Teachers’ Perspectives of Energy in Lower Secondary School Science

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Excerpt from Study

Abstract

Energy in school science has received substantial attention in academic literature over the past three decades. There has been debate over the most appropriate ways to model and introduce the concept. There has been field research within a constructivist framework involving the documentation of alternative conceptions of energy.

This study expanded such enquiry to consider energy in English lower secondary school science. The focus was practising secondary science teachers' perspectives of energy. 'Perspectives' encompass teachers' understandings of the concept and opinions about its teaching. The study used an initial survey followed by in-depth work with a number of teachers. Methodological underpinning embraced an epistemological constructivism through extension of the prior work on gathering conceptualisations. The in-depth part of the study acknowledged and explored the varied and sometimes problematic issues surrounding qualitative research.

This study was conducted through a position adopting the contemporary model of energy transfers, in accord with recommendations in academic literature. It was however revealed that there are serious gaps in the adoption of these recommendations in teachers' thinking and in their reported introduction of energy in their teaching. Teachers are still predominantly 'transforming energy' explicitly, despite recommendations to 'transfer it' two decades ago. Energy dissipation is not considered an important explicit concept at lower secondary level by many. Teachers' thinking reflects ambiguities with the modelling of energy as portrayed in some lower secondary school resources, including the National Curriculum. These include ambiguous language used to portray and often confuse energy transfers and transformations, and also the language used with the topic of 'heat'. Many teachers also frequently mix scientific and vernacular terms with the law of energy conservation and dissipation. Teachers' views on the teaching and learning of concepts are more resonant with recommendations in academic literature, albeit implicitly.

1. Introduction

1.1. The Place of this Study

> [Energy] yeah it's sort of an ethereal idea that's out there somewhere, we don't quite know what it is.
>
> Teacher 16, PSTS replication interview

Conceptualisations of energy in school science have been the subject of debate in academic literature over the last three decades (Duit and Häussler, 1996). Energy has been documented as a 'difficult concept' (Jennison and Reiss, 1991). A major change in the way it is modelled at school level was suggested at least two decades ago (Ellse, 1988). However, working as a physics teacher in a secondary school, it occurred to me that the extent of the uptake of the new model was questionable.

Throughout the 1980s and 1990s, the modelling of energy was debated in science education literature. Aspects included:

- to transfer or transform energy (Ellse, 1988);
- emphasising work or not (Warren and Richmond, 1983);
- using the term 'heat' (Mak and Young, 1987);
- the importance of energy dissipation (Ross, 1988);
- introducing energy (Osborne and Freeman, 1989);
- considering fuel-oxygen systems with combustion and respiration (McClelland, 1989).

Simultaneously, an epistemological constructivism (e.g. Fensham et al., 1994) underpinned a methodological movement spawning a field of research concerned with cataloguing and subsequently changing participants' conceptualisations of various science topics. Of relevance here are the 'conceptualisations of energy' research conducted with:

- secondary pupils (e.g. Watts, 1983);
- primary teachers (e.g. Kruger, 1990);
- primary student teachers (e.g. Trumper, 1997).

To date, no research in England has been concerned solely with uncovering practising secondary science teachers' conceptualisations of energy.

1.2 Personal Motivation for this Study

During my BSc physics degree, the concept of energy was used at an arguably high level. Aspects included:

- the interchange between quantities of energy and mass in particle physics;
- calculations of quantities of energy associated with laser light, stellar radiation and electron orbits;
- consideration of the efficiency of various heat engines.

In many cases, energy was treated mathematically. During my year of teacher training, the focus on energy was of a more qualitative and descriptive nature. The contemporary modelling of energy, to include ‘energy transfers’, after Ellse (1988), was vigorously reinforced. During two subsequent years of teaching, the conceptual part of energy was covered during one lesson, midway through Year 9. The scheme of work recommended an ‘energy circus’, where pupils were encouraged to complete ‘transformations’ of energy for various processes. Conceptual energy started and finished there on the scheme of work.

Through teaching energy to secondary school pupils and dealing with secondary science teachers, the following questions came to mind. These served to provide the initial personal motivation for this study:

What is the best way to model energy for lower secondary science teaching?

Is there a coherent path in the progression of the energy concept from secondary through to degree level?

Are secondary science teachers aware of the debates in academic literature concerning energy?

What do pupils really think energy is?

What do science teachers really think energy is?

Do pupils acquire the concept of energy best through a 'transformations' or 'transfers' approach?

1.3. Aims of this Study

This study aims to make an original contribution to knowledge by extending the enquiry of energy concepts to focus on practising secondary science teachers. The study documents practising secondary science teachers' understandings of energy and opinions surrounding its introduction and teaching. It also provides research information and thereby informed comment, on the extent to which teachers are aware of issues concerning the modelling of energy. The term 'perspectives' is used to encompass teachers' understandings, opinions and awareness of issues. The main research question is:

> **What perspectives do secondary school science teachers have about energy as it is taught in English lower secondary school science?**

A number of subsidiary research questions (SRQs) are also defined. These serve to expand the focus of the main research question:

1. To what extent do these perspectives match up to:

- **a) the educational debate about the conceptualisation and teaching of energy;**
- **b) the educational debate about the teaching and learning of concepts;**
- **c) science curricula and syllabuses;**
- **d) KS3 examination materials;**
- **e) the science text books teachers are using.**

2. To what extent are these perspectives firmly, confidently and clearly held in teachers' minds; as opposed to less well formed?

Lower secondary school science is also referred to as 'key stage three' (KS3) in England (DfEE, QCA, 1999a). SRQs 1a-e relate to the issues introduced in the previous section. SRQ2 relates to work by authors such as Polanyi (1969a) and Woolnough (2001). This work explores the dimensions of the 'explicit' and the 'tacit' with respect to knowledge and its application.

This study used a variety of methods. An initial small-scale survey was used to find out which text books schools were using and in what order the concepts of energy were introduced. In-depth work was subsequently carried out with a number of teachers. Data were organised into a number of themes. These are presented and discussed in turn.

7. Conclusions

7.1. Key Findings

This study set out to answer the following question:

> **What perspectives do secondary school science teachers have about energy as it is taught in English lower secondary school science?**

The study found that teachers held views about energy and its teaching which were often discordant with key recommendations in the literature. In particular:

(1) there were serious gaps in the adoption of key recommendations for the modelling and teaching of energy in school science by the teachers' who participated in this study;

(2) there are inconsistencies in the way energy is modelled and presented in teaching resources. These inconsistencies reflect areas where the debate on the modelling of energy in academic literature is inconclusive;

(3) in many areas, the teachers' understandings and application of energy reflected inconsistencies in teaching resources and the debates in academic literature;

(4) certain perspectives were explicit in teachers' thinking whereas other perspectives were less well formed and only emerged after deeper probing.

A key recommendation that was largely absent in teachers' thinking was the adoption of the transfers model of energy (e.g. Ellse, 1988). Teachers were still using the alternative model of transformation of many forms of energy. Another key recommendation that was largely absent was the promotion of energy dissipation as an important concept at KS3 (e.g. Duit, 1984a). Schools introduced the conceptual aspects of energy significantly more randomly than concrete aspects of energy. The introduction of energy dissipation occurred significantly later than other conceptual aspects of energy, contrary to recommendations in the literature (e.g. Ross, 1988). Conceptual areas where teachers' perspectives reflected debate in academic literature and inconsistencies in teaching resources were 'heat' and defining or describing energy. Explicit perspectives were obtained from teachers on transforming energy, the law of energy conservation, energy resources, heat as a form of energy and that energy was stored. Perspectives which were less well formed were obtained on the meaning of 'transfer', what energy was, energy dissipation, constructivist teaching, deeper meanings for 'heat' and exactly how energy was stored.

7.2. Subsidiary Findings

This section presents a summary of the subsidiary findings, which serve to expand the key findings.

7.2.1. The Conceptualisation and Teaching of Energy

1a. To what extent do these perspectives match up to the educational debate about the conceptualisation and teaching of energy?

Science education literature contains some clear recommendations for the conceptualisation of energy. These include:

- energy comprises distinct superordinate concepts (Duit, 1984a, Duit and Häussler, 1996);
- energy is transferred not transformed (Duit, 1984b; Ellse, 1988; Chisholm, 1992);
- the number of energy forms are limited (Ellse, 1988; Chisholm, 1992);
- energy dissipation is important per se and as means to introduce the topic (Duit, 1984a; Ogborn, 1986; Ross, 1988; Ross, 1991);
- energy is an abstract concept (Feynman, 1963; Osborne and Freeman, 1989; Duit and Häussler, 1996);
- stores of energy are de-localised into food/fuel-oxygen systems (McClelland, 1989; Ross, 1993).

Conversely, there are areas where the conceptualisation of energy remains debatable. These include:

- centralising energy around the concept of work (Warren and Richmond, 1983; Warren, 1986);
- de-emphasising ‘work’ (Finch, 1977; Ogborn, 1986; Duit and Häussler, 1996);
- defining and describing energy appropriately at KS3 (Duit, 1984a; Summers, 1991 Benyon, 1994);
- abandoning use of the term ‘heat’ as a noun (Shaw, 1973);
- reserving the term ‘heat’ as a verb (Mak and Young, 1987; Ellse, 1988; van Huis and van den Berg, 1993);
- retaining a technical definition for ‘heat’ as energy transferred (Mak and Young, 1987; Goldring and Osborne, 1994; Carlton, 2000).

Science education literature contains some clear recommendations for the introduction of energy. These include:

- examining phenomena and events to develop the natural idea of energy dissipation initially (Duit, 1984a; Ross, 1988 and Ross, 1991);
- developing the concept of energy conservation simultaneously (Brook and Wells, 1986 and Duit and Häussler, 1996).

There are also clear recommendations for the purpose of teaching energy. These focus on:

- promoting world awareness (Duit, 1984a);
- unifying many scientific areas (Häussler et al., 1986);
- developing skills in dealing with the abstract (Ellse, 1988).

There are areas, pertaining to energy education in general, where there is no clear advice in science education literature. These include:

- offering simplified incorrect models as opposed to simple correct models (Ellse, 1988);
- the appropriateness of abstraction at KS3 (Warren, 1986 and Summers and Mant, 1991).

The Purpose of Teaching Energy: Teachers' views of the purpose of teaching energy reflected recommendations in the literature. These recommendations occur in both academic literature, as cited above, and in literature pertaining to the National Curriculum (e.g. DfEE, QCA, 1999b and 1999c).

Teachers' Superordinate Concepts of Energy: Teachers in this study understood the following to be superordinate concepts of energy:

- the law of energy conservation;
- energy comes in many forms which are transformed (with some superordination into KE and PE);
- energy is derived from resources.

The elicitation of 'conservation' and 'transformation' are both in accord with Duit's (1984a) recommendations. Elicitation of 'dissipation' was not prevalent, in direct contrast to the recommendations in the literature that it is both a superordinate concept of energy and important for the introduction of energy. The elicitation of energy resources is not surprising, given that half of the energy strand in the KS3 Science National Curriculum is concerned with energy resources (DfEE, QCA, 1999a). However, teachers' individual elicitations of energy resources were mainly accompanied by examples of energy resources, rather than emphasis on the storage and use of energy.

The Energy Debate: Teachers' application of energy revealed the following:

- a prevalent spontaneous use of the transformation model (also as 'transferring between types of energy');
- all teachers were able to recognise and use forms of energy to create transformation chains;
- some use of 'potential' to label all the potential energies;
- very few teachers were aware of any debate concerning transfers and transformations, with terms often used interchangeably and ambiguously;
- most teachers were reluctant to abandon the forms of energy when specifically asked.

The transformations model permeated teachers' application of energy to include:

- the law of conservation – expressed as the constancy of energy when changing form;
- energy dissipating as a particular form (e.g. heat, light, sound);
- energy efficiency as useful energy conversion.

Teachers' immersion in the transformations model is possibly the single most striking finding from this study. This is contrary to the recommendations to limit the number of energy forms and speak of energy transfers (Ellse, 1988; Chisholm, 1992). Most teachers were also unaware that there has been a debate over transforming and transferring energy. These issues suggest there has been a failure of science education literature to reach the practising secondary science teacher. Where teachers did have prior knowledge of 'transfers' as distinct to 'transformations', this was often fragmented and inaccurate – except in the few cases where it was evident a teacher had been exposed to science education literature.

Energy Dissipation: Many teachers did not use the concept of energy dissipation spontaneously in applied situations. Furthermore, it was not a concept that was considered important and of priority at KS3. This may have been because (1) teachers were of the view that it was too much like the second law of thermodynamics, (2) teachers were unaware that the concept could be expressed in simple accurate terms (e.g. Ogborn, 1990) or (3) some teachers did not fully understand the subtleties of energy dissipation themselves. This represents a further failure of science education literature such as Ogborn (1986), Ross (1988) and Ross (1991), to reach teachers.

The Nature of Energy: Teachers' views of the nature of energy included:

- a general confusion concerning its nature – many thought it was a mysterious commodity that could not be pinned down;
- half of the teachers thought energy was a real thing versus half who thought it was an abstract idea.

The physicist's notion of energy being an abstract mathematical accounting system was not a common view. Science education literature portrays energy as an abstract mathematical concept (Osborne and Freeman, 1989). This aspect was not apparent in many teachers' views, who often reified energy and treated it explicitly as a physical commodity.

Teachers' definitions of energy for KS3 centred around energy being 'that' which enables things to happen. This is criticised for a number of reasons. It describes energy as a 'causal' agent (Watts, 1983), it is a watered down version of the work definition and it ignores the demarcation of useful and non-useful energy (as proposed by e.g. Ogborn, 1986 with 'exergy'). When teachers talked about 'work', this was as (i) a form of energy in its own right, (ii) an agent presiding over transformations, or (iii) a mechanism presiding over transfers. These are consistent with the way work is portrayed in physics texts (Noakes, 1963; Nelkon and Parker, 1987 and Duncan, 1995).

Teachers' views of the nature of energy reflected confusion in the literature. Energy has been defined in terms of an ability to do mechanical work (e.g. any older physics text such as Noakes, 1963), an agent that is transformed (Finch, 1977), an ability to do work, heat or cause change (Duit, 1984a) and more recently as an agent with a 'job-doing capability' (Summers, 1991). In subtle contrast, Ogborn (1986) prefers to deal with 'exergy' – that part of energy that is capable of doing something useful. However, it is argued here that much of the discussion in the literature has resulted in the mystification of energy beyond what it is to the physicist – a particular quantity with a certain dimension that is conserved. However, this does not resolve the question of an appropriate definition or description of energy. It is also questionable how relevant quantification and abstraction are at KS3 (Solomon, 1986; Warren, 1986).

Heat: Teachers' spontaneous use of the term 'heat' was notably as a noun and/or as form of energy that could be transformed and transferred. It was occasionally spoken of as a dissipated or non-useful form of energy. Adoption of the recommendation to constrain use of the term 'heat' to a verb (Shaw, 1973) was limited. In general, teachers' use of the concept of heat reflected the indecision portrayed in the literature in setting a consistent conceptual framework for heat at school level.

Most teachers did not consider it appropriate to make a distinction between U, internal energy and Q, energy transferred by heating, at KS3. This is consistent with the way heat is portrayed implicitly in school resources (e.g. QCA, 2000; Johnson et al., 1993c). However, this is not consistent with recommendations in science education literature (e.g. Mak and Young, 1987).

The Storage and Location of Energy: Teachers were very clear about the notion of stored energy as applied to food, fuels and energy resources. Language such as 'stored', 'source', 'containing' or 'providing' was used. Where ideas were probed further, many teachers suggested that there was energy in chemical bonds, contrary to the negative potential concept and energy release being due to a net balance towards bond formation (e.g. Hill and Holman, 1987).

Teachers' views on the fuel-oxygen issue, as discussed by McClelland (1989) and Ross (1993), views were diverse. Some teachers would acknowledge the importance of oxygen as recommended by the above authors. Others would simplify at the expense of absolute accuracy and locate the energy firmly in the fuel. Many teachers were not of the view that oxygen was as much the source of energy as the food or fuel. They did not consider this appropriate or relevant for pupils at KS3.

7.2.2. Constructivist Science Teaching and Energy

> **1b. To what extent do these perspectives match up to the educational debate about the teaching and learning of concepts?**

Constructivist science teaching has been discussed and debated in science education literature for at least 25 years (e.g. since Driver and Easley, 1978). Its origins can be traced to the writings of authors such Vygotsky (in Van der Veer and Valsiner, 1994) and Kelly (1955). Key tenets include:

- considering prior knowledge of learners in designing instructional sequences;
- recognising that prior knowledge is often very resilient to change;
- fostering learner self awareness and responsibility;
- recognising that learners actively construct their own knowledge through the backdrop of past experience.

Ausubel et al., (1978), Fensham et al. (1994),
Driver et al. (1985), Wittrock (1994)

Much constructivist field research has involved the elicitation and documentation of pupils' conceptions of a given topic. Specific methods used to do this include interviews about instances (Osborne and Gilbert, 1980) and concept mapping (Novak and Gowin, 1984). Watts' (1983) paper on pupils' conceptions of energy is seminal, although Driver et al. (1985) also documented popular misconceptions across many science topics. The recent KS3 National Strategy (DfES, 2002) actively encourages teachers to address the resilience of pupils' misconceptions. Other related frameworks include the 'lifeworld' and 'symbolic' domains of knowledge (e.g. Solomon, 1983a) and 'pedagogical content knowledge' (Shulman, 1986).

This study has embraced the constructivist view of conceptual learning and utilised some of the methods of prior constructivist studies (interviews about instances and concept mapping), with the addition of qualitative in-depth interviews. The main issues reported by teachers in this study as important for conceptual teaching and learning were:

(1) terminology;

(2) pupils' prior knowledge;

(3) an appropriate pedagogy for translating the abstract into something tangible;

(4) relevance of the subject matter to pupils.

Issue (1) has relevance to the ‘domains of knowledge’ framework (e.g. Solomon, 1983a). Teachers were very concerned that pupils learned the ‘language’ of science, demarcating it from everyday language. However, many teachers were observed to spontaneously mix scientific and everyday uses of terms.

This was especially apparent in the cases of:

- energy dissipation (energy was said to be ‘lost’);
- energy conservation (energy was said to be ‘produced’);
- energy efficiency (quick and convenient meant energy efficient);
- the storage of energy (energy resides in objects);
- the nature of energy (energy causes events).

It is thus argued that teachers should consciously and constantly examine their use of language and separate the domains of thinking in conversations with pupils. This may include correcting themselves when a spontaneous mixing of domains occurs. It is argued that if teachers do not separate the domains of thinking, how can pupils be expected to do so?

Issue (2) is also in accord with the constructivist framework. Teachers were concerned to make pupils aware of their ideas and for pupils to build on these ideas and challenge them if necessary.

Issue (3) was evident in the teachers’ descriptions of methods of teaching a conceptual topic such as energy. Elaborate and sometimes extensive teaching strategies were elicited. These used many real events and united them under the abstraction of energy. However, the precise method of conceptual learning or conceptual change was not made explicit. Somewhere along the line it was simply hoped that pupils would acquire the concepts. In this respect, teachers’ activities are in accord with what may be described as the ‘front line’ of constructivist theory in academic literature. Matthews (1994) criticises constructivism in that it has yet to yield clear advice on how to teach. Claxton (1990) asserts that there is a problem in formulating a theory of learning that explains such a process of conceptual acquisition when it may be personal and idiosyncratic to the teacher, pupil and learning situation. His concern is not for correct or incorrect theories but for appropriate or inappropriateness in situations.

Issue (4) is interesting in view of Solomon's (1994) criticism that constructivism fails to acknowledge the social aspects in learning situations. Many teachers in this study were acutely conscious that the way they presented subject material needed to be relevant for pupils and their lives.

There was an almost complete absence of explicit acknowledgment that their own subject knowledge was an important factor in conceptual teaching and learning by the secondary teachers in this study, in direct contrast to the primary teachers in the PSTS project. The PSTS project showed that teachers' subject knowledge is an important consideration in constructivist teaching and learning (Summers and Mant, 1995). Furthermore, primary teachers participating were naturally concerned about their subject knowledge and had a strong desire to improve it (Kruger and Summers, 1988). There is thus a distinct difference in attitude between expert secondary science teacher and non-expert primary teacher about teachers' subject knowledge.

7.2.3. Energy in the National Curriculum and QCA Schemes

1c. To what extent do these perspectives match up to science curricula and syllabuses?

The energy strand in the KS3 Science National Curriculum states that pupils should be taught the following conceptual aspects of energy:

- Heat, temperature and energy transfer
- Energy transfer and storage per se
- Energy transfer and conduction, convection and radiation
- The law of conservation and energy dissipation

DfEE, QCA (1999a, p36)

The National Curriculum does not clearly define an 'energy transfer'. The term 'heat' may be interpreted as internal energy or the energy transferred by the process of heating. It is also a matter of interpretation as to what are the superordinate concepts of energy. Defining energy is avoided.

The conceptual aspects of energy are presented more clearly in the QCA schemes of work (QCA, 2000). The models of energy transfers and energy transformations are both explicit and considered equal in importance. Heat is a definite form of energy, but it may be both stored and transferred. There is no explicit guidance on how to superordinate the conceptual parts of energy. Instead, each energy relevant unit gives links to prior concepts, thus presenting a clear teaching route. Energy resources is the first energy topic. From the outset, the notion that energy is a substance is strictly discouraged. The law of energy conservation and dissipation are taught at the end. Ultimately, the intention is to link apparently disparate areas of science through the notion of energy transfer and real changes in phenomena.

It is emphasised that this study took place before the QCA (2000) schemes came into effect. Teachers' used the notion of energy transfers ambiguously. Sometimes it was used to indicate the movement of energy. At other times, it was used in the same way as energy transformations (hence transferring between forms). This suggests the term 'transfer', as stated in the National Curriculum, has been open to multiple interpretations by teachers.

Teachers' use of the term 'heat' was ambiguous. Sometimes it was used to mean internal energy. At other times it was used to mean the energy transferred by heating. This suggests that the term 'heat' has also been open to multiple interpretations by teachers.

The adoption of the QCA (2000) schemes, in conjunction with the KS3 National Strategy (DfES, 2002) may result in a rationalisation of energy teaching. They may result in a rationalisation in teachers' thinking as concepts are explicated in a clearer manner than ever before. This rationalisation was not present at the time of this study.

7.2.4. Energy and KS3 SATs

1d. To what extent do these perspectives match up to KS3 examination materials?

KS3 SATs questions on the conceptual aspects of energy are likely to ask pupils to:

(1) identify various energy forms;
(2) describe or complete 'energy changes' for events or phenomena;
(3) identify energy ending up spread out into the surroundings;
(4) add up quantities of energy on Sankey diagrams.

Statement (1) relates to pupils' abilities to use the model of energy transformations. This suggests that pupils unfamiliar with energy transformations would not do well on such a question. Statement (2) is more ambiguous. Recent marking schemes reveal that pupils may present an 'energy change' equally in terms of an energy transformation or an energy transfer. Statement (3) relates to the concept of energy dissipation. Statement (4) relates to the law of energy conservation. Both conservation and dissipation are explicit in the National Curriculum (DfEE, QCA, 1999a, p36).

The prevalent leaning of SATs questions towards energy transformations may be a factor underpinning teachers' adherence towards this model. However, the climate is moving towards allowing explanations in terms of transformations and transfers (QCA, 2000 and DfEE, 2002).

7.2.5. Energy and KS3 Science Text Books

1e. To what extent do these perspectives match up to the science text books teachers are using?

The most commonly used science text books by participating schools were the Starting Science series (Fraser and Gilchrist, 1993a and 1993b) and the Spotlight Science series (Johnson et al., 1993a, 1993b and 1993c). Starting Science presents energy in a manner immersed in the model of energy transformations. Spotlight Science leans towards energy transfers but does not fully abandon the notion of energy transformations. The Core Science series (Milner et al., 1998a and 1998b) presents energy in a manner concordant with the contemporary model of energy transfers. Its use was minimal however. In general, it was demonstrated that by looking at KS3 science text books as a whole, there is no consistency in the way energy is presented in terms of:

- the order of introduction of the concepts;
- presenting a coherent set of terms for the topic of 'heat';
- using the transfers, transformations or transferring between forms models;
- representing an energy change / transfer;

Teachers in this study were observed to use energy in as many different ways as may be found in a number of different school texts. This is concordant with the findings of Stylianidou and Ogborn (1999). This was especially the case for the topic of heat. Schools introduced the conceptual aspects of energy randomly, not following any particular approach. Teachers appeared to exercise professional freedom in the designing of teaching sequences for energy. Monk (2000) suggests this may diminish if the QCA (2000) schemes are to be widely adopted.

The influence of school texts on teachers' perspectives is not a clear issue, contrary to the assertion made by Stylianidou and Ogborn (1999). It is suggested that while teachers' perspectives may be observed to *mirror* some of the approaches found in school texts, the texts themselves may not directly influence how teachers use energy if strong prior beliefs are held. Given the prevalence of Spotlight Science use, it was presupposed that teachers at such schools may be more inclined towards the transfers model of energy. This was not the case. Virtually all the teachers in this study were immersed in the model of energy transformations, regardless of text use. This phenomenon is described by Kelly's (1955) psychology of personal constructs in terms of the resilience of a person's core constructs.

7.2.6. Explicit or Less Well Formed Perspectives of Energy

> **2. To what extent are these perspectives firmly, confidently and clearly held in teachers' minds; as opposed to less well formed?**

Notions of tacit knowing contain propositions concerning knowing, perception and the progress of science. The following points are relevant to this study:

- the act of knowing comprises a relationship between tacit and explicit knowledge (Polanyi, 1969a);
- new knowledge may only be applied when learnt tacitly (Tomlinson, 1999a)
- scientific knowledge does not only comprise explicit principles but also the tacit knowledge built up through the experience of scientists (Woolnough, 2001);
- pupils need to be given the opportunity to experience 'authentic science' and thus acquire tacit knowledge (Woolnough, 2001).

It is suggested here that the process of concept acquisition, as described by Ausubel et al. (1978) is enriched by the theory of tacit knowing proposed by Polanyi (1969a). For a concept to be acquired in the sense that it may be usefully applied in new situations, it is proposed that an act of tacit knowing must occur. This serves to consolidate the explicit subordinate concepts.

Teachers in this study readily articulated knowledge about energy in certain areas. Such knowledge was considered to be explicit in teachers' thinking and was applied confidently without effort. However, within each area, there were aspects where knowledge was not readily articulated. This knowledge was not considered to be well formed in teachers' thinking. Table 7.2.6.1 summarises these findings. A similar analysis revealed both explicit and less well formed opinions about issues relevant to conceptual acquisition, as summarised in Table 7.2.6.2.

Knowledge Area	**Explicit knowledge obtained**	**Knowledge less well formed**
Model of Energy	Identifying forms of energy; transformation of energy forms	What is meant by a 'transfer' as distinct from a 'transformation' of energy
Conservation, Dissipation	Energy is never created or destroyed	Spontaneous and explicit use of energy dissipation
The Nature of Energy	Defining energy	Knowing what energy is
Heat	Heat as a form of energy	Dimensions of heat as U & Q
Energy Storage	That energy is stored	Where or how energy is stored

Table 7.2.6.1 Explicit and less well formed knowledge obtained about energy

Knowledge Area	**Explicit knowledge obtained**	**Knowledge less well formed**
Conceptual Acquisition	Definite teaching strategies reflecting constructivist principles	(1) That strategies were described by academic theory; (2) how conceptual acquisition occurred; (3) that teacher knowledge is an important issue
Terminology	Definite concern that pupils learn correct scientific language	Applying this in conversation without slipping into vernacular
The Purpose of Teaching Energy	Definite opinions which reflect the literature	Where these opinions come from

Table 7.2.6.2 Explicit and less well formed knowledge obtained about the teaching of energy

It is useful to distinguish three types of knowledge in view of these findings:

- explicit knowledge;
- knowledge less well formed;
- tacit knowledge.

Explicit knowledge is the type that is readily articulated and applied. Tacit knowledge is the type that is not readily articulated but forms an essential part of being able to act or apply knowledge explicitly (Polanyi, 1969a). It is a more personal form of knowledge based on personal experience (Polanyi, 1969b). Less well formulated knowledge may be described as knowledge that is not expressed spontaneously and may not be confidently or accurately applied. It may comprise isolated fragments of knowledge which are not joined into a coherent structure. In view of the theory of tacit knowing, it is suggested that the presence of less well formulated knowledge here may be a result of teachers not possessing the tacit knowledge required to express the knowledge explicitly, confidently or accurately. In the case of knowledge about energy, fragmented knowledge may consist of text book definitions and procedures which may be confidently applied within a limited range of applications. However, deeper knowledge about how these definitions and procedures relate within a larger conceptual framework may, to an extent, be missing.

At this point it is relevant to compare this study with prior studies on the conceptual understanding of energy. Watts (1983) reveals that secondary school pupils possess misconceptions about energy. Kruger (1990) and Trumper (1997) reveal the same misconceptions in practising and student primary teachers respectively. Contrary to the above work, this doctoral study revealed that practising secondary science teachers held explicit and confident conceptualisations about energy in many areas. Some of the misconceptions reported in the prior studies were observed, but to a substantially reduced degree. However, this study revealed that practising secondary science teachers may possess gaps in their knowledge of energy which indicate a lack of a thorough conceptual understanding concordant with science or science education literature.

It is suggested that teachers may be able to upgrade their knowledge from less well formed to explicit only after an act of tacit knowing has occurred. In the cases of knowledge about energy or conceptual teaching and learning, this may occur as a result of the influence of various factors. These may include academic literature, science curricula, examination materials or teaching resources, as examined in this study. These may also include other factors including past teaching experience, personal experience, professional development or chance encounters. One possible explanation for the lack of explicit knowledge in a given area is that a teacher has not had the necessary experience of that area required to build tacit knowledge. Alternatively, it is suggested that teachers of science are given the chance to experience ‘authentic science’, of the type described by Woolnough (2001).

However, acquisition of knowledge may not occur, even if one is exposed to any of these factors. This may be the case where a teacher is ingrained in a particular approach; for example the transformations model of energy. This may also be the case where knowledge is counter-intuitive; for example the importance of dissipated energy. In these cases, the resilience of existing conceptualisations may hinder the acquisition of new knowledge, as discussed in constructivist theory (e.g. Fensham et al., 1994).

7.3 Evaluation of Study

7.3.1. Paradigmatic Allegiance

This study was conducted embracing a number of aspects. These may be considered as 'lenses' on the study (Driver et al., 1985). Knowledge based aspects included:

(1) an epistemological constructivism concerned with the learners' constructions of knowledge (e.g. Fensham et al., 1994);

(2) the extension of constructivist principles through notions of 'tacit knowing' (Polanyi, 1969a), personal construct psychology (Kelly, 1955) and 'domains of thinking' (Solomon, 1983a);

(3) favouring the contemporary modelling of energy to include energy transfers (Ellse, 1988) and an emphasis on energy dissipation (Ross, 1988);

Ontological, epistemological and methodological aspects were derived from the interpretative traditions to include:

(4) acknowledging the role of the researcher in uncovering and constructing knowledge (Carr and Kemmis, 1986, p103);

(5) the symbolic interactionist / social constructivist principle of acknowledging the construction of knowledge through interactions (Blumer, 1969; Lincoln and Guba, 1985);

(6) grounded theorising and the 'constant comparative method' but only to the extent of organising data under a number of largely predetermined themes (Glaser and Strauss, 1969).

It was considered relevant to draw on epistemological constructivism (1), given the wealth of prior science education studies embracing this framework. Methods such as 'interviews about instances' (Osborne and Gilbert, 1980) and 'concept mapping' (Novak and Gowin, 1984) are well described in the literature in terms of the ability to elicit conceptual understanding. It was considered relevant to draw on other related systems of thought (2) in order to locate the findings within a wider theoretical context.

It was considered highly relevant to acknowledge the role and background of the researcher (4, 5). Qualitative data from this study contained discoveries of knowledge, which hold under a phenomenological underpinning so long as researcher intervention is minimal (e.g. Kvale, 1996, p135). However, data also contained inventions of knowledge. Also, the reporting was viewed as a reconstruction of the data through the lenses of the study. It is argued that these aspects are encouraged under a symbolic interactionist or social constructivist stance. The ontological underpinning is that of a reality created as a result of interactions (e.g. Guba, 1990, p18). These approaches represent an ontological tension. Both aspects served as sources of useful data in this study though. Lincoln's (1990) charge of paradigmatic perjury may be indemnified with the nineteenth century pragmatic maxim: if two views carry the same implication for practice then they do not differ in meaning (Hammersley, 1990).

In terms of theorising, this study departed from a traditional 'naturalistic enquiry' (after Lincoln and Guba, 1985) in that the themes were predetermined (6). However, it is argued that this is consistent with constructivist science education studies documenting participants' understanding of a particular topic (e.g. Watts, 1983 and Kruger, 1990). Data in this study were discussed in view of the contemporary modelling of energy (3). This was based on the opinion that this was in accord with science education literature and in closest accord with the higher levels of physics (e.g. Feynman, 1963). However, this presented a challenge in that these were not the ways in which most teachers in this study viewed energy.

7.3.2. Evaluation of Methods and Analysis

This study used the following methods to obtain data on teachers' perspectives of energy:

(1) questionnaire survey (Munn and Drever, 1996);
(2) semi-structured in-depth interviewing (Kvale, 1996);
(3) concept mapping (Novak and Gowin, 1984);
(4) interviews about instances (Osborne and Gilbert, 1980).

The survey (1) was designed and administered in view of advice in research manuals. However, some aspects of this advice were not followed strictly, for example the positioning of 'demographic' questions. The survey yielded a lower response rate than expected. However, no firm conclusions were made as to the reasons for this. It is thus possible that the survey data was biased, given that a limited number of schools participated and that the teachers who completed the questionnaire were interested in participating in the survey. The data says nothing about schools which were not interested in participating. It is arguable that these factors constrain the generalisability of the findings to the population.

The survey was intended to yield contacts for the in-depth part of the study. On reflection, it was apparent that this may have been best facilitated by simply asking teachers directly.

Data from the survey were analysed by preparing tables of frequencies. In addition, one and two sample χ^2 tests were used to provide a greater precision in formulating arguments about the random introduction of the conceptual aspects of energy and the late introduction of energy dissipation. Use of these statistical methods was considered appropriate and was in accord with procedures in research manuals (e.g. Diamantopoulos and Schlegelmilch, 1997). In retrospect, the data were useful in that they set foci for discussion with teachers.

The in-depth part of the study utilised established methods for eliciting both conceptual understanding and opinions (2, 3 and 4). For obtaining opinions about energy and its teaching, a brainstorming exercise and semi-structured in-depth interviews were conducted. These were considered appropriate in that a number of loosely focused questions had the scope to allow teachers to expand their views and thus give rise to a rich data base, which could be subject to coding.

For obtaining data on conceptual understanding, the concept maps, PSTS replication interview about instances and further in-depth interviewing provided a rich data base which had the scope for triangulation by participant and across participants. The order of the methods was considered appropriate in that initially, they allowed spontaneous elicitation, with minimal researcher intervention. Such data were considered as ‘discoveries’ of knowledge. Some participants were additionally probed with supplementary questions resulting in the ‘invention’ of new knowledge. Issues concerning ‘discoveries’ and ‘inventions’ of knowledge are interesting in view of the experience with participants. Many teachers felt that the in-depth work was not so much about a researcher obtaining data from them but a chance for them to learn something new. The research was often viewed *as* professional development. Moments where a teacher consolidated a piece of knowledge were considered extremely satisfying for both parties.

Due to the difficulty in securing participation, the qualitative data were fragmented. Teachers did not participate in the same number of activities. However, using the ‘constant comparative method’, data were easily coded and sub-themes were easily ‘saturated’ (Glaser and Strauss, 1967, p104). The study could have focused on the transfer-transformation debate and/or the nature and/or the superordinate concepts of energy. It is suggested that these themes alone could provide sufficiently rich and deep foci. The study had to arrive at a balance between the number of participants, individual participant depth and the number of themes under focus, in striving for valid conclusions. In interpretative studies, there are no absolutes in terms of position on any of these dimensions (Lincoln and Guba, 1985).

Participants in the in-depth part of the study must be considered a limited snapshot of secondary science teachers as a population. It is possible that a different set of participants (and a different researcher) may have given rise to different data and findings. The study says little about the teachers who were not interested or able to participate. It is arguable that the nature of the participants, the researcher and the idiosyncratic qualitative process here put a constraint on the transferability of the findings to other situations. Conversely, there is no evidence here to suggest that the views of teachers in this study would be different to the views of other teachers.

In retrospect, aspects of the design which could have been optimised are as follows:

- designing a shorter programme to ensure less fragmented participation and data;
- focusing on a narrower set of themes with increased depth;
- conducting fewer interviews and observing earlier ‘saturation’ of themes.

7.3.3. Quality Audit

Qualitative research has been subject to debate in terms of the most appropriate criteria with which to make judgments about a study. For the sake of this discussion, the ‘trustworthiness’ criteria described by Guba (1981) and Lincoln and Guba (1985, pp294-301) form a useful focus. However, it is acknowledged that these may not form an absolute frame of reference, as pointed out later by Lincoln (1990).

> **Credibility** (≡ internal validity): is the subject of the enquiry accurately defined and described?
>
> **Transferability** (≡ external validity): what can be said about generalisation of the findings to the population?
>
> **Dependability** (≡ reliability): is the study systematic, clear and well documented?
>
> **Confirmability** (≡ objectivity): do the findings flow from the data?
>
> Derived from Lincoln and Guba (1985, pp294-301) and Robson (1993, pp403-406)

This study demonstrates credibility based on the following. The culture of the enquiry was well defined in respect of my background as a physics teacher; descriptions of energy in higher level physics, science education literature and school resources; and the wealth of paradigmatic issues pertaining to the research. The study utilised persistent observations and triangulation of observations from different sources.

Transferability / external validity is a criterion that qualitative studies historically have problems demonstrating. It is reinforced that this study comprises one set of themes in a possible set of many. Furthermore, the report may be construed as a reconstruction of the data through the particular lenses of the study. Robson (1993) points out that it is inappropriate to make statistical generalisations to a population from a qualitative study. This study has the potential for transferability in that throughout the report, every aspect was clearly exposed. Subsequent readers are invited to relate the findings to the whole design. This is concordant with the description of transferability by Lincoln and Guba (1985, p316).

This study demonstrates dependability based on the systematic, clear and well documented nature of the procedures, as described. The study demonstrates confirmability in that the procedures clearly show how raw data were transcribed, coded, condensed and organised into the themes. Furthermore, the design of the main study was clearly described in terms of its evolution from the pilot studies.

7.4 Further Avenues

A direct challenge emerging from this study is the question of how the contemporary modelling of energy may become more widespread. The QCA (2000) schemes in conjunction with the KS3 National Strategy (DfES, 2002) partially rationalise the introduction of the concepts of energy. However, an obvious criticism is that there is still emphasis on many forms and transformations whereas a kinetic-potential-transfer mechanism model is more in accord with higher level physics as argued. In the language of Kuhn (1970), such a move may be likened to a paradigm shift – will we thus have to wait until the 'old scientists die' before the new approaches are fully embraced? Constructivist epistemology clearly suggests reluctance to any change in thought. This is due to a person's thought structure being influenced by a catalogue of past experiences which work in terms of meeting new situations. In terms of energy, perhaps the transformations model is a 'safe' model? Most teachers can use it and there is a wealth of school literature promoting it (albeit with slightly differing language: conversions, changes etc.) The challenge for thinking will be to present evidence that there can be simple models which progress naturally to higher levels. Furthermore, that the new models are able to explain certain facets with more accuracy e.g. the dynamic steady state (Ellse, 1988).

The findings from this study represent a start of potential research on energy at KS3 with *teachers*. In a similar way, Watts (1983) started with *pupils'* conceptions of energy. An immediate point of action here should include a translation of findings into professional development for teachers.

Specific further avenues for research could include:

- ⇒ Quantitative study of specific foci e.g. responses to statements as in prevalence phase in PSTS, factor analyses using qualitative data to generate prompts
- ⇒ Action research: can teachers adopt contemporary approaches or at least change their thinking? Would teachers consciously choose a different way to model energy?
- ⇒ Examine the extent of new paradigm assimilation to the field of physics education e.g. evaluation of constructivist epistemology underpinning any drive for change. Examine in view of the extent to which this is related to awareness of the literature.
- ⇒ Do pupils learn energy well by the transfers approach?

- ⇒ Do pupils learn energy well being introduced to it in a manner concordant with recommendations in academic literature?
- ⇒ Development of the energy concept and its modelling at KS3 in problematic areas e.g.:
  - ◊ a need for an accepted framework to represent energy transfers;
  - ◊ a need for a consistent set of terms within the topic of ‘heat’;
  - ◊ persuasion that energy dissipation can be expressed simply;
  - ◊ how can energy transfers explain the KE-PE interaction without resorting to fields?
  - ◊ Expression of energy in chemical word equations so as not to suggest it is a product or ingredient;
  - ◊ dealing with energy from exothermic chemical reactions: how does the fuel-oxygen system reconcile with the higher level negative potential energy and that chemical bonds exist as an absence of energy?

On a final note, it is asked, does any of this matter for the majority of students who will never take science to a higher level, for whom operational living does not demand higher thought on e.g. negative potentials, or even a need for precise technical language? This study is of direct relevance more for the continuing science student in terms of a concern for coherence in progression of models, in best accord with the current consensus views in science. However, it is evident that the contemporary modelling of energy still has some way to go before it may challenge the bastion of traditional thinking.