitative distinction is of limited value once we shift beyond the description of the data itself to its analysis. Moreover, if the focus is on the nature of the data itself, then it makes little sense to align methodologies such as case study and grounded theory, which may commonly employ both qualitative *and* quantitative data collection and analysis, under a qualitative paradigm as Creswell does.

Where the focus of qualitative and quantitative is sometimes on the type of data being analysed, the term quantitative research is also sometimes reserved for the use of hypothesis testing approaches, excluding studies that analyse quantitative data to offer purely descriptive statistics. Similarly, some authors limit the term qualitative research, in this case for studies that admit the necessity of a subjective element (Piantanida & Garman, 2009), and are based on an interpretative approach that does not claim objectivity in the normal scientific sense – because it is argued that some kinds of social phenomena can only be understood through the inter-subjectivity formed through establishing researcher-participant rapport, and that the kind of detached observer who could claim objectivity would not be able to access suitable data for the study. There are clearly many studies based on the collection and analysis of qualitative data that are not 'qualitative' research in *that* sense.

Two paradigms for educational research?

It seems clear that when used as primary descriptors without further qualification, the terms qualitative and quantitative can be ambiguous, and so unhelpful. Gilbert and Watts (1983) also used the descriptors 'quantitative' and 'qualitative', *inter alia*, when they described two common traditions or paradigms for research that could be employed in science education. However, Gilbert and Watts offered explanations for their uses of the term, in the context of setting out two clusters of characteristics of these two traditions. Their two paradigm descriptions are summarised in Table 3, and several of their points will be reflected in the following treatment.

One aspect of the Gilbert and Watts scheme that needs comment is the notion of their 'paradigm 2' (*Verstehen* tradition) being a relativist one. For some commentators any admission of relativism is seem as antiscientific, and indeed Scerri has attacked the prevalence of 'constructivist' thinking in science (and in particular chemistry) education because of its associations with relativism. Space does not allow this debate to be explored in detail here (see Scerri, 2003, 2010, 2012; Taber, 2006b, 2010c), except to note it is a rather different proposition to suggest (as a hypothetical example) (a) that the choice between (i) the Ancient system of earth, fire, water, air and æther as elements and (ii) the modern periodic system as a basis for scientific progress is all a matter of cultural perspective (a kind of relativism difficult to justify scientifically), than it is to suggest (b) that it is important to investigate and respect learners' alternative conceptual frameworks because of their importance for those individual's *learning of* science.

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Tradition	*Erklären* tradition: explanation is the goal	*Verstehen* tradition: understanding is the goal
Outlook	Realist – adopting an empirical-inductivist view of knowledge.	Relativist – influenced by post-inductivist views of knowledge.
Target	Seeking causal mechanisms.	Seeking understanding as shown by the individual actors (without the overt pursuit of generalisations).
Characteristics:	'Nomothetic': general laws are sought; 'Quantitative': suitable sections of a general population are enquired into; 'Prescriptive': outcomes of enquiry are intended to determine future actions.	'Idiographic': relates to the study of individuals 'Qualitative': seeks to enquire into phenomena without undue regard to their typicality; 'Descriptive': no overt intention of determining future actions.
Approach to phenomena	Reductionist - phenomena are subdivided and the divisions selectively paid attention to	Holistic - phenomena are studied in their entirety
Methodological approaches	'Experimental': controlled situations	'Naturalistic': natural occurring situations

Table 3: Two traditions or paradigms for educational research after Gilbert and Watts (1983, p. 64)

As suggested above, the research focus on students' ideas in science derived from concerns with the common patterns of conceptual development and the difficulties of learning canonical science, rather than any suggestion that students' ideas offered a viable alternative basis for scientific progress. Indeed it has often been noted that common alternative conceptions often share at least superficial similarities with historical scientific models and theories, long abandoned (Piaget & Garcia, 1989).

Often in education we are concerned with exploring the personally constructed 'realities' (i.e. the reality as experienced) of individuals because personal sense making is at the heart of the learning process (Glasersfeld, 1989). The decision to focus on such 'second-order' perspectives (Marton, 1981), i.e. other people's construing of reality, *need not* imply abandoning a belief in an absolute external reality. This can be considered analogous to how the historian of science may use hermeneutic methods to understand how scientists of the past understood scientific concepts because of the value of knowledge of those personal conceptions to our understanding of the history of science, NOT because anyone is suggesting that such outdated ideas are valid as current scientific thinking.

The extensive research into student understanding and thinking in science associated with 'constructivism' / the ACM was strongly informed by existing traditions of work which emphasised the importance of a person's existing ways of understanding the world as the basis for how they made sense of experience and so how that interpretation of experience informed their actions in the world (Taber, 2009b). In particular, key constructivist thinkers in science (and mathematics) education were informed by the genetic epistemology (Piaget, 1970/1972) of Jean Piaget (Driver & Easley, 1978; Gilbert & Watts, 1983; Glasersfeld, 1989) and the personal construct theory (Kelly, 1963) of George Kelly (Gilbert & Watts, 1983; Pope & Gilbert, 1983).

One significant distinction between research methodologies does closely resemble that suggested by Creswell; but is not best distinguished by the labels qualitative and quantitative. Rather, these two types of research are better characterised according to whether the research is intended to test out existing established theory through deductive methods, or rather to better understand poorly understood phenomena to aid the development of new theory (Biddle & Anderson, 1986). Developing this idea suggests two clusters of characteristics of research studies, as shown in Figure 3.

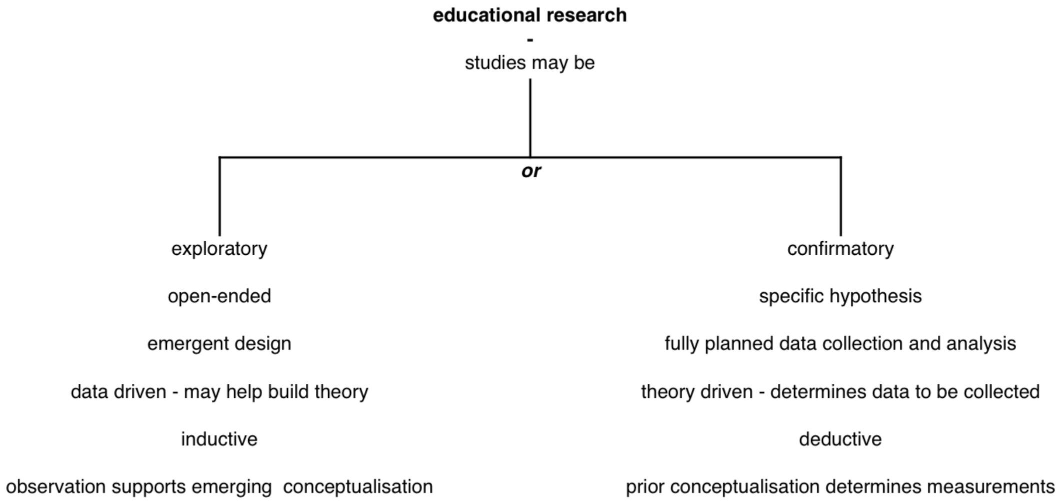

Figure 3: Two main types of research in education

This perspective does not set out different methodologies as fundamentally concerned with different research enterprises, but rather reflects how in any area of scientific activity there has to initially be a period of exploring and categorising and 'making-sense' of the phenomena of a field - what has been termed the 'natural history' phase (Driver & Erickson, 1983) - that can lead to the kinds of theorising, and subsequently bold conjectures (Popper, 1989), suitable for formal testing (see Table 4).

Paradigmatic commitment	Application	Suitable methodologies
Exploratory	In areas where no clear theoretical picture has emerged, due to limited research or complexity of phenomena	Case study Grounded theory
Confirmatory	To test hypotheses drawn from established theory	Experiments Surveys

Table 4: Exploratory and confirmatory research

That much of educational research concerns the former, more exploratory, types of study may be partly related to the relative immaturity of educational research compared with the established natural sciences. However there are also inherent features of education that channel much research towards the discovery pole. One of these features, noted above, concerns the inherent complexity of educational phenomena, which are often embedded in situations from which they canmot be readily be disembodied whilst retaining their integrity.

This complicates attempts to use experimental method, as there may be myriad potential confounding factors that may be difficult to identify, let alone manipulate to control conditions, or failing that measure, to attempt to allow for in analysing data. As suggested below, this has encouraged much educational research to be focused on understanding the individual case in depth (see Table 5), despite the problem of generalising from the individual to the wider 'population' (of teachers, of lessons, of learners, etc).

Paradigmatic commitment	Application	Suitable methodologies
Idiographic	To enquire into educational phenomena where understanding requires detailed engagement with specific instances in their naturalistic context	Case study (to explore individual learners, classes, teachers, etc) Ethnography (to explore cultures of identifiably groups)
Nomothetic	To enquire into aspects of educational phenomena that may be described in terms of norms and general laws	Experiments Surveys

Table 5: Idiographic and nomothetic research

Another key issue concerns the nature of teaching and learning as human activities. As such, there is a limit to the extent they can be seen as the subjects of objective study, because humans make personal meaning of and from their experiences, and many of the things we wish to study relate to those meanings (see Table 6). So whilst we might be more 'objective' when exploring class size, or curriculum content, or even whether student examination responses match specified features of canonical target knowledge; if we are interested in how a learner understands a concept, or the values they bring to science learning, or their experiences of a new teaching approach etc, then we need to use ('constructivist' / 'interpretivist') methods that can engage with and explore how others make sense of the world.

The best, though highly imperfect, apparatus we have for exploring one person's meaning making is the interpretive (meaning making) facility of another human being who can develop rapport with that first person and engage with them in some form of dialogic conversation. This affordance in some kinds of research, is also linked to a serious threat to validity for those attempting to set up experimental research (i.e. in nomothetic mode). The expectations of researchers, or teachers working with them, are readily transferred to learners, and teacher enthusiasm or cynicism about some innovative approach being evaluated in a teaching-learning context an influence learners own expectations, which in turn influence their perceptions of the innovation, and the learning itself. One common type of study compares learning in two 'comparable' classes where teaching by an innovative ('progressive') approach is compared with teaching through a 'traditional ' approach. This immediately creates problems for making a fair comparison whether the teaching is carried out by the same teacher (will they be as equally adept and enthusiastic in both conditions?) or different teachers (who inevitably will bring different skills, and knowledge to their teaching). Added to that, the learners themselves may well react to the novelty of the innovation purely in terms of it being something different from the norm (which may well be welcomed, but could for some learners be perceived as threatening).

However we *collect* data about the ideas, feelings, opinions, attitudes etc of others, we can only meaningful *analyse* that data by relying on the interpretations of other humans. This is what some commentators mean by 'qualitative' research (see above): research that relies on the inter-subjectivity between researcher and study participants.

Paradigmatic commitment	Application	Suitable methodologies
Objectivist	When dealing with issues where there is consensus ontology (the nature and demarcation of what is being studied) and clear epistemology (agreed means of learning about objects of research).	Experiments Surveys
Constructivist - interpretive	Where exploring phenomena that are socially constructed and culturally relative, or nuanced mental phenomena that can only be communicated through dialogue	Grounded theory (for understanding the central issues in social phenomena and institutions) Case study (to allow detail exploration of an individual or group) Ethnography (to provide immersion in culture to identify emic (insider) perspectives)

Table 6: Objectivist and Constructivist-interpretive research

Whilst at first sight instruments such as questionnaires seem to avoid this by presenting statements to be ranked or rated, the items in such instruments are only going to have validity (as statements that are both meaningful to respondents, and understood by them *in the sense intended* by the researchers) when derived from previous research which explores what ideas and language will be meaningful for those surveyed – previous research which will necessarily have involved in-depth dialogic approaches (cf. Treagust, 1988). Here again, the type of research which would fit under the right hand fork in Figure 3 relies upon earlier rather different work that would fit under the left-hand column

Mixed methods – a third paradigm, a subsuming paradigm, or a rejection of paradigms?

In recent years those preferring the notions of quantitative and qualitative paradigms have admitted a 'new' paradigm known as mixed methods research: that is research that employs a combination of quantitative and qualitative features (Creswell, 2009; Creswell & Plano Clark, 2007; Johnson & Onwuegbuzie, 2004). Clearly if we focus on data type, there is nothing of special interest about mixed methods, as studies using quantitative and qualitative data are not themselves novel. It is less clear how a single study could at the same time employ genuinely distinct approaches such that it was at the same time objectivist/positivistic and constructivist/interpretivist if we take the former to suggest a realist ontology and an epistemology which allows claims that research offers in some sense an objective, researcher-independent, account of that reality; and if the latter means accepting that the kinds of knowledge that is possible about the research foci are necessarily constructed by human beings and relative to the interpretations of a particular knower (Symonds & Gorard, 2008). Given this, the claim that there is a distinct research approach known as 'mixed methods' - depending whether it refers simply to data type or something methodologically more substantial - is either fair but of no great significance; or alternatively is important but problematic (Taber, 2012a).

This cynicism regarding the *label* of mixed methods derives from seeing it sometimes used in practice to describe a study's methodology when both quantitative and qualitative data is collected. In that situation the label is generally unhelpful as it *at best* stands in place of a more informative label for the methodology adopted, and *at worse* substitutes for the choice of an actual substantive coherent methodology. That is, in practice we sometimes find the label 'mixed methods' stands in place of principled thinking about the nature of what is researched and how to best enquire into it.

However, Johnson and colleagues (Johnson, Onwuegbuzie, & Turner, 2007, p. 13) position their version of 'mixed methods' as "an approach to knowledge (theory and practice) that attempts to consider multiple viewpoints, perspectives, positions, and standpoints (always including the standpoints of qualitative and quantitative research)". They define mixed methods research as "the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration" (p.123). Clearly these authors are not restricting their discussion to types of data, as presumably the "standpoints of qualitative and quantitative research" relate to ontological and epistemological issues (are we dealing with the kind of things that can be countered and/or measured?; are we enquiring into something that will require inter-subjectivity as an 'instrument' to elicit data?).

The position taken in this chapter, developed further below, is that such choices cannot be established in the abstract, but need to be addressed in the context of particular studies. As a field, science education cannot be well served either by limiting data to be collected to quantitative or qualitative forms; and nor can it progress by committing to the "standpoints of qualitative [or] quantitative research" independently of the particular questions being addressed. However, if adopting 'mixed methods' as a paradigm (Johnson & Onwuegbuzie, 2004) for educational research is taken to mean that we include within our methodological repertoire a wide range of approaches, from which to select according to the need of particular studies, then this fits well with the stance adopted here. The term mixed methods is perhaps unfortunate, as this approach is less a matter of 'mixing' our methods, than of making principled choices of methodology on a case-by-case basis for each RQ we wish to address. Yet it is the very diversity of methodologies, and research techniques adopted within them, that makes this approach quite unlike the kind of 'paradigm' that Kuhn intended in characterising normal science.

The Logic of an Extra-ordinary 'Sort of Science': Science Education as an Aparadigmatic Scientific Field

It was suggested above that perhaps research in science education, and indeed educational research more generally, might fail to look like Kuhn's normal science in part because of the pre-paradigmatic (Gilbert & Watts, 1983; Jevons, 1973) nature of the field, in which case we might be reassured by Kuhn's acknowledgement that another sort of science will be found in immature fields. Alternatively, we might share Shulman's (1986) view that this is not a matter of immaturity, but rather of the nature of what is being studied (e.g. social institutions and processes; often idiosyncratic personal meaning-making) which makes science education unlikely to develop clear a clear paradigm in Kuhn's sense. That is, we might considered science education will remain 'aparadigmatic.

In the next section I want to focus on these key features of educational research, the complexity and diversity of the phenomena of education and the inherent complications of research with human participants. The argument here is that science education may be a relatively immature field, but that even as it matures it is unlikely to develop a structure that supports an array of relatively discrete sub-fields each with its disciplinary matrix to support the induction of researchers in a kind of normal science. Rather, given the high level of interconnectedness between different foci of research, all of which should ultimately inform teaching, science education should aspire to be a different 'sort of science' to Kuhnian normal science.

The ontological diversity of educational phenomena

We have seen that (a) particular research methodologies (strategies) rest upon fundamental assumptions, and may cease to make sense as research strategies when those assumptions do not apply; yet (b) this does not restrict the researcher to a limited range of the available methodological choices in any absolute sense. Research design in education then must always (explicitly) take account of ontological and epistemological issues which logically constrain what may be considered sensible methodologies to adopt for particular studies: and as the educational world does not comprise only of entities of one particular ontological status, the starting point for designing research can be quite different for different studies – even within a particular subfield of science education.

That is, there are things of interest to science education researchers that can be tightly defined, fairly objectively identified in the world, and counted and measured. These types of things are open to forms of investigation (in particular, research which collects quantitative data to test hypotheses through inferential statistical techniques: experiments, surveys) that would not make sense when the objects are clearly culturally relative, socially constructed entities. So methodological choices must relate to the nature of *what* one wishes to research (which will have been posited in developing the conceptual framework for the study, cf. Figure 2). Consider the following potential starting points for educational RQ:

- What is the average secondary school science class size in different countries?
- Is teacher subject-knowledge or extent of classroom experience more important for successful science teaching?
- How do 11 year-olds understand energy?
- What are 11 year-olds perceptions of the difficulty of science lessons?

One immediate point to make, is that all of these topics involve research into some kind of entity external to the researcher him or herself, so the commitment to undertake research would seem to clearly be an acknowledgement that there is external reality which can be considered the object of (or subject for!) study. This immediately excludes some extreme philosophical positions from usefully informing research. Indeed the commitment to undertake educational research would seem to require the adoption of some key aspects of what is sometimes considered the scientific worldview (Matthews, 2009). In particular, embarking on any educational research project would seem to require at least tacit commitment to:

- the existence of some kind of external reality;
- which has some form of permanence;
- and exhibits certain regularities;
- and which human beings are capable of learning more about.

The posing of particular RQ goes beyond this and sets out certain specific types of entities (schools, classes, teachers, 11-year olds, understanding, lessons, etc.) as targets of foci of research. That is, even at this stage, certain ontological commitments are revealed. Sometimes these entities are linked to our theoretical perspectives as when research seeks to investigate Piagetian developmental levels, students' mental models or, their alternative conceptions.

Adopting a common epistemology meant to refer to all that we recognise in our world (Crotty, 1998) would not seem a sensible starting point. One needs to start from ontology: schools, classes, teaching, understanding, perceptions, mental models etc. may all be considered to *in some sense* exist in the world, but they are not the same kind of things, and consequently one's epistemological assumptions about them may justifiably differ. So a fairly crude positivistic stance might well be appropriate and effective in seeking to find out the average secondary school science class size in different national contexts, as it is likely to be possible to identify countries and secondary school science classes in ways most observers would find unobjectionable, and determining class size is in principle a simple counting task.

Yet 'successful science teaching' (for example) does not present itself so unproblematically as the subject of investigation: what counts as successful science teaching has shifted over time and is culturally relative, and even in educational contexts that might be considered most progressive there will not be agreement on the appropriate balance between different mooted aims of science teaching – let alone the most suitable indicators that might allow us to make comparisons. Still, even here, in principle we can envisage that researchers might be equipped with an observation schedule of some kind and sent to observe lessons to evaluate the success of science teaching. (Indeed such a process may be part of quality assurance and compliance inspections schemes in some contexts.)

Of course no matter how well the data collection and analysis was carried out in such a hypothetical observation study, a reader of the eventual research report would only give credence to the findings to the extent that they accepted the particular conception of 'successful science teaching' informing the design of the observation schedule, and were satisfied that the instrument itself could provide valid indications of whether teacher observed was indeed 'successful' in those term.

Then again, depending upon how 'successful teaching' is understood, it is entirely feasible that it could even be considered something that could be 'measured' based on quantifiable outcome measures (such as student grades or satisfaction ratings). Where successful teaching is seen simply as teaching that leads to high levels of student examination success, then coming to know where teaching is successful is relatively simple.

Yet, if instead, successful teaching it is considered to be about inculcating attitudes and values, about developing relationships, and supporting maturation, and an interactive process that necessarily involves modifying teaching objectives according to the goals, needs, motivations and personal situations of individual learners, *then* coming to identify and differentiate successful teaching is going to be more challenging, more complex, and so inevitably less precise. As always the researcher's epistemology has to be informed by their particular ontological understanding. Where researchers do not agree on the nature of what they are researching (and so in effect are not researching 'the same thing') they are unlikely to agree on how best to go about their work.

This potentially puts some areas of educational research well outside the type of 'normal science' that Kuhn (1996) characterised as the basis of most work in the natural sciences - adopting canonical definitions, and instrumentation widely considered to give valid and reliable results when applied within accepted ranges of application. There is a good deal of creativity and ingenuity at work in the natural sciences, but usually applied within a fairy well agreed understanding of the nature of what is being researched, and the methods appropriate for the job. This is less often the case in educational research. Ziman (1968, p. 115) notes how an "experienced professional scientist seldom comes into conflict with the referees of his [or her] papers…because…he [or she] has internalized the standards that the referee is trying to enforce, and has already anticipated most reasonable grounds for criticism". However, in science education, few papers are published without significant revisions required by referees: the experienced professional science education academic may come into conflict with the referees of his or her papers much more regularly than they would wish. This does not reflect on the professionalism of science educators, but on the lower level of shared commitments and standards for work of those writing and refereeing for particular journals.

Admitting the subjective element into research

Similarly, the classic distinction between the object of research and the (nominally interchangeable) researcher that is an ideal of natural science is often inappropriate in educational research: so where in the natural sciences it might be reported in depersonalised terms that that a sample was ground in a pestle and mortar, in an educational research reports *we* might well report how *we* spoke to a group of students. Eliciting student understanding, for example, is likely to require some kind of co-(re)construction of meaning through interaction between researcher and learner; and when investigating pupils' perceptions of lessons, it is indeed appropriate to consider that meaning is imposed on their experiences by the students themselves rather than being inherent in the activities they take part in.

As suggested above, this does not mean giving up belief in an external reality, but in this case part of that reality is the experiences of others, and these are not open to being measured or counted like class sizes. Indeed, the best we can hope for, is to ask others to represent their (internal mental) experiences in the 'public space' we share (e.g. through talk, drawing, role-play etc), and then to look to make sense of these representations in terms of the mental frameworks we have developed through our own experiences in the world. This type of research will then *require* an interpretivist (i.e. subjectivist) approach that acknowledges the inherent difficulties in the task.

Of course as individuals all we ever really know are our own experiences in the world, and there is always something of a leap of faith involved in assuming we share understandings with others. Yet there are differences of degree. We would generally except that training different observers to reach the same objective 'head count' when surveying class sizes, is likely to be less problematic than expecting different interviewers to construct the same model of a learners' understanding of energy, or to reach the same understanding of how a female student experiences being the only young woman in an undergraduate physics class.

In the case of understanding energy, we might reasonably expect that such factors as subject knowledge, teaching experience, interviewing experience and expertise and familiarity with prior research could all influence the process of the researcher constructing a model of the learner's understanding, and so the 'results' of the study. In the case of the only woman in the science class, we might consider that the gender of the interviewer could be influential: both in terms of the experiences that the researcher brings to the research as interpretive resources, and possibly in terms of the extent to which the female student feels able to access and express her experiences and feelings about them.

Such complications undermine the possibility of doing research on people's thinking and experiences that can be as objective as we expect when investigating the resistivity of an alloy, or the rate of a chemical reaction. Research always depends on the interpretive resources we bring to the work, *even* in the natural sciences (Keller, 1983; Sacks, 1995), but in educational research there are many things we want to study where we are unable to eliminate subjectivity, because the interpretive resources relevant to the task (needed to understand another's understanding; or to appreciate another's perceptions and experiences) are highly variable among potential researchers. Indeed, we might often expect that the most insightful work is likely to depend upon researchers who have very *particular* knowledge, understanding, and experience: such that any objectivist notion that we can substitute another qualified researcher and expect the same result becomes highly questionable.

The scientific approach to educational research is to adopt a meta-methodology

The picture painted above is of a field that appropriately draws upon diverse methodologies *because* it deals with a range of different types of research foci, which vary both in how well they are understood and indeed how directly they might be known. The intrinsic variety of educational phenomena, and the subsequent diversity in ontological status and epistemological commitments appropriate to particular studies, suggest that a mature science education would still lack the kind of constrained disciplinary matrix Kuhn associated with normal science. So science education is not pre-paradigmatic because of its relative youth, but is aparadigmatic because of its need to make principled judgements about methodology in the context of each new research design. Some may refer to this as a mixed methods paradigm, but this seems to pervert the term paradigm to something quite incongruent with its original meaning of an a pattern that one can adopt to approach a certain kind of problem.

Rather, if we consider methodologies such as experiment, survey, case study etc as main types of methodology that we select between, then science education needs to be informed by a meta-strategy, a meta-methodology, that offers guidance on the selection process. We might consider Figure 2 to represent the operation of this meta-strategy, and the principles outlined above - regarding how building a research design needs to be informed by an ontological and epistemological analysis of the basis for the enquiry - indicate the kind of guidance needed. Perhaps, we might see this as aspiring to working within a 'meta-paradigm', not looking to induct researchers into adopting turnkey solutions for well-defined problem areas, but preparing them to confidently build research designs bespoke on a principled basis.

However, if we need to abandon the aspiration of evolving a research paradigm for the field of science education, then this suggests that if we wish to consider science education as a scientific enterprise, we may need to look elsewhere for a demarcation criterion for what counts as science. Popper is well known for his prescription that science should proceed by a process of conjecture and refutation (Popper, 1934/1959, 1989). However, in practice, it is well accepted that there is no simple way to determine what counts as a falsification of the theory being tested (rather than, for example, of technical competence, or some auxiliary theory of instrumentation), and that in practice crucial experiments only become accepted as such in hindsight, whilst many apparent refutations are quarantined as simply anomalies to be put aside for the moment. However, an alternative perspective on the nature of scientific work, able to distinguish science from pseudoscience, was developed by Lakatos, in his 'methodology of scientific research programmes'.

Thinking of Research within Scientific Research Programmes

As suggested above, Kuhn's ideas have been widely criticised although they remain highly influential. In particular, Karl Popper was very critical of the apparently relativist flavour of Kuhn's worked, and there was a high profile debate around aspects of Kuhn's thesis (Lakatos & Musgrove, 1970). Popper rejected the 'myth' of the incommensurability between paradigms implied in Kuhn's original formulation of his work (Popper, 1994). It was also argued that the account of mature sciences as each consisting of successions of individual paradigms only interrupted by occasional revolutions leading to paradigm-shift was an over-generalisation (Machamer et al., 2000), and perhaps was less true in sciences other than physics.

In particular, Imre Lakatos, argued that that whilst paradigm-like traditions existed in science, and whilst individual scientists would tend to work within such traditions - and indeed often continue to work within them for extended periods of time – it was not unusual for several competing traditions to coexist over extended periods within the same field of science (Lakatos, 1970). Whereas in Kuhn's model this could only happen if one tradition was in the process of being supplanted by its revolutionary successor; for Lakatos it was quite possible for several alternative traditions to continue to be productive and successful in parallel. In Lakatos's terms, these would be considered as co-existing progressive research programmes.

Lakatos's notion of scientific research programmes

Lakatos's model of scientific research programmes is especially relevant to the theme of this chapter, as it offers a demarcation criterion for what can be considered a scientific tradition that can be applied well beyond the natural sciences. Lakatos's work can be considered to set out the nature of a research programme (RP), and to also offer the criteria upon which such a programme should be considered scientific.

A Lakatosian RP shares some features with a Kuhnian paradigm. Both are research traditions that involve an initial establishment providing the basis for considerable later development work; and both require those working within the tradition to make particular commitments. Lakatos (1970) described RP in terms of four key elements in particular that he called the hard core, the protective belt, and the positive and negative heuristics.

The heuristics give guidance on how to develop the RP. The hard core comprises of those key commitments (e.g. ontological commitments), set-out at the establishment of the programme, that are essential to the nature of that programme, such that if abandoned the essence of the programme is undermined and in effect has ceased. The protective belt comprises of auxiliary theories that build upon and develop what is established in the hard core, and the positive heuristic sets out how this component is developed (e.g. strategic and methodological aspects of the programme). The auxiliary theories acts as 'refutable variants' of the programme in the sense that they are consistent with the hard core, but may themselves be abandoned without risk to the programme as a whole.

Consider, as an example, how modern chemistry has made considerable progress since the establishment of a RP based around modern atomic theory. A core commitment there is that at a submicroscopic level matter can be understood to be quantised, and to comprise of discrete entities, particles (or perhaps better, quanticles) which can be considered to have specific properties such that chemical behaviour as observed in the laboratory can be explained by models at the submicroscopic level. Few chemists today will direct research at testing hypotheses that are in direct contradiction with those commitments (i.e. the negative heuristic suggests such work would be counter-productive given the core commitment). Given that commitment, the development of the RP can be furthered by the positive heuristic guiding chemists in how to study the nature and properties of the discrete entities, and relating the properties of these entities to macroscopic chemical phenomena.

Within such a programme, specific theoretical ideas will be developed in response to the positive heuristic: so now we tend to distinguish atoms, molecules, ions etc. Particular models and concepts – a planetary model of the atom, the notion of discrete atomic orbitals, etc. may be introduced, developed and perhaps sometimes abandoned. This does not threaten the programme itself as long as these refutable variants are consistent with the hard core, and no aspect of the hard core itself is put aside. For example, the notion of the atom, and the role it plays within this system, has shifted considerably over time (Taber, 2003), but this has not brought into question the core ideas that matter has structure at the submicroscopic level, and that the properties of the quanta of matter at this level provide a basis for explaining chemical phenomena: rather such changes are part of the process of considering how best to model and understand the submicroscopic structures that are assumed to exist.

Lakatos (1970) thought that the notion of RP could apply well beyond the natural science - for example psychoanalysis, Marxism and astrology could all be considered to be RP – but that a *scientific* RP remains 'progressive' in the sense that new theory adds to the protective belt (without simply explaining away difficult results) and empirical work continues to respond to and stimulate theoretical developments.

Research in science education as a scientific enterprise

Lakatos's work can be considered to offer a form of synthesis of the thesis of Kuhn and the antithesis of Popper. Where Kuhn's descriptive analysis lacked any means to distinguish science from non-science, or good science from bad, Lakatos's ideas do offer a basis for deciding when a RP is 'progressive' and so deserves support from scientists. According to Lakatos, several RP may operate in parallel, as long as each offers evidence of being progressive. However, once a programme is clearly degenerating, it should only hold a scientist's loyalty until a new promising alternative appears.

Where Popper offers a prescription that is difficult to operationalise - as all scientific theories are formally refuted on a regular basis; and all refutations can be explained away with sufficient imagination – Lakatos offers an analysis that is tolerant of individual failures, so long as the general trend within a programme clearly shows development. Gilbert and Swift (1985) characterised research in the Piagetian traditions and the ACM as co-existing Lakatosian RP in science education. Lakatos's approach not only has the potential to distinguish progressive (and so scientific) programmes from degenerating programmes, but also highlights how within a genuine RP there is heuristic guidance for moving the field forward. This can be potentially very valuable to researchers (and new research students) providing research traditions are conceptualised as RP (in Lakatos's sense), where the features that offer heuristic value are made explicit.

Given the considerations explored above which lead educational research to draw upon such multiplicity of methodologies, it seems unlikely that the adoption of an explicit Lakatosian perspective would allow the fields of science education to be reorganised (substantially or simply conceptually) into a number of discrete programmes with each developing the kind of disciplinary matrix Kuhn recognised in the natural science: RP in science education are likely to remain too pluralistic to seem like normal science.

However, a Lakatosian analysis can identify key commitments for particular strands of work, and identify clear directions for those strands, and make it easier to judge whether they are empirically or theoretically progressive at any point in time. That would certainly be valuable, both in the task of helping those in the field to consider that they are involved in a scientific enterprise – despite the multiplicity of theoretical perspectives and methodologies that will continue to be adopted across, and sometimes within, programmes – and in guiding researchers, journal reviewers, and funding agencies in making rational choices of where to commit valuable and limited resources.

According to Lakatos, RP are adumbrated at the outset; and it is possible to identify elements of such programmes in science education. To demonstrate this, I have developed an analysis of a tradition of work in science education (exploring the contingent nature of learning in science building on the tradition of the ACM, drawing initially on a personal constructivist perspective) as a Lakatosian RP (Taber, 2006a, 2009b). This analysis identifies a number of hard-core assumptions that were set out in seminal papers that established the programme, and which have provided the taken-for-granted assumptions of those taking up work in this tradition. The assumptions give rise naturally to a set of initial RQ (i.e. a basis for the positive heuristic) that have been answered (and refined) to differing extents through the development of a range of auxiliary theories and constructs that act as refutable variants of the programme. Arguably (i.e., according to this analysis) this has been a progressive programme, as it has developed its theoretical apparatus in relation to an increasing base of empirical investigations and results.

Despite this, there is clearly something of a shift away from a core aspect of the programme (the strong focus on learning as personal sense-making and knowledge construction). This implies that many researchers see this tradition as having less potential for progress than alternative perspectives. This may be so, as undoubtedly as the programme has proceeded, the questions to be answered have become more nuanced, and the means of answering those questions have required more effort (e.g., long-term, in-depth study of individuals, rather than surveying groups of learners at one point in time).

Without a shared recognition of the heuristics of established RP, decisions about what RQ to follow-up will be made by individual graduate students and researchers, with limited moderation by the community. Arguably that tends to be the way of scholarship in the humanities, but it is not how science is organised (Ziman, 1968). Individuals will naturally tend to make decisions in their own interest, which is why the apparatus of a scientific enterprise (peer review for publication, funding opportunities, appointment and promotion committees) needs to be well informed about the state of a field to put the right motivations in place for individuals. The mechanisms of RP offer support for that community apparatus. My own analysis of the programme of research into the contingent nature of learning in science (Taber, 2009b) is certainly not beyond criticism, and indeed invites alternative conceptualisations. However it does show the feasibility of adopting Lakatos's approach as one means of seeking to take seriously the challenge of making science education a scientific enterprise.

Conclusion

In conclusion, research in science education may never resemble Kuhn's normal science, because of the complexity of educational phenomena, the difficulty of maintaining the integrity of many of those phenomena outside of naturalistic settings, and the nature of teachers and learners as individuals each constructing their own understandings of the world, and entitled to negotiate the basis on which they might participate in our research. It is likely that many areas of work in science education will continue to draw upon diverse theoretical perspectives and to call upon an eclectic range of methodological tools selected to meet the needs of different specific studies.

However, science education can certainly be a 'sort of science', albeit an 'extraordinary' sort of science: organised to ensure that the adoption of diverse perspectives and methodologies is informed by a meta-methodology, and so always based upon rational choices in view of a good understanding of the current state of knowledge in the field. Given the nature of educational phenomena, the convergent channeling of Kuhnian paradigms would be too limiting and restrictive. Yet giving researchers completely 'free range' to seek their own problem and develop their own original approaches to solve it - often seen as the path to academic recognition in the humanities – is unlikely to lead to optimum progress in addressing pressing educational problems. Lakatos's notion of RP offers a middle road here, as RP provide guidance to researchers about research priorities, and allow the community to take stock of progress, without the blinkers of 'the' paradigm. The way in which educational researchers are commonly trained to develop their projects, with a strong open-ended phase to creatively consider divergent options before making rational and justifiable methodological choices, can be framed (i.e. guided, but not prematurely constrained) within the heuristic guidance of a progressive RP. This would allow the principled development of research designs on a problem-by-problem basis, but guided by the heuristics of an established tradition that the research community considers to be progressive. Arguably, that offers a 'sort of science' that best suits the field of science education.

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