The active use of concept mapping to promote meaningful learning in biological science.

by

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Abstract

The focus of this work is the use of student concept mapping to promote meaningful learning in the classroom. All the studies reported were done in secondary schools and an undergraduate science course. All results and their discussion are presented within a human constructivist framework. The central question on which the research is based can be given as:

How can concept mapping be used to contribute to understanding?

This thesis is presented as a process of enquiry. Thus questions addressed by particular methodologies and approaches are later superseded with new questions and methods. This is consistent with a grounded approach and is part of an authentic constructivist research process. The main findings can be summarised as:

1. Quantitative methods of concept map analysis are inappropriate for promoting meaningful learning among secondary science teachers and their students. It is too time-consuming, fails to recognise the individualised nature of learning and emphasises curriculum-centred notions of ‘correctness’ – a stance at odds with the constructivist viewpoint.

2. A qualitative approach to concept map analysis has been developed in this thesis. It is shown to emphasise a contextual understanding of students’ and teachers’ conceptual ecologies in which development may indicate learning (through conceptual change) or switching (through contextual appreciation).

3. Finally, this work offers arguments against a rigid and didactic prescription of the curriculum that fails to respect the students’ perspective. A teacher-student dialogue to promote meaningful learning is likely to occur only when teachers question their own beliefs and approaches to teaching and learning. Constructivist classroom approaches can be mediated by concept mapping to emphasise the exploration and sharing of meaning rather than absolute correctness. Such approaches are likely to have an impact upon teaching quality and should be a key part of initial teacher-training and continued professional development.
Frontispiece

"The visualization of the new, the creation of a coherent picture from disparate data, is the beginning of all great journeys."

*To seek out new life: The biology of Star Trek.*
Crown Publishers Inc., NY.

"so much of originality or creativity is not new ideas, but new connections."

Glaser, B. (1992)
*Basics of Grounded Theory Analysis: emergence vs. forcing.*
Sociology Press, Mill Valley, CA.

"Creativity is seeing things that everyone around us sees while making connections that no one else has made."

Wycoff, J. (1991)
*Mindmapping: your personal guide to exploring creativity and problem solving.*
Berkley Books, NY.
Dedication:

To my children

For whom the 21st Century promises so many learning experiences.
This thesis is not a solo effort, but the result of numerous interactions. Many thanks are due to those who have contributed comments, ideas and general support. In particular, I would like to thank:

- Karen Evans and David Hay for their enthusiastic supervision. It was greatly appreciated.
- Anne Kinchin for providing the necessary support and encouragement needed to start the work and to get it completed.
- The staff within the School of Educational Studies. Particularly Gareth Parry and Tom Black for their interest; John Holford and Gill Nicholls for providing introductions to school departments and to the PGCEA team for their understanding.
- The teachers at the various schools involved for letting me disrupt their lives.
- Frans de Leij in the School of Biological Sciences (UniS) for his co-operation and enthusiasm.
- The students that I have taught, from whom I have learnt so much.
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1.1 Overview

This thesis is about conceptual change – how it can be achieved and communicated. The work includes the study of change in learners’ understanding, using concept mapping in the context of biological education. It focuses on the development of classroom methods that can be used to promote learning. In parallel to this, the work documents change in the researcher’s views - my conceptual change.

This thesis is intended to influence contemporary classroom teaching in the UK through the development of classroom-based methodologies in which effective teachers are viewed as learners. I see learning and change as separate, but complementary elements of effective teaching. This teaching is, in turn, set within the context of a National Curriculum for science that has been accused of inhibiting innovation and professional development of teachers (eg. Donnelly, 2000).

The work aims not only to be of interest to the research community, but also to have utility and application for teachers and learners. Teaching and learning are two elements that both require and facilitate change in learners and teachers. The relationship between these elements is complex with no one functioning in isolation. Therefore, an investigation of learning will also require a consideration of teaching and of the resulting changes in both teacher and learner as they interact. Whilst the initial focus on this work is on learning achieved by students, the thesis goes on to consider the impact on the other elements. Change is also considered here with particular reference to the researcher. I will return to this in Chapter 7, where it will be discussed and developed in the context of the findings of this study.
Curriculum change has been centre-stage in UK secondary education for over a decade (since the introduction of the National Curriculum in 1988) and has been the source of considerable debate and disagreement. Much more subtle have been attempts at promoting teachers’ epistemological change with various efforts encouraging reflection upon the ‘nature of science’; promoting teacher-transition from objectivism towards constructivism (eg. Lakin and Wellington, 1994; Jenkins, 1996). However, it has resulted in creating tensions, with science teachers having to ‘serve various masters’:

Constructivist science education typically presents a relativist image of scientific knowledge that is not shared by scientists.

(Harding and Hare, 2000: 225).

At the same time, much of the science education research literature has been concerned with the cataloguing of student misconceptions (eg. Driver, et al., 1994). There has, however, been criticism that the literature reveals few teaching strategies that take account of this research or give advice on how to approach different topics in the classroom. Millar (1989: 588) concluded that:

.. many teachers are now persuaded of the value of knowing about the prior ideas their pupils are likely to have about a given science topic ... but are much less sure about how to act on this knowledge when teaching a class of 25 or more learners.

There is, therefore, a need to develop classroom strategies and teaching/learning tools to create a bridge between constructivist models of learning and classroom practice. Various classroom strategies have been promoted to help bridge this gap. Of these, concept mapping (sensu Novak and Gowin, 1984) has produced positive effects in experimental situations. The background to this is considered in detail in Chapters 2 and 3.
My own experience suggested that secondary biology teachers were not exploiting concept mapping within their classrooms (a view reiterated by Brown, 1995: 131). Additionally, whilst constructivism may have provided ‘the dominant conceptual framework for science education over the past two decades’ (Sandoval, 1995:357), my experience suggested that it had not really impinged upon my own consciousness or those of my colleagues. In order to broaden this perspective beyond my personal contacts, I administered a brief questionnaire to teachers attending the ‘Life Science 2000’ conference organised by the Institute of Biology at Warwick University in July of 1998. Responses from secondary science teachers are summarised in table 1-1.

These data are only from a small sample of teachers and are probably not representative of the entire population of secondary science teachers in the UK – teachers attending such a conference are likely to be more aware of curriculum innovations than the ‘average’ teacher. However, it does seem to support my informal perspective: 67% having never used concept mapping and 78% never having employed constructivist teaching approaches. Also interesting is that there is no-one in the sample who has tried either of these approaches and found that they did not like them!
Table 1-1. Responses from secondary science teachers to a questionnaire distributed at the Life Science 2000 Conference at Warwick University (July 1998).

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<th>Have you used the following resources or teaching methods?</th>
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<tr>
<td><strong>Concept Mapping</strong> (not the same as 'spider diagrams').</td>
</tr>
<tr>
<td>Tried it and liked it</td>
</tr>
<tr>
<td>33%</td>
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<table>
<thead>
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<th><strong>Constructivism</strong> (constructivist teaching)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tried it and liked it</td>
</tr>
<tr>
<td>22%</td>
</tr>
</tbody>
</table>

This suggested that there was a need for further research into the constructivist application of concept mapping, in an attempt to bridge the divide between research and classroom practice.

An overview to the thesis is summarised as a concept map (Fig. 1-1). Such maps were used as an integral part of this research, through design and implementation and are seen as an aid to maintaining cohesion between the research elements.
1.2 Classroom impact

Given the generally positive attitudes of the research community towards concept mapping and the researcher's experience of teachers' concerns about the quality of learning among their students, it seemed that an opportunity was being repeatedly missed by not exploiting the technique. With this in mind, research questions are framed in Chapter 4.

The objective of the research was to explore the application of concept mapping to teaching and learning biology and see how the apparent benefits of its use can be made explicit. The literature expresses enthusiasm for concept mapping as a tool to help communication between students and teachers in experimental conditions, but how can it be used most effectively to contribute to understanding within a normal classroom? Throughout this work, understanding is meant in the sense of deep (rather than surface) learning in which it refers to the ability to use and apply knowledge in appropriate contexts, rather than simple memorisation or verbatim recall of information. Whereas memorisation implies that a copy can be reproduced, understanding implies that a reconstruction can be made (Newton, 2000).

Such an exploration of concept mapping requires the use of various research methods. These methods have evolved during the course of this study in response to the emerging data and have, therefore contributed to the development of a grounded approach.
The investigations described here are undertaken in the contexts of secondary and higher education science (predominantly, but not exclusively, biology). Reports in the literature show that concept mapping can be used effectively with students from primary to higher education and there is no reason to believe that the findings will be restricted in relevance to this curriculum area. The literature from across these sectors is referred to herein. The work is also described by the conceptual framework by which it is underpinned, the structure of which is described in the following section.

1.3 Conceptual framework.

Key elements that can be used to construct the conceptual context (=conceptual framework) of a research study have been identified by Maxwell (1996: 27) as: experiential knowledge; pilot and exploratory research and existing theory and research (indicated in figure 1.2). These combine to form a base upon which further research can be built.

![Figure 1.2](image)

*The combination of components that together build the conceptual framework for this research.*
Depiction in this way also shows how all three components impinge on each of the other two. Variations of this figure are offered at the beginning of chapters 2, 3, 5 and 6 to emphasise how each chapter contributes to this framework by highlighting the key component.

Chapter 5 gives detailed description of the instruments and methods used within this work. This includes the classroom procedures and tests as well as a discussion of the development of my ideas. The researcher is considered here to be a research instrument – a notion that is a prerequisite to an authentic constructivist approach. In this thesis, the researcher happens to be me and is reflected in the personal nature of the account given in Chapter 5. In future research conducted by others, ‘the researcher’ will still have an important influence, but the details will reflect the particular backgrounds of the individual(s) involved.

In Chapter 6, the three main ‘experiments’ are described and their results are given. These include

- An examination of the effects of concept mapping on individual students within a cohort of Year 10 students. This was in the context of GCSE biology, focusing on the topic of photosynthesis (referred to hereafter as the ‘photosynthesis trials’).
- The potential of a collaborative concept mapping activity with groups of Year 8 students (referred to hereafter at the ‘collaborative trials’).
- The impact of an evolving concept mapping activity on learning within an undergraduate microbiology course (referred to hereafter as the ‘microbiology trials’).

These three elements are linked methodologically as findings from one have been used to inform the development of the others and represents a ‘grounded approach’ (Fig. 1-3). Though analyses of the quantitative data do not demonstrate any statistical
significance of the concept mapping intervention, this is not considered as their primary importance. Rather, the quantitative phase is a prerequisite to the development of the later phases, and is therefore an essential component of the overall picture presented in the thesis.

Collective consideration of these data sets is given in Chapter 7. This is enriched with participant feedback gained from interviews with teachers and students who were involved in concept mapping investigations. Implications are described for student progression in the curriculum and the utility of the conceptual ecology analogy is explored.

In Chapter 8, a synthesis of the findings is presented, contributing to the development of a model of teaching and learning to which the constructivist application of concept mapping may contribute (the TLC Cycle). Possibilities for future research are also described.
Figure 1-3
Map showing the methodological links between the three experimental strands described in Chapter 6
Chapter 2  Background Research

2.1 Misconceptions

2.1.1 Terminology

The unorthodox ideas that children hold have been variously termed as preconceptions, alternative frameworks, alternative conceptions, naïve theories, naïve beliefs and misconceptions (eg. Abimbola, 1988). The term ‘misconception’ has been avoided by some authors as it is seen as judgmental or misleading (eg. Duit, 1991). However, Hodson (1998: 45) has criticised this stance and stated that:

If we are unwilling ... to judge some ideas as better than others ... we give our students no incentive to change or develop their views, we give ourselves no incentive to design good curricula, or even to teach science at all.

In considering ‘alternative frameworks’, a term coined by Driver and Easley (1978), Fleer (1999) has raised the question, ‘alternative to what?’ She concludes that ‘alternative’ implies alternative to Western science – a stance that may not be appropriate in a multicultural society. Fleer's work implies that the term ‘alternative views' may provide a superficial veneer of ‘political correctness’ while masking a deeper and more pervasive ethnocentricity. The term ‘misconception’ is used throughout this work as it was considered to be the term with which the collaborating teachers would be most comfortable. It is acknowledged that whilst such frameworks
may be flawed and limited, many are found to be useful and acceptable in a variety of everyday situations and provide resources for cognitive growth (Smith et al., 1993).

2.1.2 Conceptual foundations

Students' misconceptions and naïve theories have been extensively studied within the context of the school science curriculum (Carmichael et al., 1990; Driver, Squires, Rushworth, and Wood-Robinson, 1994; Pfundt and Duit, 1994) and have been described in considerable detail in the case of photosynthesis. A discussion of the possible origins of some of these naïve theories is given below and the major misconceptions that have been recognised in this topic area are summarised. In general terms, it has been found that misconceptions tend to converge along common 'conceptual trajectories' and this has led to the production of state-of-the-art teaching materials that are based explicitly on understanding and remedying common areas of misconception; an approach that is based on the constructivist methodology (eg Needham and Hill, 1987).

By the time children start their elementary science education, there appears to be a considerable development of biological knowledge within many concept areas. A variety of studies have investigated the conceptual foundations and development of the biological domain (eg. Carey, 1985; Coley, 1995; Hatano and Inagaki, 1994, 1997; Keil, 1992; Mintzes, et al., 1991; Richards and Siegler, 1986), and have shown that young children can hold various naïve theories concerned with ideas such as the characteristics of life; genetic inheritance and internal body organs before they are taught these topics in school. Some of these naïve theories may be in agreement with the accepted theory, whilst others may not. Therefore, it may not only be the students' lack of prior knowledge that makes learning difficult, but frequently a conflict.
between new knowledge and existing naïve theory (Champagne Gunstone and Klopfer, 1983). In the first stage of the process of conceptual change, these misconceptions need to be identified so that they do not become a barrier to further learning.

The ideas expressed here are applicable across the curriculum, but as problems in the teaching of the key biological concept of photosynthesis have been so well described by previous authors, the exploration of concept mapping is developed here using photosynthesis as a vehicle. A number of studies, using a variety of techniques to probe students' understanding, have identified various commonly held misconceptions regarding photosynthesis (eg. Wandersee, 1984a; 1984b; Bell, 1985; Bell, Barron and Stephenson, 1985; Stavy, Eisen and Yaakobi, 1987; Storey, 1989; Amir and Tamir, 1994; Lavoie, 1997). There is considerable overlap in the findings of these studies, and the most fundamental misconceptions can be summarised as:

a) Plants get their food from the soil, via their roots.
b) Photosynthesis produces energy.
c) Gases (in particular CO₂) are not involved in food production.
d) Photosynthesis occurs in plants, but respiration occurs in animals.

These misconceptions are set in context within the concept map in Figure 2-1. Here it can be seen that these are not isolated ideas, but can be built upon each other to produce a coherent framework that may offer utility to the student in most everyday situations.
Figure 2-1
A concept map showing how many of the most common misconceptions associated with photosynthesis can be linked to create a conceptual framework for a naïve theory. (from Kinchin, 1998b).
The sources of biological misconceptions are many and varied; some lie within the control of the teacher, but others are attributed to influences outside of school (Soyibo, 1995b). In their recent review of misconceptions in chemistry, Garnett, Garnett, and Hackling (1995) identified several main sources of misconceptions, though many of these sources are difficult to separate as they overlap and interact. Their categories have been modified to provide the structure of this section.

2.1.3 Uses of everyday language in a scientific context.

The conceptual frameworks students develop to describe and explain phenomena frequently conflict with those recognised as valid by their teachers. This conflict is exacerbated where everyday language terms are given precise technical meanings (Watts and Gilbert, 1983). Learning a second word for a familiar concept is unlikely to be unsettling (as in learning a foreign language), but learning that a familiar word can have an unfamiliar meaning in a new context is likely to be more problematic (Carey, 1986). When studying plant nutrition, this can include words as familiar and deceptively simple as ‘food’ or ‘energy’.

Whilst Nicholls (1992) has shown that primary school pupils do have a structure to their concept of ‘energy’, namely that they can make a distinction between sources and consumers, it is possible that the legitimacy of such early conceptual frameworks may be compromised by the clumsy introduction of conflicting terminology in related topics. The arrows in food chain diagrams commonly depict the ‘flow of energy’ through an ecosystem (from producers - plants - to consumers - animals ) Leach, Driver, Scott and Wood-Robinson (1996). Frequently, the source of this energy (the sun) is omitted from such diagrams in school textbooks and this creates the impression among pupils that the producers
(plants) are the source (ie. producers) of the energy in food chains. This is a plausible explanation for the common misconception among biology students that, ‘photosynthesis produces energy’ and among physics students, that ‘energy is the product of a process’ (see Watts, 1983; Gayford, 1986). Furthermore, Simpson and Arnold (1982b) and Eisen and Stavy (1993) suggest that the terms, ‘producers’ and ‘consumers’ are misleading because plants do not produce energy, but require it. They concluded that at early secondary level this terminology can only reinforce the erroneous idea that the food required by plants accretes through the growth of the plant, thus providing food for animals to consume. Changing the terms used in this context may help to develop the idea that plants produce food for their own consumption and that like animals, they obtain energy from it by continuous respiration. Schmidt (1991) has coined the term, ‘hidden persuaders’ to describe such examples where the meaning of a word may change to such a degree that a term that was quite appropriate at the time of its inception, eventually turns out to be misleading or confused with other terms that have been derived independently.

Terminology is not only misleading because of changing patterns of usage, but problems also arise because of inconsistent usage dependent upon context. For example, Simpson and Arnold (1982b) make the point that teachers use the word ‘food’ to convey a variety of concepts in different contexts. Coping with this variability in the definition of ‘food’ used by teachers requires considerable linguistic agility on the part of the pupils and so makes it difficult to state that a pupil has developed a model of ‘food’ akin to the ‘accepted science view’. Within human nutrition topics, the words ‘food’ and ‘nutrient’ are often used interchangeably with nutrients, including energy-rich compounds such as carbohydrates, fats and proteins, in addition to vitamins and minerals. In plant science, however, nutrient uptake has a
much more specific meaning that is confined to the absorption of minerals from the soil. Misconceptions are thus not simply brought into classrooms as part of the naïve theories that have developed from everyday discourse and experience, they are present in the classroom itself in the language of teaching and can be compounded by different patterns of use in different areas of the school curriculum. Veiga, et al. (1989) have drawn attention to this problem, but concluded that it is impossible for teachers to avoid the introduction of everyday terms to the classroom, emphasising the importance of teachers’ sensitivity to the problems inherent in language use, and in particular of inconsistent changes in meaning from the scientific to the colloquial. Even if there is to be prescriptive delineation of terminology, Solomon (1993) explains that teachers should not run the risk of cultural alienation by the neglect of colloquial and everyday language. Cobern (1996: 583) has warned that ‘to suggest that students break with everyday thinking is to suggest that they break with that which is meaningful’. In fact there is evidence to suggest that the use of analogies based on cultural traditions can be beneficial to conceptual development and could be used to help students to construct meanings of biological concepts, including photosynthesis, transpiration and transportation in plants (Lagoke, et al. (1997). Hodson (1998: 51-52) argues against the over-use of specialist terms with which students may be unable to relate:

Greek and Latin terms are often employed in science with the specific intent of eliminating ‘unwanted’ associations. While the increased explanatory power of specialised terms such as photosynthesis is sometimes a sufficient argument for their use, it is also the case that jargonization can increase difficulty and decrease interest for some children. It may even alienate some children from science. By contrast, it is likely that these ‘other’ aspects of meaning, with their everyday associations, can provide the key anchoring points for new learning, and so render it more meaningful. We should be encouraging rather than discouraging the connotative aspects of understanding.
The challenge, therefore, is for teachers to devise strategies to help their students to recognise the differences between 'scientific' and 'everyday' uses of terms and the contexts in which it is appropriate to use each (eg. Driver, Asoka, Leach, Mortimer and Scott, 1994; Leach and Scott, 1995; Henderson and Wellington, 1998).

2.1.4 Students' preconceptions from prior world experience.

One of the underlying assumptions within this thesis is that children's minds are not blank slates when they start formal schooling as the process of 'meaning making' is well-established in early infancy. Inagaki and Hatano (1996) have shown that 4- and 5-year-old children have a well-developed sense of 'group' and could spontaneously use the category of 'living things' in which to classify animals and plants. This classification is based on two properties which are at the core of the living-nonliving distinction: 'growth' and 'taking in food/water'. Inagaki and Hatano's interpretation of these findings supposes a child's anthropocentric view of the world. ie. 'living things' refers to those beings which are similar to humans in terms of taking in 'vital force' from food and water, with its surplus inducing growth. As soon as children start to regard plants as living things, they will find it feasible to apply this principle. A firmly established framework encompassing the idea that living things take in food is, therefore, in place by the time children start their formal education.

This 'food-gathering' view of the living world is then continually reinforced by colloquial language used in such descriptions as 'plant food' which are commonly used by informal educational sources such as television and magazines, and by adults who may share misunderstandings of the scientific concepts involved (Simpson and Marek, 1988). Once at school, the idea that plants require sunlight to remain healthy
(eg. Smith and Anderson, 1984) does not conflict with the child’s established framework any more than the idea that the child should exercise to remain healthy. When pupils are learning new scientific ideas, naïve theories (incorporating misconceptions) associated with familiar words remain important (and probably dominant) for a long time and may even be reinforced by the misinterpretation of experimental observations and by terminology that has a meaning for the students that was not intended by the teacher. Thus it can be seen that factors involved in the development of misconceptions cannot be viewed in isolation as they are linked and will act in combination to compound a problem (summarised in Fig. 2-2):

![Diagram showing the relationship between Naïve Theories, Teaching, and Familiar Language.](image)

Figure 2-2
*Components of learning that may work together in the development of a misconception*

The anthropocentric nature of many naïve theories is understandable as the child uses the 'familiar' as a constant reference point. Teaching also tends to view natural processes from a human perspective, and this may have unexpected
consequences for children’s learning. A focus on starch as a product of photosynthesis (a common practical class being the ‘testing for starch in leaves’) may reflect an anthropocentric leaning within the curriculum. Starch is of particular interest because of its role in human nutrition. However, glucose, required as a substrate for respiration, and cellulose (and other structural carbohydrates forming plant cell walls), may be considered to be at least as important, particularly from the point of view of the plant. Yet glucose and cellulose are relatively neglected within photosynthesis, particularly in practical lessons. The example of starch and its emphasis within the school curriculum further exemplifies the way in which teaching can reinforce common misconceptions that are based on prior experience. The biological role of starch is confused when plant storage organs (such as potato tubers) that are rich in starch are described. Whilst practical experiments on leaves are designed to show that starch is only produced in the presence of sunlight and chlorophyll, it is clear that potato tubers lack both of these, but still manage to be rich in starch. The additional complication of phloem needs to be introduced to overcome this apparent anomaly. Additionally, an emphasis on the storage of starch may tend to confirm that it is not actually used by the plant (eg. for respiration) and may contribute to the idea that ‘only animals respire’.

2.1.5 Inadequate prerequisite knowledge.

If learning is to occur across the curriculum, then knowledge in one discipline must be carried across to another to avoid creating barriers to concept development. Material presented in the lower school years (particularly in chemistry an physics) may be seen as prerequisites to higher level studies in biology. For students to be able to understand the complexities of photosynthesis, Simpson and Arnold (1982a) have
identified four prerequisite concepts that they believe are essential. These are the concepts of 'living things', 'food', 'gases' and 'energy'. Whilst Bell, Barron and Stephenson (1985) identified four areas which presented specific learning difficulties: the concept of food; the relationship between glucose and starch; the role of energy in photosynthesis and students' understanding of the particulate nature of matter. The overlap in the findings of these two studies is self-evident. A general lack of knowledge about elements in living tissue (especially Carbon, Hydrogen and Oxygen), has been described by Stavy, Eisen and Yaakobi (1987) with students finding difficulty in recognising the link between the Carbon in carbon dioxide and the Carbon in carbohydrates (such as starch and cellulose). This is also highlights the difficulties students have with recognising 'gas' as a substance (in particular CO₂) as it has no apparent mass and so, within the students' framework, for example, cannot logically contribute to the mass of wood in a tree.

If the nature of matter is poorly understood, then natural cycles (such as the Carbon cycle) will be difficult to comprehend (eg. Helldén, 1995). In their study of ideas about the cycling of matter found in children, Leach, Driver, Scott and Wood-Robinson (1996) found little evidence that 16 year-old students differentiated matter from energy. Children often see food as being used up in the process of growth, but do not see it as actually contributing to the matter which makes up the body of the consumer. The cycling of matter and the flow of energy in ecosystems requires the application of physical science knowledge in a very complex context. Leach, Driver, Scott and Wood-Robinson (1996) speculate whether the students in their sample would differentiate between energy and matter more successfully in a physical science context. Such understanding may be context-specific so that an appreciation of matter and energy in physics may not be transferrable to the biological domain.
This may be compounded by biology teachers who describe the energy from the sun being ‘turned into’ starch (Jennison and Reiss, 1991). It would be better to describe the energy as being required to recombine the raw materials of water and carbon dioxide into carbohydrate and oxygen.

### 2.1.6 Lacking an overview

Stavy, Eisen and Yaakobi (1987) concluded from their study of secondary students’ understanding of photosynthesis that ‘students know many bits and pieces of information about photosynthesis, but they lack a meaningful and general view of it’. The organised arrangement of these components may prove to be the stumbling block for many students. As the separation and control of variables is a characteristic of formal thought, Simpson and Marek (1988) have stated that a full appreciation of the concept of food production in plants requires formal operations because students must separate, control and exclude variables to understand that water, carbon dioxide, light and chlorophyll must all be present before a plant can produce food. Water is particularly difficult for students to observe directly as a variable in the food making process as it is integral to so many other fundamental aspects of the plant’s life (water is key to the maintenance of cellular integrity, making its isolation and removal impossible). The other variables involved in photosynthesis can also be problematic for the student. Carbon dioxide cannot be seen and so its removal from an experimental system has, to a degree, be taken on trust, whilst the removal of light can give confusing results if students are left with etiolated seedlings (e.g. Smith and Anderson, 1984).

The scientifically acceptable ‘bits and pieces’ that are already incorporated into the student’s conceptual framework have been described by Clement, Zietsman
and Brown (1989) as 'anchoring conceptions' and defined as 'an intuitive knowledge structure that is in rough agreement with accepted scientific theory'. Whilst some students within a group may hold such anchoring conceptions, others may hold opposing misconceptions. Identification of such instances may indicate a suitable starting point upon which to build further instruction for individual students. Indeed, it has been shown that a failure to appreciate the prior knowledge that pupils bring to the topic may result in pupils reaching very different conclusions after a lesson to those anticipated by the teacher. Ultimately the pupils may fail to assimilate the goal concept as a result (eg. Smith and Anderson, 1984). Many of the points made in the preceding sections support the point that photosynthesis, and other areas of the curriculum, should not be treated as topics in isolation, but should be given a context if meaningful learning is to be achieved (Aleixandre, et al. 1996). The use of appropriate teaching methodologies is essential if this is to be achieved.
2.2 Conceptual change

2.2.1 Concept structure

Some of the theoretical questions that need to be addressed here include such basic problems as providing a definition for the term 'concept'. Various authors have given definitions from a variety of perspectives (eg. Novak, 1998; Thagard, 1993). It seems that there is little consensus in the literature regarding concept structure and conceptual change, highlighted by a recent special issue of the International Journal of Science Education (Stavy, 1998). In part, the problems associated with defining conceptual change arise from the lack of agreement on the nature of concept structures.

Komatsu (1992) and Eysenck & Keane (1995) give useful summaries of the development of theories of conceptual structure during the 1970s and 1980s. I have summarised the main points from these reviews in figure 2-3. Overall, the 'similarity-based views' of the 1970s gave way in the 1980s to a view emphasising the role of explanations and inferences. The latter is summarised by Keil (1989: 1) as a view in which:

concepts are construed as intrinsically relational sorts of things. They are not isolated entities connected only in the service of propositions. No individual concept can be understood without some understanding of how it relates to other concepts.

The importance of considering concept structure when describing conceptual change is stressed by diSessa and Sherin (1998:1155): ‘How one understands and describes the processes of conceptual change must flow from an account of the entities that are changing’. That concepts do change may be one of their defining characteristics. Concept instability has been described by Barsalou and Medin (1986: 189) in which they stress that ‘concepts, instead of being viewed as static definitions, should be viewed as dynamic, context-dependent representations’. 

2 - 14
Figure 2-3. Summary of the connections between emerging views of concept structure.

Based on Komatsu (1992) and Eysenck & Keane (1995).
Schaefer (1979) has shown that the level of understanding of the concept beneath a label is not constant and changes in the course of school education - related to the development of associated concepts. This suggests that the formation of helpful links with other concepts is vital for conceptual development. The quality of these links may have implications for 'concept stability'. If concepts are defined by the ways in which they are linked to and interact with other concepts (eg. Benlloch and Pozo, 1996), then concept maps, as reflectors of conceptual understanding (eg. Edwards and Fraser, 1983) would seem to be a good way of illustrating conceptual change both in terms of the overall framework and the quality of individual concepts (eg. Chi, 1997; Chi, Slotta and de Leeuw, 1994; Ferrari and Chi, 1998). Comparing sequences of such maps would also enable the observer to monitor changes in understanding rather simply provide a static assessment of learning at a particular time. While viewing concepts as a networked structure, Thagard (1993) has described several kinds of conceptual change (Table 2-1) which may contribute to a description of weak or strong restructuring and is elaborated below.

Table 2-1 Conceptual change

<table>
<thead>
<tr>
<th>Degrees of conceptual change</th>
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</thead>
<tbody>
<tr>
<td>1 Adding/deleting an instance</td>
</tr>
<tr>
<td>2 Adding a new weak rule</td>
</tr>
<tr>
<td>3 Adding a new strong rule</td>
</tr>
<tr>
<td>4 Adding a new part-relation</td>
</tr>
<tr>
<td>5 Adding a new kind-relation</td>
</tr>
<tr>
<td>6 Adding a new concept</td>
</tr>
<tr>
<td>7 Collapsing part of a kind hierarchy</td>
</tr>
<tr>
<td>8 Reorganising hierarchies by branch jumping</td>
</tr>
<tr>
<td>9 Changing the organising principle of a hierarchical tree</td>
</tr>
</tbody>
</table>

(After Thagard, 1993)
2.2.2 Conceptual development

A review of work describing the nature of knowledge change has been presented by Chinn and Brewer (1998) who recognise such changes as being of two dimensions, either ‘local’ or ‘global’. Local changes are seen as minor changes to a knowledge structure that involve:

a) Generalisation - applying a principle to a range of instances.
b) Specialisation - creating two conceptions where there was only one.
c) Addition - new knowledge is simply added to old.
d) Deletion - old knowledge is deleted or suppressed.
e) Exchange - a simultaneous addition and deletion.

Most of the changes described by Thagard (Table 2-1) would be regarded as local changes. Global changes are, predictably, seen as rather more complex. Chinn and Brewer (1998) recognise five ways in which new knowledge can be related to old knowledge:

1) **No new knowledge → Structured knowledge.**

   Requires that the mind starts as a clean slate (*tabula rasa*) onto which new knowledge is deposited. It is argued that when learning about phenomena that are ‘invisible’ in everyday life (e.g. cells or osmosis) then the student has no knowledge upon which to build.

2) **Fragmented knowledge → Structured knowledge.**

   Argues that naïve learners start out with a multitude of disconnected intuitions (*p-prims*) which are gradually refined to form a ‘structured whole’.
3) **Simple core knowledge → Elaborated knowledge.**

Learning simply elaborates and adds to core conceptions without changing them.

4) **Structured knowledge → Conceptually-consistent structured knowledge.**

A change in theory or understanding that does not require any change in explanatory concepts.

5) **Structured knowledge → Conceptually-inconsistent structured knowledge.**

Involves a major shift in underlying theories such that there is a fundamental change in key conceptions.

The relationship between local and global changes in knowledge is unclear and may be described with reference to changes in concept map structure. This is explored later in this thesis.

One of the most frequently cited papers within the literature on conceptual change is the influential work by Posner *et al.* (1982); providing a model of conceptual change. In this there is an implication that students' conceptions need to be exchanged for the new science conceptions. For this to occur, Posner *et al.* (1982) identified four prerequisite conditions: there must be dissatisfaction with currently held conceptions and that any new conception must be intelligible, initially plausible and fruitful.

In a later revision of this model, Strike and Posner (1992) accept that the interaction of prior conceptions and new conceptions was not sufficiently acknowledged and that their initial theory had placed too much emphasis on the rational and neglected affective and social issues. Their initial model has been strengthened by the inclusion of Toulmin's (1972) idea of a conceptual ecology.
(Strike and Posner, 1992). A conceptual ecology includes the learner’s epistemological commitments, metaphors, analogies, beliefs, competing conceptions and knowledge from outside the field - all of which influence conceptual change. Possible application of this notion to the work presented here is described below.

2.2.3 Conceptual ecology

Within science education it is widely perceived that prior knowledge is a key factor that influences learning, as summarised by Clifton and Slowiaczek (1981: 142):

Our ability to understand and remember new information critically depends upon what we already know and how our knowledge is organised.

However, such a presumption is not always evident when research is communicated to teachers. Whilst science curriculum reformers are often anxious to see teachers pay respect to students' constructions of science, it has been pointed out by Wallace and Louden (1998) that they fail to pay comparable respect to teachers' current constructions of teaching. This leads to the perception that research and practice are failing to interact, (eg. Kinchin 1998a), and is aggravated by misunderstandings in the use of specialist language and a failure to target the personal relevance of the material to the audience.

The literature concerned with conceptual development and conceptual change is littered with terminology that may be unfamiliar to many classroom teachers – reducing the possibility that it will influence classroom practice. This problem may be overcome by the use of analogies with which the teacher is familiar. In particular the analogy of ‘conceptual ecosystems’ within a conceptual-ecology-perspective may provide a foundation upon which to build understanding of the research literature. Toulmin (1972: 316) has indicated why such a pursuit may be fruitful:
What makes it worthwhile to extend ecological terminology from organic to intellectual evolution is, simply, the extensive parallels between the ecological account of organic change and the disciplinary account of intellectual development.

Watson (1986: 85) has suggested that, by extending the ecological metaphor, it is possible to evoke and describe a level of connectedness between biological and conceptual ecosystems that goes beyond simple comparison.

Concept mapping has been recognised as a powerful tool for helping teachers understand the notions of conceptual frameworks and the construction of knowledge (Shymansky et al., 1993). Similarly, the idea of a conceptual ecosystem is much easier to visualise if it is depicted graphically as a concept map. When this is done, a teacher of biology will intuitively make the comparison between ‘conceptual ecosystems’ and ‘biological ecosystems’.

Using the ‘teaching with analogies’ model developed by Glynn (1991), features of the analogue concept (biological ecosystems) are mapped against corresponding features of the target concept (conceptual ecosystems) in figure 2-4.

Descriptions of concepts given by other authors contribute to this analogy and help to strengthen the intuitive links between food webs and concept maps. For example, Pines (1985: 109) has stated that:

One might describe a specific concept as the hypothetical meeting place of all propositional relations in which that concept participates. There are an infinite number of such relations and a concept is a summary of all those relationships.

Whilst Hodson (1998: 52) has asserted that:

Concepts cannot be ‘evaluated’ separately from their relationships with other concepts and the roles they play within conceptual structures.
These views fit with the ‘explanation-based view’ of concept structure [described in section 2.2.1] and within a biological context, such comments resonate with descriptions of an ecological niche. Pintrich et al., (1993: 172) carry the analogy a little further in describing ‘competing ideas in a purposeful ecosystem of the mind’; where ideas compete for the same ‘conceptual niche’ and only the ‘fittest’ concepts survive. The development of such an analogy provides a whole new perspective to the application of concept maps in the analysis of conceptual frameworks.

There are also a number of parallels between the development of ecology and the development of the research perspective developed in this work [discussed in Chapter 5] For example, Watson (1986) has described how both conceptual ecosystems and biological ecosystems are all unique and, although limited generalisations can be
made about the nature of interactions within them, these have to be moderated by an acceptance that no two are identical.

Whilst the similarities between a concept map and a food web are evident, there are two fundamental differences that have been made explicit:

- Within a food web, all the entries can be viewed as being of equal status in that they are all organisms which interact with others in the ecosystem. In a concept map, however, entries occur at various levels of importance (ie. superordinate concepts above subordinate concepts).

- Within a food web, all the links have the same meaning (showing the flow of energy through an ecosystem), but in a concept map each link has a unique meaning which must be written on the linking arrow to avoid ambiguity.

Some authors now consider conceptual change not to be an exchange in which the initial conceptions are extinguished, but can include instances when two competing conceptions are held and applied (eg. Tyson et al., 1997, Taber, 2000a). Initial conceptions that hold explanatory power in non-scientific contexts may be held concurrently with new conceptions, even when the two are seen to be in conflict. Watson (1986) has commented that conceptual ecosystems may be colonised by a number of conceptions which may not be co-active, but which do co-exist in a relatively autonomous way. These conceptions fluctuate in their use within localised domains and are selected by the task context and the group dynamic. Such a systems view of concept frameworks necessarily colours one's view of misconceptions and their role in learning. A comparison of key features of the objectivist view of learning with the 'misconceptions view' and the 'systems view' are summarised in table 2-2.

The value of the conceptual ecology analogy is seen as two fold:
- Enhancing the understanding of conceptual systems by the application of established theoretical models of biological systems
- Enabling more effective communication of conceptual change research to practitioners through language that is familiar to teachers of biology.

Within the scientific community, there has been a debate between those who have advocated a holistic view of ecosystem ecology and those who have adopted a reductionist stance (outlined by McIntosh, 1985: 252 - 256). The debate concerns whether or not properties emerge at higher levels of organisation in such a way that the 'whole' is seen as more than the 'sum of the parts'. Such properties are seen as not being reducible to the parts and so need to be examined at the appropriate hierarchical level. Other authors have rejected such a polarised debate and claimed that it is not that a whole is more than the sum of the parts, but that the parts themselves are re-defined and re-created in the process of their interaction. In carrying this across as an analogy to conceptual ecosystems, it seems that some authors at least are promoting a holistic view when, for example, Smith et al. (1993) claim that strength is a property of conceptual [eco]systems, not of individual misconceptions (Table 2-2). It would, therefore, be interesting to find out if different frameworks (described by different concept map structures) that describe the same material exhibit different properties (re: stability and resilience). If such structures do show different properties, this may help to explain why researchers have found some misconceptions to be resistant to change whilst others are more amenable to it (eg. Newton, 2000).
Table 2-2 Comparing views of learning.

<table>
<thead>
<tr>
<th>OBJECTIVIST VIEW</th>
<th>MISCONCEPTIONS VIEW</th>
<th>[ECO]SYSTEMS VIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students come to class knowing little about the topic.</td>
<td>Misconceptions exist – students come to class with preconceptions that differ from scientific conceptions.</td>
<td>Novices answer conceptual questions incorrectly, but there is a great deal of continuity from novice to expert thinking.</td>
</tr>
<tr>
<td>Students may have some wrong facts gleaned from informal sources such as TV, friends and family.</td>
<td>Misconceptions originate in prior learning – classroom instruction or interactions with physical or social world.</td>
<td>Misconceptions result from the extension of productive prior knowledge.</td>
</tr>
<tr>
<td>Any wrong facts should disappear when the students learn the right facts - if presented in a clear and authoritative manner.</td>
<td>Misconceptions can be stable, widespread and resistant to change.</td>
<td>Misconceptions are not always resistant to change; strength is a property of conceptual [eco]systems, not of individual misconceptions</td>
</tr>
<tr>
<td>Students should recognise their wrong facts as such when they are taught the correct facts</td>
<td>Misconceptions interfere with learning expert concepts.</td>
<td>Students' prior conceptions provide the only starting point for instruction.</td>
</tr>
<tr>
<td>Emphasis should not be placed on the wrong facts, except to briefly point out that they are wrong.</td>
<td>Instruction must help students to replace their misconceptions</td>
<td>Instruction should help the student to appropriately extend their prior knowledge.</td>
</tr>
<tr>
<td>Instruction should focus on explaining the correct ideas in as clear a fashion as possible</td>
<td>Instruction should help students confront their misconceptions.</td>
<td>Instruction should help students fruitfully engage in the gradual process of systemic conceptual change or reorganization.</td>
</tr>
<tr>
<td>Research should focus on how to most clearly explain ideas.</td>
<td>Research should focus on uncovering misconceptions so that they can be confronted.</td>
<td>Research should focus on the evolution of students' ideas from root conceptions.</td>
</tr>
</tbody>
</table>

Based on Smith et al. (1993)
2.3 Constructivism

2.3.1 Characteristics

The constructivist stance has its origins in the neo-Piagetian theory, but has come to emphasise the importance of understanding the individualised learning process and the nature of conceptual change rather than the recognition of discrete developmental ‘mental stages’ (eg. Cobern, 1993). This led to the development of personal constructivism which has focused on the individual. Whilst having a major impact upon science education research, personal constructivists have been described as excessively rationalistic (eg. Posner et al., 1982). Perceptions of insufficient progress toward improved science instruction led some researchers to doubt the theoretical adequacy of personal constructivism, leading to a greater emphasis on the roles of language and social interaction within the classroom (eg. Solomon, 1987). This shift from personal to social/contextual constructivism has been paralleled by a complimentary shift from a dominantly quantitative research perspective towards a more qualitative appreciation.

As in organic evolution (where the arrival of more ‘advanced’ animal groups does not automatically announce the extinction of their predecessors), the evolution of the constructivist movement has seen some researchers maintain a ‘tenacious grip’ on existing viewpoints, and a hybridisation of ‘old’ and ‘new’ by others. In consequence, the term ‘constructivism’ is seen as having a range of meanings. This is a predictable consequence of the construction of meaning among a diverse research community.

The number of science education research articles concerned with constructivism (encompassing the range of traditions mentioned above) has been seen to exhibit a sharp increase over the past two decades (White, 1997), reflecting its growing dominance as a research philosophy (eg. Sandoval, 1995). Because
constructivism has been interpreted in various ways by different authors, it is
described as a 'heterogeneous movement' (Matthews, 1994: 139) that does not offer a
'unified perspective' (Schunk, 2000: 230). Schwandt (1998: 221) goes so far as to
say that as a general descriptor for a 'loosely coupled family of methodological and
philosophical persuasions, constructivism is best regarded as a "sensitizing concept"
to steer the reader'.

The constructivist epistemology has been summarised by Novak (1993) as
being based on the belief that from birth to senescence or death, individuals
continually construct and reconstruct the meaning of events and objects they observe.
Matthews (1994) has given an overview of the major traditions represented within
constructivism and this has been summarised and is presented in Figure 2-5. It is
psychological constructivism, (building on the work of Piaget), that has influenced
science education and the elements presented within the shaded section of Fig. 2-5
that have been most influential in this work.

It is worth noting here that Matthew's overview omits the work on personal
construct theory (PCT) by Kelly (1955) even though this has been seen to be an
important influence on constructivist science education in the U.K., particularly
through the work of Ros Driver (eg. Driver and Easley 1978; Driver and Erickson,
1983), and in the USA through the work of the Human Constructivists [described
below]. One of the defining features of PCT is regarded as being its explicit valuing
of the active, anticipatory nature of the meaning-making process, with Kelly
envisioning people as architects of their own learning (eg. Pfenninger and Klion,
1994).
CONSTRUCTIVISM

two major traditions

PSYCHOLOGICAL
CONSTRUCTIVISM

builds on

SOCIOLOGICAL
CONSTRUCTIVISM

originating with

Emile
Durkheim

emphasising:
extra-individual
social factors

Figure 2-5.
A summary of the major traditions represented under
the constructivist heading (based on Matthews, 1994).
The shaded area represents the elements that have
most informed this work.

STUDIES OF
MISCONCEPTIONS

'alternative
frameworks'

SOCIAL

developed by

Vygotsky

emphasising:
language
scaffolding by
others
(ZPD)

PIAGETIAN
MODEL

split by emphasis

HUMAN
CONSTRUCTIVISM

emphasising:
meaning making
shared
understanding
active teaching

PERSONAL

developed by

Von Glaserfeld

emphasising:
individual creation
history & culture
relativism
no extra-experiential
reality
2.3.2 Human Constructivism

Human Constructivism (sensu Mintzes, Wandersee and Novak, 1997; 1998) has been described as a synthesis that attempts to integrate the psychology of human learning and the epistemology of knowledge production (Novak, 1993). It acknowledges the influence of the other authors including Kelly (1955); Toulmin (1972) and Vygotsky (1978), and a particularly close relationship with Ausubel’s (1963; 1968) Assimilation Theory (eg. Novak, 1981b; 1984). The appeal of Ausubel’s work has been described by West and Fensham (1974) as providing educational theory that does not require extrapolation from non-human learning or from the learning by humans of nonsense content. It also benefits from Ausubel’s focus on real classroom situations, thus providing ecological validity for his focus on the role of prior knowledge in future meaningful learning (eg. Mintzes, 1979). The essence of Human Constructivism can be outlined in three key assertions:

a) Human beings are meaning makers. From a very early age, the human brain endeavours to construct order from apparent chaos. The desire to form meaningful patterns is considered by some authors to be an innate characteristic of children in which emotion, personal relevance and context are seen as contributing factors (eg. Jensen, 1998).

b) The [a] goal of education is the construction of shared meanings. This allows a community of learners (students and teachers) to exchange ideas within a common framework of understanding.

c) Shared meanings may be facilitated by the active intervention of well-prepared teachers. Such preparedness refers not only to subject expertise, but also to an appreciation of the students’ perspectives on the world.
Whilst I have considered various components of previous educational research which may give an appearance of a set of apparently disjointed elements, these elements are seen to relate with one another, and only reveal their significance when seen in the context of the other elements. In consequence, many parallels can be drawn across the elements described in this chapter. For example, just as conceptual change has developed from a reductionist view towards a more holistic (or ecological) appreciation, so constructivism is also perceived at different levels of resolution:

Whilst personal constructivism is the anatomy and physiology of constructivism, contextual constructivism is the ecology (Cobern, 1993: 66).

An ecological view of constructivism provides a parallel to the ecological view of conceptual change that is explored in this work.

2.3.3 Criticisms

Critics of constructivism have paid particular attention to the notion of 'relativism' (eg. Phillips, 1995; Osborne, 1996) that could damage both science and education by promoting 'a view of science that its practitioners would not recognise as true' (Harding and Hare, 2000: 234). Harding and Hare (2000: 226) suggest that 'open-minded realism' provides a compromise between the ideals of education and the realities of science. Science teachers operate simultaneously in both worlds and so are required to straddle the two philosophies.

The critics of constructivism have acknowledged some positive contributions that it has made to science education, in particular:

- Fostering the development of innovation in science education.
- Increasing teachers' awareness of learners' perspectives.
• Raising the profile of epistemological issues in discussions on teaching and learning.

• Highlighting the role of misconceptions in science education


2.3.4 Constructivism in practice

Reports in the literature describe the advantages of a constructivist approach to the teaching of biology, including improvements in test results, student attitudes and student enjoyment of the subject (eg. Yager, 1995; Lord, 1997). Constructivist teaching is characterised by a number of steps:

1. **Orientation**: to arouse interest and set the scene.

2. **Elicitation of ideas**: to enable pupils and teachers to become aware of their prior ideas.

3. **Restructuring of ideas**:
   i/ **Clarification and exchange**: recognise alternative ideas and critically examine own.
   ii/ **Exposure to conflict**: Test validity of existing ideas.
   iii/ **Construction of new ideas**: Modify, extend or replace existing ideas.
   iv/ **Evaluation**: Test validity of newly constructed ideas.

4. **Application of ideas**: reinforcement of constructed ideas in familiar and novel situations.

5. **Review**: awareness of change of ideas, familiarisation with the learning process and reflection upon change.

(eg. Driver and Oldham, 1986; Needham and Hill, 1987).
Implicit in much of the work that has been built upon this scheme, is the assumption that pupils need their ideas to be replaced (as in 3 iii/ above) with more scientific ones. This is seen as rather negative by Reiss (1993: 39) who prefers the assumption that:

all pupils come to science lessons with ways of thinking that have so far served them well. The aim of the science lesson would then be to enable pupils to see why their thinking often works, and to allow those pupils who want to, to develop their thinking.

This is supported by longitudinal studies of students’ understanding (eg. Helldén, 2000) which demonstrated a strong element of personal continuity and is in line with the ecosystemic view of conceptual change summarized in Table 2-2.

As teachers do not have much time in their daily routine for reflection upon their practice, Newton et al. (1999) claim that the term ‘constructivism’ is probably more descriptive of what teachers do than of what they think, with good teachers exploiting this approach successfully and intuitively (Von Glaserfeld, 1989: 138). This is supported by the data gained from the exploratory questionnaire (summarised in Table 1-1) in which the majority of respondents were not familiar with the terminology. General characteristics of a constructivist teacher have been offered by Watts and Jofili (1998), suggesting that such teachers:

1) value quality of learning over quantity, and place the focus on the learner rather than the subject discipline.

2) interact with learners closely in order to enhance social interactions, provide a range of meaningful experiences for each learner, help learners explicate and elaborate their own prior knowledge.

3) take a variety of roles in order to monitor and evaluate learning, and then constrain and structure learning environments to challenge what they see as

2 - 31
learners’ non-viable constructs, and to channel learning in productive directions through the negotiation of knowledge between knower and known.

4) encourage a plural, tentative and contingent view of scientific knowledge.

However, because covering a curriculum and testing children on the information that has been transmitted are fundamental to the practical realities of teaching in schools, constructivism can be seen as generating issues that interfere with the traditionally fundamental goal of teaching (Russell, 1993). Russell goes on to say (ibid, 251) that: ‘Society wants genuine understanding and students who love to learn and value lifelong learning, yet it imposes conditions that make those goals unattainable’.

Constructivist theory has been described as providing teachers with a new set of theoretical or conceptual ‘lenses’ can be empowering, but it also complicates their lives. Prawat (1992) warns that teachers are unlikely to complicate their lives in this way without undergoing a significant change in their thinking. Such change is likely to take time, as:

Like students’ knowledge of science, teachers’ knowledge of constructivist science teaching is likely to grow through slow and gradual reformation of their established understanding of classroom theory and practice.

(Louden and Wallace, 1994).

Mechanisms that can ease this process for teachers could have a major impact on typical classroom practice. The exploration of concept mapping described later on in this thesis may offer such a mechanism.

2.4 Collaborative learning

2.4.1 The setting

The increased popularity of collaborative group work as an instructional strategy within the sciences has been described by Jones and Carter (1998). They
view this growth as a parallel to a perceived shift in the focus of educators from an individual (Piagetian) perspective towards a wider social (Vygotskian) perspective. This appears to be an active area for current research, reflected in the number of recently published reports examining the structure and value of students’ conversations and subsequent learning outcomes when working in groups in formal and informal settings and at various levels of education (eg. English and Lewis, 1997; Mason, 1996; Mueller, 1997; Okada and Simon, 1997; Rafal, 1996; Richmond and Striley, 1996; Tunnicliffe, 1996a; 1996b; Woodruff and Meyer, 1997). This suggests a general perception within the research community of the need for a greater understanding of this area of teaching.

Previous authors have suggested that the exchange of ideas in small groups promotes the development of complex conceptions (eg. Driver, 1987) and that students who vocalise during problem-solving were more successful in concept attainment than were students who did not vocalise (eg. Durling and Schick, 1976). The mechanism for improved performances in group work has not been widely investigated in the sciences, though Okada and Simon (1997) suggested that pairs of students were more successful at discovering scientific laws than students working alone because they participated more actively in entertaining hypotheses and considering alternative ideas.

Group work is widely used in science teaching, with calls in the literature to increase its implementation in the classroom (eg. Lazarowitz et al., 1994). The possible impact of concept mapping within such strategies has been explored by few authors (eg. Sizmur and Osborne, 1997; Roth and Roychoudhury, 1992; 1994), with studies concentrating on the quality of the discourse generated between students as a result of collaborative mapping activities.
2.4.2 Group composition

It has been stated by Blumenfeld et al. (1996: 39) that ‘The mix of achievement levels, race and ethnicity, and gender influences how students interact, who benefits and whether students actually engage in serious thought’. Other studies have also shown that the composition of collaborative groups to be an important factor for consideration (eg. Gilbert and Pope, 1986; Howe, 1990). English and Lewis (1997) suggest that qualitatively different forms of collaborative processes take place in cross-sex and same-sex groups. Some studies having deliberately focused on single sex environments to ‘eliminate the noise of gender differences’ (eg. Rafal, 1996: 281), because it was believed that in general terms, girls tend to communicate in a more collaborative style, whereas boys tend to be more competitive or adversarial. Webb (1989) also found the development of high level elaboration to be dependent upon the composition of the group, particularly for 'medium-ability' students.

Similar studies have deliberately arranged students in mixed-ability groups as it was believed that this provides better learning opportunities for all students (eg. Mueller, 1997). If differences between group members’ ‘abilities’ are maximised, this may generate a greater level of ‘cognitive conflict’ within student interactions. This will act as a stimulant for the promotion of conceptual development (eg. Mugny and Doise, 1978; Thorley and Treagust, 1987). However, if the ability range within a group is too wide, it is suggested by Blumenfeld et al. (1996) that middle-ability students, in particular, will benefit less.

The potential difficulty generated by the inequalities in participation among high- and low-status members of co-operative groups has been recognised by Rafal (1996). To overcome differences in the status of individuals, Bianchini (1997: 1044) allocated roles to group members (facilitator, materials manager, reporter, recorder
and harmonizer), as an attempt to prevent such inequalities from becoming a potential barrier to learning. Hirokawa and Johnston (1989: 515) went further to explain that ‘the individual must recognise whether others generally view him or her as a superior or as a subordinate and must structure the message to conform to that general perception’. Rafal, (1996: 291) also gives the reminder that ‘small groups occur in a larger social and academic context, embedded within a history of relations’. The group should not, therefore, be viewed in isolation, but seen in the context of the whole class. Just as some individuals within a group may be perceived by their peers as being of ‘high’ or ‘low’ status, some entire groups may also be working under similar implicit or explicit labels given to them by other groups in the class or by the teacher.

The presence or absence of group or individual incentives have been considered by other authors (eg. Watson and Marshall, 1995), inviting the question, ‘what do pupils perceive the purpose of the activity to be?’. Classroom innovations have been seen to encourage improvements from common patterns of classroom talk (eg. Sizmur and Osborne, 1997) though this might not subsequently translate into better classroom performance (eg. Lumpe and Staver, 1995; Wood and O’Malley, 1996).

2.4.3 Wider implications of collaborative learning

In their study on collaborative concept mapping, Sizmur and Osborne (1997:1125) make the point that ‘collaborative exchanges were more likely to result in a link in the concept map compatible with canonical scientific meaning’, but fail to elaborate upon this point in terms of its social implications. Their remark supports the assertion by Mayberry (1998: 444) that a collaborative teaching style is a ‘socially
reproductive pedagogy which can have the effect of reproducing the dominant discourse of existing science systems’ - along with all its stereotypes, prejudices and biases. This is particularly considered to be the case when insufficient guidance is offered to the group (Linn and Burbules, 1993). The biases revealed are considered by some authors to ‘exploit and oppress ... in the name of a dominant class’ - namely white, middle-class males (Maher, 1998: 461). This view can be seen as a challenge to the value some authors have placed on collaborative learning, and is briefly acknowledged here by reference to the relevant body of literature (reviewed recently by Mayberry, 1998). Analysis of cross-cultural differences may also be of interest as Tudge (1990:156) points out that ‘learning unfolds in the direction of culturally appropriate practices’. In a multicultural collaborative group, the direction of learning may be more ambiguous. Blumenfeld, et al. (1996) suggest that students from ethnic minorities can often be presumed to be less competent by their ethnic majority peers, leading them to be excluded from conversations within mixed groups. It would, therefore, be interesting to know if ethnicity influenced individual’s participation within their group. The lack of ethnic diversity in the schools available for this study mean that it is not possible to pursue this line of enquiry here.

Research into students conceptual change, the role of misconceptions in learning and possible contributions that can be made by constructivist methodologies raises many questions. One of the biggest problems is gaining access to the structure of understanding that is used by students and teachers. With this in mind, concept mapping has been increasingly used as an investigatory tool, particularly in science education. The literature describing the uses of concept mapping is described in Chapter 3.
3.1 Introduction

The National Curriculum documentation that summarises the material to be presented to students in England and Wales gives an impression that biology consists of a series of separate chunks of information (Education and Training Board of the Institute of Biology, 1998). This may strip the subject of some of its richness by masking the context of the material and by losing meaning if links to associated concepts are not made explicit. The burden then rests on teachers to highlight such links in the development of a departmental scheme of work so that students can appreciate biology as an interconnected body of knowledge. In attempting to promote the development of a cohesive view of knowledge, Shambaugh (1995: 8) describes the classroom use of a range of visual tools to provide a mechanism to aid the construction of understanding and states:

"This approach adopts the belief that true knowledge and understanding can be developed in the learner and by the learner through the transformation of fragmented, compartmentalised bits of knowledge into knowledge of personalised meanings."

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# elements from this chapter have been accepted for publication as:

The development and sharing of personalised meaning is a goal of the approach to teaching and learning embodied within Human Constructivism (Mintzes, Wandersee and Novak, 1997; 1998), as outlined in Chapter 2.

There are various visual construction devices or 'graphic organisers' available for use in the classroom (eg. Bromley et al., 1995). Such tools help students to visualise how major ideas are related to: (a) their own prior knowledge; (b) subordinate ideas; (c) associated ideas from other topic areas (Tarquin and Walker, 1997). With specific reference to science education, the range of graphic organisers has been reviewed by Trowbridge and Wandersee (1998) and Hamer et al. (1998). Each of these devices has their own strengths and weaknesses, but it is concept mapping as developed by Novak (1990; 1995; 1996; 1998) about which the literature has been so consistently positive. This technique is explicitly grounded in David Ausubel's assimilation theory of learning, of which the central idea is that of meaningful learning (described in Novak, 1981b; 1984). In this the student is required to make a conscious effort to identify the key concepts in new knowledge and relate them to concepts in his/her existing knowledge structure.

Concept mapping is a highly flexible tool that can be adapted for use by almost any group of learners. The standard presentation (described here) can be modified to include colour-coding of different concept types; grouping of concept types or using variously shaped concept boxes to help students with special needs (eg, Adamczyk et al, 1994; McIntosh, 1995; Wallace et al., 1998); or creating three dimensional map structures as mobiles or cones to facilitate discussions or the creation of concept mapping games (eg. Kinchin 1999b).
AMMALS can be INVERTEBRATE I I VERTEBRATE most are can be COLD WARM ARTHROPODS BLOODED BLOODED can be insulated with TERRESTRIAL MARINE FUR FEATHERS eg. beetles eg. crabs eg. sheep eg. robins flies lobsters cats penguins

**Figure 3-1**

*Hierarchical concept map of 'animals'.*

An example of a ‘traditional’ concept map format is given in figure 3-1. The concepts are written in boxes and linked by labelled arrows. The most inclusive concepts appear towards the top of the map with more subordinate concepts towards the bottom. Where possible, these are anchored with specific examples. Whilst each concept can only appear in one place on the map, it may be linked to any number of others. The map in Figure 3-1 has been drawn in a way that emphasises the hierarchical nature of the ideas described.

In general, the research literature demonstrates reluctance to highlight any problems associated with concept mapping. Hodson (1998) notes that some students may wish to conceal some aspects of their understanding and so their maps would not provide ‘total insight’ to the students’ perspectives.
One possible source of confusion for biologists is that concept maps look very similar to ecological food webs, but there are two important differences that need to be emphasised:

1) in a food web all the entries can be viewed as being of equal status in that they are all organisms which interact with others in the ecosystem. In a concept map, however, entries occur at various levels of importance (i.e. superordinate concepts above subordinate concepts).

2) in a food web all the links have the same meaning (i.e. showing the flow of energy through an ecosystem and often interpreted in class as ‘... is eaten by...’), but in a concept map each link has a unique meaning which must be written on the connecting arrow to avoid ambiguity.

The use of concept maps could be applied to various stages of the teaching/learning process, including planning and preparation; classroom learning; revision/summarising and assessment:

3.2 Planning and preparation

It has been shown that the planning of instructional sequences can be helped by the use of concept mapping by providing a coherent structure to the materials and making essential links explicit (eg. Martin, 1994; Cliburn, 1986). This may be particularly helpful in cases where ‘non-specialists’ (ie chemists or physicists) are teaching biology as they may appreciate the support offered by a ‘more expert’ colleague’s concept map.

Mapping can be used to break down a course into different levels of complexity (Figure 3-2). In this way one group of major concepts can be viewed to provide an overall framework (A-D), smaller concepts can be considered when...
organising a particular lesson sequence (E-G) and specific concepts can be considered to help explain a particular idea (H-J).

In planning for the future, evaluation of what has gone before is an essential part of planning what is to come. The use of concept mapping for evaluating teaching programmes has been demonstrated by Thomson (1997). In such planning and evaluation, it is helpful to view materials at different levels of magnification (Fig. 3-2).

In summary, Martin (1994: 27-28) gave the following advantages to be gained by this approach to lesson preparation:

- Increased meaning of the material for the teacher
- Ownership of the material by the teachers
- Increased concept integration
- Decreased likelihood of omitting key material
- Increased capacity to meet student needs through recognising students' perceptions of the material
- Increased likelihood that teachers will see multiple ways of constructing meaning
Figure 3-2

Focusing on the different levels of concepts in a course from overall framework (A-D) to fine detail (H-J).
Following from this, Martin (1994) viewed concept mapping to be a viable agent for curriculum change. This would put teachers in the position of being ‘active innovators’ rather than the ‘passive receivers of innovation’ that has been the implicit assumption of so many recent educational reforms.

3.3 A classroom learning tool

Previous studies have suggested that the use of concept mapping in class can help students to gain a more unified understanding of a topic; organise their knowledge for more effective problem solving and also to help them understand how they learn (ie. become more metacognitively aware) eg. Arnaudin et al. (1984). In addition, it has been suggested that the promotion of meaningful learning resulting from concept mapping can also act to reduce subject-based anxiety and help to overcome differential gender-related performance with respect to learning and achievement in science (Jegede et al., 1990).

Concept mapping can also be used as a cognitive approach to compensate when a learner exhibits a one-sided learning strategy (Huai, 1997). Concept maps may provide an indicator of a student’s learning approach for a given context (Fig. 3-3).

Rayner and Riding (1997: 21) have speculated that:

‘The idea that ‘style awareness’ may help reach the ‘hard to teach’, and perhaps contribute to reducing failure generally by enhancing the learning process, is an elusive but tantalising prospect which clearly merits further attention’.

The most widely recognised and accepted dimension of learning style is described as holist (=wholist) → serialist (=analyst) (reviewed by Adey et al., 1999). Holists like to get an overview of what is to be learned and to reach a conclusion based on the ‘big picture’ whilst serialists tend to look at the details, bit by bit. Huai (1997) suggests that for ‘holists’, who have a ‘global approach’, concept mapping can
help the learner to focus on critical details, whereas, 'serialists' can be stimulated to take a wider perspective. Students who gain most from concept mapping may be those identified by Silverman (1989) as 'visual-spatial learners', who excel when provided with visual representations. Such students reject rote memorisation and have a need to see how the parts relate to the whole before they can make sense of isolated ideas.

In describing the value of concept mapping, Schmid and Telaro (1990: 78) have commented that:

'Biology is so difficult to learn because it consists of a myriad of unfamiliar concepts involving complex relations. The schools' favored approach to teaching unfamiliar material is rote learning. Rote learning predictably fails in the face of multilevel, complex interactions involved in biology. Concept mapping ... stresses meaningful learning, and appears to be ideally suited to address biological content.'

Figure 3-3

*Holists and serialists*
Class contact time is the critical learning time when the act of concept mapping is most likely to influence exchanges about the work and, therefore, have greatest impact on the learning process as this is the time when students can talk to each other and to their teacher about the materials to be learned. Within the class, concept mapping can have various functions:

### 3.3.1 Revealing/activating prior knowledge.

Prior knowledge is seen as an important factor in students' learning. West and Fensham (1974: 62) comment that:

> Despite the obviousness of prior knowledge as a major factor in learning science and its wide acceptance intuitively by science teachers, they proceed to ignore it in so much of their regular practices.

Ausubel recommended the use of introductory materials that support learning by activating relevant existing knowledge; this is often termed an "advance Organiser". The idea is that this will prepare the way for more effective learning by making the students (and teachers) aware of what they already know in a given topic area.

Advance organisers are thought to enhance learning in the sciences by:

- Providing an overview
- Providing reference points for organisation
- Providing cues for what to look for
- Directing students to look for relationships
- Providing a succinct review
- Providing graphic elements that help in the construction of a framework of vocabulary and concepts

(Hawk, 1986: 86).

The use of concept maps as advance organisers has been shown to contribute to the points highlighted above (eg. Willerman and Mac Harg, 1991; Hirumi and Bowers, 1991). However, within the classroom it is possible that teachers may simply
present their students with a concept map to use as an advance organiser which may be viewed by the class as 'the right answer' to memorise. This is not seen as the point of a concept map - it is intended rather to reveal the personal perceptions of the map’s author (Jonassen et al., 1997). Memorisation would be taking learning away from a constructivist standpoint and away from the active use of concept mapping towards a more passive reproduction of received information. This highlights the difference between using ‘concept maps’ to summarise information and using ‘concept mapping’ as a learning activity. This dichotomy is significant and indicative of different teaching philosophies: lessons that use teacher-produced maps are generally expository and product-centred, while those that feature a student concept mapping approach tend to be process-orientated, focusing on the students’ construction of meaning (Cliburn, 1990). Only in the former is the constructivist philosophy implicit.

Figure 3-4
A concept map used as an advance organiser.

3 - 10
The map in Figure 3-4 is an example of an advance organiser suitable for a Year 8 class. This map summarises a section from a student textbook (Johnson et al., 1994) in which a number of related topics are considered. This helps students navigate through a section of their book and recognise the links between ideas. It can also act as a revision guide for an end of topic test (the inclusion of page numbers helps in exploring some ideas in more detail). The map includes general ideas (such as ‘heart’). During the course of instruction, students would generate more specific concept maps to explain the details within these areas. As the students become more familiar with the use of concept maps in this way, it would be anticipated that subsequent advance organisers would be presented with gaps so that the students would have to work out more of the connections for themselves.

3.3.2 Identifying misconceptions

The importance of student misconceptions and the impact they have on further learning has been described in Chapter 2. In a large proportion of the studies reported, concept mapping has been used as the tool to reveal students’ misconceptions. Many such misconceptions are so common among students of any given age group that they may be anticipated.

In addition, it is clear that similar misconceptions contain variations in detail. As Chi et al., (1994: 37) have noted, ‘even though the false beliefs of a significant minority of students may share similar elements, they are not the same beliefs’. For example, regarding plant acquisition of food from the soil, some students were including minerals as food items (based on their understanding of the components of a balanced diet), while others were considering carbohydrates (which they thought were released from decaying animal remains in the soil as part of the Carbon Cycle).
Concept mapping is able to reveal the detail of individual misconceptions in this way so that teachers can address each one in an appropriate manner.

An explicit description of the potential of concept maps as tools to identify students' biological misconceptions has been offered by Abrams and Wandersee (1992). They make the analogy that just as doctors learn to read x-rays to diagnose medical problems, science educators must learn to interpret concept maps in order to help their students to regain 'conceptual health'.

3.3.3 Directing reading.

Concept mapping has been referred to by Novak and Symington (1982) as providing an interface between students' cognitive frameworks and text summaries (summarised in Fig. 3-5).

![Diagram of concept mapping](image)

**Figure 3-5.**

*A cycle in which concept mapping is seen to act as an interface between hierarchical cognitive structures and linear sequences presented in text or as lectures (Modified from Novak and Symington, 1982).*
Novak and Symington (1982: 8) emphasise that:

'The problem of moving from linear [text] structure to a hierarchical [psychological] structure and back again is in some ways the fundamental educational problem.'

Concept mapping can help to move reading from a passive experience towards one that is more active and requires the student to manipulate or transform the material to be read. Davies and Greene (1984: 24) describe the way in which teachers are often vague in their instructions when setting reading tasks. This is particularly problematic when tasks are to be completed for homework, when teacher support is not available and when:

'reading purposes are no more specific than 'read these pages/chapter for revision or a test' or 'make notes from this section'. Giving a general instruction like this is analogous to giving pupils a general instruction to do an experiment without any indication of the particular purpose of the experiment or of how to go about doing it'.

Concept mapping of biology texts also shows that organisation of key concepts can vary from one book to another (eg. Soyibo, 1995b). Such an analysis reveals ‘defects’ in texts, described by Soyibo as a) misconceptions, b) misleading terms and c) inexplicit elaboration. However, even when everyone in a class is reading the same textbook, there seems little guarantee that they are all focusing on the same information or constructing the same understanding from it.

In a concept mapping analysis of interpretations of text from a GCSE biology textbook, Kearsey (1998) concluded that it is not safe to assume that the meaning or structure of the text are shared by teacher and student. Kearsey (1998: 11) went on to say, 'If teachers require there to be consensus on meaning within teaching situations, they must provide students with experiences which enable a consensus to be reached based on the individualistic readings of text'. The use of concept maps as advance organisers (described above) may be of value in guiding students through text; signposting key concepts and showing connections between them, whilst
student-produced maps which function as text summaries will help gauge understanding. Slotte and Lonka (1999: 516) have commented that ‘students need to challenge the science text they read by struggling with it and trying to make sense of the subject matter. They do this by selecting and organising relevant information and making links between concepts’. Concept mapping may help in this process and is thought to be more effective than other reading strategies (such as underlining) because it requires students to process text at a deeper level (Amer, 1994).

3.3.4 Focusing discussion.

Concept mapping can be used as a focus for a class discussion. Selected concepts from the students’ textbook can be printed on to clear acetate sheet and cut up so that they can be moved around an OHP screen and projected. Students can suggest where concepts should go in relation to the others and may be asked to justify their decision (ie. suggest a link with another concept). In this way a class may eventually reach a consensus. If linking arrows are included, but linking statements omitted, the students have the freedom to personalise their map with their own links, but still have an ‘agreed core’ when they copy it into their notes (Fig. 3-6).

Those students who completed this task quickly were then asked to build upon this core by including other ideas from their textbook or from their own knowledge (such as ‘toothpaste’ or ‘dentist’) and deciding how they link with other concepts. This, therefore, became a differentiated activity in which everyone in the class was stretched to their ability, but was also set an achievable goal.
Figure 3-6
An ‘agreed core’ for a concept map on teeth, developed from a class discussion and with gaps for students to add their own linking phrases.

The benefit of focusing on a map during a discussion is that it reduces strain on the working memory of the participants. As agreement on various statements within a developing map change, students can still ‘see’ where their ideas fit in with the group consensus. To support discussions among smaller groups, the use of sticky ‘Post-It Notes® has a number of benefits (Weisenberg, 1997). They allow individuals to think out part of a map on their own and then later integrate their ideas with those produced by their colleagues without having to re-write everything. Sticky notelets also allow for repeated repositioning of concepts on a map, permitting reflection on the differing perspectives presented by various group members.
3.3.5 Differentiation for collaborative learning

In the literature on collaborative learning, most studies are in agreement that group composition is one of the key factors affecting successful group dynamics (eg. Wood and O’Malley, 1996). The literature describes a trade-off between creating groups where individuals bring different perspectives to the task, but without creating a counter-productive situation where learners within a group are labelled as ‘more-able’ and ‘less-able’ [Chapter 2]. The formation of heterogeneous groups, based primarily upon quantitative differences used to compute ‘base scores’ constructed from achievement test results (eg. Jonassen and Grabowski, 1993). Detail of such a scheme has been described by Stahl (1996). However, the regularity and reliability of such test scores and their relevance to a particular topic for collaborative enquiry must be in some doubt. This also conflicts with the view of ‘real learning’ on which Reinsmith (1993) makes the claim (often repeated by teachers) that tests are poor indicators of understanding. Therefore, to found group structure on an average of a series of poor indicators seems to make little sense. This method also fails to reflect the diversity of materials (and skills required to master them) under the umbrella of biology. For example, a student who does well in a series of tests on theoretical genetics may or may not subsequently perform at the same level in a module on practical ecology, due to issues of ability or motivation. Test scores would, therefore, be poor predictors of future performance in collaborative groups. In addition, it should be noted that it is not only ability that determines effectiveness of a group member - the possession of good communication skills and a willingness to participate are equally as important.
3.4 Revision / summarising

Concept maps are seen as excellent summary / revision tools in which large amounts of information can be condensed. There are few published revision aids that have taken a concept-mapping approach, with exceptions being the study guide written by Taylor (1993) which uses completed maps as summaries, and the book of exercises produced by Burggraf (1998) in which mapping blanks are provided for students to complete. As revision is largely conducted as a solitary and unsupervised activity, research into the use of concept maps in this context is not described in the literature. It would be difficult to ensure any standardisation in the use of the concept maps by students for experimental comparison.

One possible use is to provide evidence of revision in the form of a map of the work to be learned. The creation of such a map forces students to revise actively and to manipulate the information to be learned. Many of the students I have talked to during my teaching have told me that their main revision strategy is to read through their notes and hope to absorb information. This leaves no evidence of the effort that has been made. With students producing a revision concept map to be handed in, the teacher is getting much more information about each of his/her student’s performance than would be gained from a test mark alone. Mistakes in the test might be picked up as misconceptions or gaps in the concept map. Discrepancies between test scores and concept map quality might also highlight the relationship between effort and achievement and may be indicative of the student’s learning style:

'A poor concept map coupled with reasonable performance on a test of detail suggests that this student's learning may be rote, and hence that knowledge will soon be lost'.

White and Gunstone (1992: 36)
3.5 Assessment

A number of authors have suggested the use of concept maps for assessment and several problems and issues have been highlighted and reviewed, including the reliability of scoring schemes and their classroom practicality (e.g., Stow, 1997; Campbell, 1999; Rafferty and Fleschner, 1993; Liu and Hinchey, 1996; Ruiz-Primo and Shavelson, 1996; Rice et al., 1998).

Many of the scoring protocols that have been applied to concept maps have been derived from that given by Novak and Gowin (1984). This is summarised in figure 3-7. In their perceptive introduction to concept mapping, White and Gunstone (1992) see concept maps as being more suitable for use as a teaching tool than as a tool for summative assessment of students' performance. They go so far as to say that 'giving any form of grade to a map can alter students' attitudes to them and so threaten their potential to promote learning' (ibid.:38).

Some authors have suggested evaluating student maps by reference to a teacher-produced or 'expert' map (e.g., Dorough and Rye 1997). However, whilst this is appealing for its apparent simplicity, there are some problems associated with this approach which can be illustrated by reference to the hypothetical example given in Figure 3-8. The map in Figure 3-8a is a possible 'expert' map showing a basic framework that a teacher might hope for his/her Year 9 students to have at the end of a lesson sequence on photosynthesis. This could be viewed as a 'base-line' upon which student could later develop their knowledge and add more concepts.
Scoring for this model:

- Relationships (if valid) = 14
- Hierarchy (if valid) = 20
- Cross links (if valid and significant) = 20
- Examples (if valid) = 4

58 points total

Figure 3-7
Scoring model for concept maps (redrawn from Novak and Gowin, 1984)
The map in Figure 3-8a is also shown reduced to a list of the ten propositions embedded within it. Student maps could then be marked according to how many of these propositions are incorporated in them - so that a student with five of these propositions would score 50%; six would score 60% and so on.

However, if one marks the map in Figure 3-8b in this way, the teacher has to decide what to acknowledge and what to ignore. If the teacher is only looking for propositions from his/her own map, then the map is awarded 30% (for propositions 1 - 3). If, however, credit is given for other sensible ideas within the map, then the score jumps to 110% (for propositions 1 - 11). On the positive side, it can be seen that students can score more than 100% (by having more propositions than the expert map) and this would have a strong motivating effect. On the negative side, it can be imagined that a student could score 100% or more with a map that contained none of the propositions in the teacher's map. This may give a false impression of achievement. The scorer also has to decide whether or not to deduct marks for factually incorrect propositions (propositions 12 and 13, reducing the score here to 90%). This could reduce a student’s score to zero if enough incorrect propositions were included, even though some excellent ideas may also be represented. If pre-instructional maps were scored in this way, all three scores may be of interest and could be used to compare a student’s ‘before’ and ‘after’ understanding of a topic and indicate the degree of convergence (or divergence!) between the students’ views and the teacher’s view. It can be seen that even a straightforward comparison such as that presented in Figure 3-8 presents the teacher with some dilemmas (or opportunities!) which may deter him/her from quantitative scoring of concept maps altogether.
Figure 3-8
A possible expert map of photosynthesis (a) compared with a hypothetical student's map (b) (scored according to propositions presented – as described in text)
The literature concerning the use of concept maps as assessment tools has been reviewed recently by Edmondson (2000). From her review a picture emerges of a technique that has some potential for summative assessment of student understanding, particularly if the focus is on a particular element such as link quality. Assignment of an overall summative grade is less helpful and does not pin-point misunderstanding any more effectively than other forms of testing. The real value of concept mapping seems to be in providing formative feedback that can promote reflection upon the material to be learned and to focus discussion. It is here that further research would be valuable in developing mechanisms to facilitate such feedback and make it more effective.

3.6 Attitudes towards concept mapping

It has been found that when they are first introduced to concept mapping, the attitudes of teachers (Okebukola, 1992), and students (Taber, 1994) are generally positive. Though some negativity should be anticipated if students are suddenly given more responsibility for their own learning during concept mapping exercises than they are used to. A number of teachers had commented to me that most of their students prefer to be 'spoon fed' rather than having to work out problems for themselves and that many students were concerned with producing the 'right answer' rather than displaying what they do or do not know, either in a concept map or by any other means.

The constructivist stance values and builds upon students' prior knowledge, but must also recognise students' existing study strategies as these also form part of a student's knowledge framework. A lack of recognition of a student's existing strategy may cause problems if meaningful learning is not part of their agenda:
'some students who are whizzes at rote memorization object to concept maps, for rote learning has little value in concept mapping'.


Other students may be learning meaningfully already and may be employing strategies similar to concept mapping, possibly subconsciously. One teacher I interviewed commented that it was not helpful ‘trying to overlay something on a process that they were doing already’. This point has been recognised recently by Slotte and Lonka (1999:515) who stated that ‘it is possible that the instructions given by researchers limit or interfere with students’ customary approach to learning’. Views of the teachers involved in my own work reflect the comments in the literature that it is preferable to introduce concept mapping earlier in a student’s academic career rather than later so they can more easily integrate it into their developing study strategy (eg. Santhanam et al, 1998), and that students who tend to embrace the use of concept mapping are those whose study habits are not already well-defined (Carter, 1998).

3.7 Focussed reflection

For concept mapping to provide maximum benefit to the learner, it would seem sensible that the mapping activities should be integrated with a variety of other classroom methods (eg. Francisco et al., 1998). It is not sufficient to simply ‘tack on’ a concept mapping exercise to a ‘traditionally objectivist’ lesson sequence and hope that the students will somehow gain some benefit from it. A combination of learning cycles (Marek and Cavallo, 1997) and concept mapping is recommended by Odom and Kelly (1998) as this provides both the concrete experiences and cognitive structure that are required for meaningful learning to occur. Lahtinen et al. (1997:14) make the assumption that:
‘more generative study strategies [including concept mapping] produce qualitatively better learning, because of the internal connections between idea units and current knowledge. ‘Generative processing’ refers to the degree to which the learner is able to actively build these connections’.

The problem is that traditional testing does not often expose such connections and so the value of such learning may not be registered or recorded. In responding to this, Hyerle (1996) has called for a shift in the focus of future teaching, learning and assessment away from remembering ‘isolated things’ towards a recognition of ‘how students interactively construct the pattern that connects’.

Like all teaching tools, concept mapping is not a panacea; it will not suit all learners or all learning situations. However, concept mapping may encourage teachers to question their teaching and to reflect upon their students’ learning. This in itself may provide long term benefits to their classroom environment by encouraging in them development of the characteristics of learner empowerment as discussed by Cannella and Reiff (1994); these are inquisitiveness, enthusiasm, reflection and autonomy.

An aspect of concept mapping in which there has so far been little research is the effect of its classroom use on in-service teachers’ beliefs and practices. Jones et al. (1998: 983) found from their study of in-service teachers that students can have a powerful effect on teachers’ conceptualizations of science topics. They concluded that:

Examining students’ naïve conceptions and ideas appeared to free teachers from their self-consciousness and allowed them to look closely at their own conceptual understandings.

Teachers have participated in considerable change over the past decade, but the personal detail of teachers’ experiences of transition is known largely from anecdotal evidence, Studies display a lack of understanding of how changes in teachers’
understanding come about or what the consequences are (Desforges, 1995). Lasley et al. (1998: 129) have commented upon this:

'We know that people can and do change when innovations are introduced, but we have much yet to learn about the 'history' that develops as teachers begin to practice new ideas and reflect on their own growth.'

It is possible that a constructivist application of concept mapping as a classroom tool may act as a catalyst to promote such personal reflection and also (through teachers' maps) provide a means of accessing 'developing histories'. Such an approach respects the constructivist philosophy and recognises that effective teachers are also active learners (sensu Shymansky, 1992). The use of concept mapping as a tool to widen the perspective of teacher reflection has been explored by Leino (1996) who found that it also has the effect of revitalising creativity among participants when considering curriculum development. While investigating methods to promote critical reflection among science teachers, Nichols et al. (1997: 86 – 87) found that mapping activities provide:

'teachers opportunities to critically reflect on their referents for science teaching, justify their visions of practicing science teaching, and construct alternative ideas about science teaching and learning – possibly leading to a changed set of referents upon which they will base their teaching practices.'

3.8 The need for further exploration

Concept mapping is presented in the literature as a versatile tool with considerable potential to support teaching and learning in science classrooms. However, it would appear that teachers with whom I have had contact have not exploited this potential. There seems a need to identify barriers that prevent its use and to establish possible classroom applications that may overcome or circumvent such barriers. Specific questions for research are given in Chapter 4.
4.1 Research Question

Concept mapping (a constructivist educational tool) has been widely used as a means of researching the naïve misconceptions of school pupils, particularly with reference to science education. However, its use in day-to-day teaching and learning is less well documented. The focus of this work is, therefore, the research of concept mapping techniques as a method for promoting meaningful learning in the classroom.

The central question can be written simply as:

How can concept mapping be used to contribute to understanding?

Such a focus will tend to be applied and practitioner-based and a variety of other questions logically follow, such as:

\[ a) \text{ what is the impact of concept mapping when it is used privately or individually by learners?} \]

\[ b) \text{ what is the impact of concept mapping when used in social, collaborative groups?} \]

Similarly, how can concept mapping provide teachers with descriptive and evaluative representations of students' understanding so that their teaching can be focused by:

\[ c) \text{ quantitative evaluation of maps} \]

\[ d) \text{ qualitative description of maps} \]

Testing such a method relative to classroom practice requires a comparative analysis against other indicators of performance to investigate:
e) how does concept mapping evaluation compare with other assessment procedures such as test scores.

The use of concept maps may also provide a method for monitoring the dynamic nature of conceptual change by looking and categorising factors that contribute to:

f) overall map quality / concept quality / link quality.

Answers to these questions may help to develop approaches to teaching and learning that will promote meaningful learning aided by well-informed teaching.

4.2 Assumptions

Implicit in the central research question are the assumptions that:

a) concept maps are a useful reflection of a learner’s conceptual framework

b) the use of concept maps can, in some way, enhance learning.

c) meaningful learning has more value than rote learning.

There is a considerable research literature dealing with concept mapping (considered in Chapter 3) which is overwhelmingly positive in its conclusions regarding the value of the technique. Typical is the comment by Sizmur (1996b: 75) that it is difficult to escape the conclusion that ‘concept mapping can have a positive effect on learning in science’. Sizmur goes on (like many authors in recent years) to cite the meta-analysis by Horton et al. (1993) as providing evidence that the technique is somehow an intrinsically good and worthwhile activity that promotes learning in the secondary science classroom. Whilst I have no quarrel with the general findings of those authors, I feel the need for caution in generalising too much from such a study. Whilst Horton et al. (1993) considered 113 studies for inclusion in their review, only 18 met their designated criteria of: a) occurring in classrooms; b) comparing quantitatively measured outcomes for treatment classes with outcomes for control classes and c)
including sufficient data to calculate an effect size. Of the 18 that satisfied these
criteria, some were considered to be influenced by ‘novelty’ or ‘Hawthorne’ effects
whilst others only considered maps produced by teachers. Of those remaining, only
three were concerned with biology and published in educational journals (Lehman et
al., 1985; Heinze-Fry and Novak, 1990; Schmid and Telaro, 1990). These might be
considered as the most significant studies from Horton’s meta-analysis in terms of
supporting this work. When viewed in this way, the supporting literature seems quite
small. However, further studies published since Horton et al. (1993) have continued
to demonstrate the positive influence of concept mapping on classroom learning –
contributing to the context of the study. From this brief discussion, it can be seen that
there is a need to:

treat the literature not as an authority to be deferred to, but as a useful but
fallible source of ideas about what’s going on.

Maxwell (1996: 27)

The value of this supporting literature will be re-appraised in the light of this study’s
findings in Chapter 7.

4.3 Methods evolution

Whilst there are numerous recognised methodological approaches for
educational research, reviews tend to make the implicit assumption that the
methodology within a given research project will be ‘fixed’ at the outset - typical of
the ‘hard science’ approach (eg. Keeves, 1998). Consequently, they do not address the
issue of the ‘evolution of methods’. Within the qualitative research tradition, revision
of research questions during a study is seen as proof that post hoc analysis is working
effectively by discovering subtleties and contingencies that could not have been
foreseen when the study was undertaken (eg. Erickson, 1998). This leads to a
reformulation or refocusing of the research question. Such a change may also require
a re-orientation in terms of methods. The most appropriate approach to address the initial question may not be the most appropriate for subsequent questions. Additionally, research often fills a need in the researcher for personal change (eg. Reason and Marshall, 1987) and could be considered as one of the criteria for the success of a research project. Such a change in a major component of the research process will have an impact on the overall ‘environment for research’, making an evolution of methods within a project to be a likely occurrence.

The notion of an ‘emergent design’ is seen as a necessary element of a constructivist inquiry by Guba and Lincoln (1989: 175). They elaborate upon this and go on to say that:

Constructivists are unwilling to assume that they know enough ... to know what questions to ask. Constructivists typically enter the frame as learners, not claiming to know pre-ordinately what is salient.

This is compatible with the Human Constructivist stance that underlies this work. Whilst different phases of this work may be categorised as essentially ‘quantitative’ or ‘qualitative’ this should not obscure the underlying transition that represents a ‘grounded approach’. This approach uses different ‘slices of data’ to provide various ‘vantage points’ as a means of methodological triangulation (Taber, 2000b: 470). The iterative nature of such a research process means that such accounts may not follow the traditional distinctions between methods, results and conclusions that are expected in objectivist studies. For example, the instruments described in Chapter 5 (such as the qualitative typology for concept map description) are both an outcome of the research process and an instrument for data collection in the same study – something that is not unusual in a study adopting a grounded approach (eg. Taber, 2000b).

If the outcome of the quantitative analysis is viewed in isolation through the perspective generated by the objectivist, science paradigm, it may be considered to be
disappointing as the analysis failed to confirm any statistical advantage conferred by
concept mapping activities. However, from a constructivist perspective, the
quantitative phase has been an essential starting point for the research and wholly
successful for the following reasons:

- It has stimulated personal reflection on my own epistemological beliefs.
- It has permitted a point of contact with science teachers who might otherwise have
  been hostile towards an unfamiliar approach.
- It has illustrated the extent of the diversity of learning approaches and learning
  pathways that may occur within an ecologically valid classroom and their
  incompatibility with descriptions of ‘trends’ or ‘averages’.
- It has generated material that has stimulated the evolution of the qualitative phase.
  This evolution could not have happened without starting at a point within my own
  conceptual ecology and so demonstrates an authentic constructivist methodology.
- It has permitted an informed re-appraisal of the ‘scientific paradigm research
  literature’ on concept mapping from an alternative perspective.

4.4 Reading this thesis

Discussion of the literature on the value of prior knowledge [Chapter 2] and of
concept mapping studies into students’ reading of scientific text [Chapter 3] shows
how an individual’s understanding depends on the structure of the reader’s existing
conceptual ecology [Chapter 2]. Reading of this thesis is no different. Readers will
take different views on this work depending on the links that are made to their
existing frameworks of understanding.

In trying to communicate this thesis, I have to acknowledge (and try to
accommodate) a variety of possible readers’ perspectives along a range of continua;
from objectivist to constructivist and from ‘change-resistant to ‘change-ready’. In a
reciprocal acknowledgement, the reader needs to appreciate my change in perspective along this continuum during the course of this research. This is reflected upon in Chapter 5, and explains the evolution of experimental designs [mentioned above and described in detail in Chapter 6]. The final writing of the thesis is from a constructivist standpoint.

Where participants' concept maps are included, they have been redrawn for clarity, but original spellings and (as far as possible) topologies have been retained. Where the reader is referred to other parts of this thesis, square brackets [ ] have been used. References to the literature are enclosed in round ( ) brackets.
5.1 The researcher

5.1.1 Why consider the researcher?

As the researcher is considered by many commentators as the primary instrument for data collection and analysis (e.g. Merriam, 1988), a description of the researcher's professional and academic background is outlined in the following sections. This research was focused initially on the students who were the subjects of the classroom interventions that I had designed. However, while reflecting on this work, it became clear to me that my own views were being influenced. The process of research in which I was engaged was overturning many of my preconceptions about teaching and learning and the research process itself. This reflects the comment made by Reason and Marshall (1987:112) that 'the motivation to do research is personal and often expresses needs for personal

# elements from this chapter have been accepted for publication as:

development, change and learning'. This personal change process is described below and is put into the context of the body of literature that has informed it. The literature has at times been a catalyst for questioning, but more often has been 'discovered' after the initial thought processes have occurred and been used to support and develop ideas. Figure 5.1 shows the processes of cognitive development and change that were both consequences and drivers of this research and constitutes a summary of this section of the thesis.

The autobiographical nature of part of this section is reminiscent of what Maxwell (1996:29) refers to as a 'researcher experience memo'. It is included to illustrate the influence of the researcher's background on the development of this piece of work, and in turn the impact of the work upon the researcher's beliefs. ‘Belief’ is referred to here sensu Chiou (1995: 48) as ‘an experience-based and knowledge-based meta-conceptual structure’ in which education is grounded. It is hoped that the reader will see the relevance of this discussion and not regard it as an indulgent opportunity for self-citation, as that was not the intention in writing. Coming from an objectivist science background where consideration of ‘self’ is not seen as either appropriate or relevant, such a personal examination has been an exploration of foreign territory.

From a constructivist viewpoint, it is clear that my past experiences as a teacher and a researcher of biology would have an influence on this research. They could not be blocked out and so I could not be a neutral observer of the data gathered which could realistically only be used to inform my existing prejudices.
Figure 5.1 – A concept map explaining the 'role of the researcher' and the process of cognitive change that was a consequence of this research.

1 = Starting point for this research
A recognition of the origins of one’s developing perceptions is seen by some as a vital step in research design:

My subjectivity is the basis for the story that I am able to tell. It makes me who I am as a person and as a researcher, equipping me with the perspectives and insights that shape all that I do as a researcher, from the selection of topics clear through to the emphasis I make in my writing. (Glesne and Peshkin, 1992: 104)

I see its inclusion here as a strength of this thesis, as a more complete account of the research process can be offered than is customary in ‘sanitised versions of scientific report writing’, and is, therefore a move towards ‘strong objectivity’, as considered by Pidgeon and Henwood (1997). My previously held ideas, or ‘experiential data’ (Strauss, 1987) would either be built on and developed or overturned in favour of new ideas that offered greater utility. My starting point for this research was, therefore, constrained by my personal views of science and of teaching (ie. the structure and extent of my personal conceptual ecology – see 2.2.3). Rogers (1993: 199) makes the point that ‘we all build maps, pictures, paradigms, what you will, of reality and that these control our approaches to learning’. The realisation that there could be another view was for me (as it was for Phelps, 1994), challenging a comfortable paradigm. It is probably because this challenge arose from intrinsic dissatisfaction, rather than being imposed from an extrinsic source, that it was acknowledged and initiated a chain of events leading to the production of this thesis.

Within a constructivist enquiry, where the emergent design is grounded in the data that guide its evolution, human beings are considered, by Guba and Lincoln (1989) to be the instrument of choice. This is because they represent a highly adaptable instrument that can enter a context without prior programming,
but can after a short period begin to discern what is salient and then focus on that. Changes recorded in the researcher are analogous to development and refinement of other research instruments. These [other] instruments and their development are explained in detail in parts 5.3 - 5.5 of this chapter. The links between the elements that comprise section 5.1 are summarised in Fig. 5.1.

5.1.2 Teaching experience.

After 12 years spent in the classroom (between 1984 - 1997), I was aware of a feeling of growing personal dissatisfaction with my own performance as a teacher. I felt that so much of my energy was being diverted towards peripheral concerns that were a distraction from my efforts in the classroom. Such frustrations are echoed by Hughes (1997; 65):

As a profession we spend many hours in meetings and talk about a great many things. Some are worthwhile, many are clearly not. Somehow it seems we manage to find time to discuss whether children should be allowed to wear overcoats in corridors or eat in their form room, but never seem to get around to discussing really important issues such as 'how children learn' or 'effective teaching strategies.'

This conflict between core and peripheral concerns seems to result, in part, from the differing priorities derived from the varying perspectives of those who influence teaching from outside of the classroom (e.g. headteachers, governors and parents) in comparison with those of the classroom teachers. This has been described by Spector (1984) in terms of 'role theory'. In this, role conflict occurs when the demands placed on teachers interfere with classroom goals. Spector's (1984) report about the American experience and published in my first year of teaching, seems to be of equal relevance to the UK situation now (a decade and a half later), suggesting a continuing lack of effective dialogue between curriculum
innovators and classroom teachers.

Concerns about my teaching could be divided into two broad categories:

a) Personal issues related to my own performance and teaching style, including:

i/ concerns over my perceptions of emphasis on the quantity rather than the quality of learning that took place in my classroom. To me this seemed to be most pronounced in A-Level classes where students were required to digest an enormous volume of information, but without studying any topic in sufficient depth to recognise its significance beyond the immediate curriculum demands.

ii/ awareness of dissatisfaction among students who considered that science classes did not put any value on creativity or on students' personal perspectives. Traditionally science departments have encultured students in the standardised presentation of laboratory work (i.e. methods-results-conclusions) and deviations from this are seen by some as heretical. A view echoed by Jones (1992) who expressed surprise at the perception of science described by an A-Level student who resented the constraints imposed on his work and interpreted this as creating an environment that generated a lack of intellectual stimulation.

iii/ an awareness that while some students were attaining good grades, they were able to give 'correct answers' without really demonstrating an appreciation of the subject or the interconnected nature of the scientific disciplines. In other words, they were good at playing the 'exam game' without becoming committed biologists, by adopting surface learning approaches – particularly rote memorisation. Gott and Johnson (1999) have suggested that the curriculum is based on progression of complex recall and has, therefore, been designed to be learnt by rote. The teachers’ goal of aiming for students to engage
in the subject by adopting deep learning approaches was not supported by the curriculum and its methods of assessment.

iv/ I was becoming less convinced that time spent on practical sessions was contributing as much towards the students' learning as I always assumed. Similar concerns have been expressed recently in a book edited by Wellington (1998). Even when practical work is focused and appropriate, it seems students find it difficult to separate the 'noise' of the classroom procedures from the 'signal' of the underlying message (Johnstone, 1991). Hodson (1996) has pointed out that students who hold different frameworks of meaning essentially conduct different investigations, make different interpretations and achieve different learning outcomes - even when the students' learning agenda are in line with the teacher's expectations. When students hold different agenda, the chances of meaningful learning are reduced (Anderson and Lee, 1997) - procrastination at the lab bench is seen by students as offering an escape from 'real work', ie. writing up. It is also clear from comments made in the literature that there is a wider perception that all is not well in school laboratories, summed up by Nott (1996: 86):

.. if it works in physics it's a miracle, if it works in chemistry it's pure and if it works in biology it's probably a fix!

b) Issues where imposed constraints were affecting my teaching, including:

i/ I could see that by applying National Curriculum criteria, I was having to award students of widely differing talents and abilities the same level of attainment.

ii/ National Curriculum documentation (DfE, 1995) placed
emphasis on what was taught rather than what was learned.

iii/ The presentation of the National Curriculum for science appeared as an apparently unconnected listing of materials to be taught - a concern echoed by the Education and Training Board of the Institute of Biology (1998), which describes the programmes of study as reinforcing the idea of separate chunks of learning. These chunks are scattered throughout (at least) three levels of thought recognised by Johnstone (1991) to occur in biology: macro; micro and biochemical. It is probably justified to add a fourth level - 'global' - as students are frequently expected to recognise the global significance of various biochemical and chemical reactions.

iv/ I was also concerned about the relevance of what was being taught; a concern which I had expressed earlier (Kinchin, 1993a). I considered that 'relevant' was often confused in teaching materials with 'mundane' and also that relevance is a personal issue - it is not the same for everyone and so is difficult to generalise. Where students do not recognise such personal relevance they fail to connect with the curriculum. In this context, Johnstone (1991) describes much of the content of formal school science as 'non-events' that are evaluated by students' responses to 'non-questions'.

All of these factors contributed to my dissatisfaction with my own experience of teaching, and frustration at the general situation in which I found myself. Before I began the research reported in this thesis, I was questioning my role as a science teacher; dissatisfaction was a starting point of enquiry (see Figure 5.1).

These points are summarised in Table 5.1. and correspond to a number of types of role conflict described by Spector (1984).
Table 5.1 Teaching concerns

<table>
<thead>
<tr>
<th>Personal Issues</th>
<th>Imposed Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity vs. quality of learning</td>
<td>Poor recognition of student achievement</td>
</tr>
<tr>
<td>Student dissatisfaction (creativity vs. compliance)</td>
<td>N.C. emphasis on teaching not learning</td>
</tr>
<tr>
<td>Grades vs. appreciation of the subject</td>
<td>Poor connections across the curriculum</td>
</tr>
<tr>
<td>Unproductive practicals (recipe following)</td>
<td>Relevance vs. 'non-events' (personal Relevance)</td>
</tr>
</tbody>
</table>

I recognise that ‘personal issues’ and ‘imposed constrains’ are not mutually exclusive categories as impositions will affect teaching style. Typically, my experiences suggested that a greater workload pushes teachers towards a more didactic, teacher-centred approach for fear of not completing the course.

Van Leuven (1997: 261) makes the comment that ‘preservice teachers typically enter teacher preparation programs believing that teaching is telling and that learning is reproducing what the teacher says’. Prawat (1992) has summarised it as ‘transmission teaching’ and ‘absorption learning’, and it is this model which predominates among new and experienced teachers within English and Welsh classrooms (Hacker and Rowe, 1997). I have certainly been guilty of this in my own teaching, even if the telling has been delivered through a polished or stimulating ‘performance’. In a damning indictment of such practice, Bodner (1994: 873) goes so far as to say that we can teach, and teach well, without having the students learn.

Consideration of such issues had been a long time in gestation, and when
stated in this way, may appear to be obvious to someone looking in from the 
outside. Providing an ‘outsider’s view’, an unnamed Chinese scholar is cited by
Su et al (1994) and describes American science education in the following way:

They use a content-mastery approach to science, which is
organised around discrete topics with little attempt to make
connections across topics. Some of the hands-on-activities and teacher
demonstrations are often added because they are easy to do or fun
rather than for their usefulness in developing conceptual
understanding.

My own experience is that such a view is as relevant to the U.K. today as it was in
the U.S.A. in 1994.

5.1.3 Previous research experience.

During six of my twelve years in the classroom, I was also undertaking
part-time study in zoology leading towards the award of an MPhil (Kinchin,
1993b). During this, and my previous studies in biological sciences, I had adopted
a view of science that I would now recognise as ‘objectivist’ or ‘positivist’ (eg.
Nott and Wellington, 1993). This was emphasised in the frontispiece of the book
that developed from the research (Kinchin, 1994) in a quote attributed to Sir Isaac
Newton:

I do not know what I may appear to the world, but to myself I
seem to have been a boy playing on the seashore, and diverting myself
in now and then finding a smoother pebble or a prettier shell than
ordinary, while the great ocean of truth lay all undiscovered before
me.

This Newtonian view of science certainly represented my own thoughts.
However, even within certain chapters of that book, there are signs that a
straightforward Newtonian search for truth was not sufficient to explain the work
described. In the chapter entitled ‘Origins and Systematics’ it was clear that
‘interpretation’ was as important as ‘evidence’. The chapter described how
various authors attempted to 'construct' an evolutionary history of a group of animals (the tardigrades) from the available fragments of evidence. As a result, divergent views and 'opposing camps' were able to develop - supposedly searching for the same truth. I recently explored the implications of this for the field of invertebrate zoology and concluded that 'the implicit epistemological beliefs of the most influential members of an academic community will have implications for the direction of development of that field of enquiry' and that 'an inflexible epistemological stance may prove to be an impediment to advancement' (Kinchin, 2000: 250). I now suspect that this is equally true for the field of science education.

When investigating how biological knowledge grows, Abrams and Wandersee (1995) demonstrated what they referred to as a 'biphilosophical’ view of science among the researchers within their interview sample. Their interviewees tended to be traditionally objectivist, assuming that science would ultimately learn the 'truth' about natural phenomena, but adopted a more constructivist stance with respect to controversial issues until their field reached a stable consensus. During the period of developmental instability, observers tend to align themselves with whichever view appears to offer them the greatest utility. What is not clear is at what point the shift from one paradigm to the other (constructivist to objectivist) actually takes place. Indeed, this may be such a gradual process that to pin-point a critical moment may be impossible. With the benefit of hindsight, a particular event may be seen to have acted as the catalyst for change. That such a shift can occur so seamlessly as a common place event in the development of a branch of knowledge should allay possible fears among 'objectivist scientists' that the 'constructivist science educators' have got it
wrong. A fixed, objectivist view of knowledge may even be an impediment to the
cognitive development of the next generation of scientists. It can be argued that
such ‘conceptual revolutions’ are a necessary part of the development of scientific
understanding. (eg. Thagard, 1993) and that teaching people to be scientists
should include helping them to understand the conceptual frameworks within
which they operate. The objectivist ‘straitjacket’ to understanding may need to be
overcome for a new discovery to be made.

As students may switch from one conceptual framework to another (re:
Palmer, 1999) so professional scientists may switch from one epistemological
stance to another depending upon the context. Thus a dynamic tension is
established in which in certain contexts the social construction of understanding
and establishment of a consensus view is accepted whilst at other times, the
unshakeable truth of ‘scientific fact’ is seen as a reliable foundation upon which
to confidently build further understanding. Despite the apparent harmonious co-
existence of these two views as described by Abrams and Wandersee (1995), it is
considered by other observers that one necessarily challenges the other, giving
rise to what Selley (1996) calls conflicting types of science education.

Examination of the literature on constructivism in science education
[considered in Chap 2] initiated a period of self-reflection concerning my own
classroom practice. I found a number of areas where my own feelings overlapped
with the published views - particularly the ‘Human Constructivist’ views
developed by Mintzes, et al. (1997; 1998). This enabled me to articulate my own
views that had been developing on my teaching, but for which I had previously
lacked an appropriate vocabulary. As Davis et al. (1993: 633) point out,
‘Teachers may believe that change is necessary but never take any steps to change
because they lack alternative images'. Once I had the time to examine the research literature, I was able to explore the range of 'alternative images' of teaching and learning that was described. This made me realise that others in my situation had experienced similar anxieties about the quality of classroom practice and added to my frustration that such issues were not a point for discussion in schools. I was, therefore, drawn to the conclusion that there was a barrier between research and practice (argued by Kinchin, 1998a), a barrier I wished to break in my research.

5.1.4 Curriculum innovation.

From my own experience of trying to disseminate innovative teaching ideas through the practitioner journals, particularly the School Science Review and the Journal of Biological Education, I realised (from feedback from colleagues and from teachers' workshops) that this was probably only influencing a minority of teachers. For example, after I published accounts of the uses of urban habitats for the teaching of ecology (Kinchin, 1986a; 1986b; 1988) a subsequent survey suggested little impact on teaching preferences. Use of the suggested materials was still minimal in comparison with use of more traditional materials (Kinchin, 1993c). This was not altogether surprising. White (1998: 55) has noted that 'teachers do not reject research, they ignore it'. If, however, the most widely-read journals aimed at practitioners were having little influence on classroom practice, it seemed highly unlikely that the less-accessible research literature would be having any direct effect on more fundamental issues. If teachers were reluctant to experiment with novel teaching ideas that did not generate any philosophical conflict (simply describing 'new' materials to teach familiar concepts), then it
seemed likely to me that work which challenged 'core beliefs' about the nature of science, teaching and learning may well be dismissed out of hand. This could have led me to reject the prospect of three years out of teaching to complete a thesis that no other teacher might read. However, I also began to question the very approach I had taken. Perhaps the work I had done (eg. on urban ecology) was neglected not because teachers were not interested in my examples of innovative practice, but because I had 'missed the point'. Perhaps other teachers were questioning the philosophy that supported what they were doing and rejected my 'quick fix' solutions because they did little to address teachers’ real needs and concerns. Maybe the challenging of 'core beliefs' was exactly what was needed and so if I tried to explore this, my work could be of interest to others in a similar position to my own.

Returning briefly to the theme of urban ecology, I argued that this approach offers a number of clearly demonstrable advantages over the traditional study of, for example, rocky shores and woodlands. I suspect many teachers were not motivated to adopt unfamiliar teaching vehicles to simply illustrate 'key concepts' or 'ecological processes'. It would seem that they were (and perhaps continue to be) working to an alternative agenda which may have been student- or teacher-centred and included the following:

- teachers were keen for the opportunity to take students on fieldwork away from the school environment for an ‘extended dialogue’ in the language of science. The data used by Kinchin (1993c) showed that proximity to the study habitat was not an issue with some schools situated on the coast, but still driving across country to visit other, more favoured coastal sites. It seems the ‘need to get away’ is a
powerful force in the design of fieldwork.

- 'processes' (which can be explained in class) were seen as secondary to learning numerous examples (eg. naming Algae on rocky shores) which are only available for first-hand examination in the field. This needs to be done in a field situation that is familiar to the teacher - who probably did much of his/her field biology on rocky shores and in woodlands.

I conclude this argument (and critique of my stance as a practising science teacher in the 1980s and 1990s) by stating that I think my approach had validity (as does similar work by others who have looked for novel and innovative ways of teaching conventional and respected parts of the science curriculum). However, I also think that work on urban ecology would have been more widely adopted if I had demonstrated a more complete understanding of the issues, agenda, priorities and anxieties among the teachers in the target audience. It is precisely this understanding of a world view or context that has become a focus of my interest and is perhaps part of my contribution to the dialogue concerning the very philosophy and real needs and concerns of teachers. As Sarason (1990: 99) states:

> ideas whose time has come are no guarantee that we know how to capitalize on the opportunities, because the process of implementation requires an understanding of the settings in which these ideas have to take root.

A practitioner's inside knowledge of the teaching community is therefore essential to enabling effective 'marketing' of a classroom innovation. This shows that locating relevance, is important not only to promote meaningful learning in students but also for meaningful curriculum innovation. Others appear to agree, for example Hoyle (1973) commented that:
The most fundamental form of innovation is the transformation of teachers. All other forms of innovation - in materials, pupil-groupings and so forth - are often dependent for their success upon a shift in the values of teachers.

Though there has been considerable change imposed upon teachers in the U.K. over the past decade or so, this has tended to cast practitioners in a role, described by Prawat (1992: 355) as 'passive receivers of innovation' - a role which is at odds with the constructivist perspective taken in this work and by many advocates of educational reform (Wallace and Louden, 1998). Where teachers' beliefs are not consistent with those implicit in an innovation, a teacher may reconstruct the innovation and its associated beliefs to match his or her own beliefs, thus making the innovation more familiar or practical to the teacher (Briscoe, 1996). The nature of the innovation may therefore be so fundamentally corrupted that 'reality' and 'intention' do not correspond.

Context and change have become core to my interest in better understanding good science teaching and the question of 'locating relevance' is central to the approach I have come to adopt. Teachers cannot be assumed to represent an homogenous group with respect to their willingness or need for change and development. Lasley et al. (1998) describe teachers as 'change-ready' or 'change-resistant', but even within the 'change-ready' group in their study, no single process or trajectory of change was clear:

We know that people can and do change when innovations are introduced, but we have much yet to learn about the 'history' that develops as teachers begin to practice new ideas and reflect on their own growth.

(Lasley et al., 1998: 129).

It is also clear that teachers have a number of strategies for avoiding change, including adopting the language of change, but retaining their old behaviour (Nicholls, 1997).
5.1.5 Expressing a personal view.

In trying to identify the structure and origins of my own views along a continuum of possible epistemologies, I have begun to develop my position in relation to the teaching of innovative areas of biology (eg. Kinchin, 1999a). This reflects the view that teachers must be viewed as changing adults who vary in their constructions of teaching and learning, as put forward by Glickman (1985). However, this also contributed to an internal tension in which I felt my own developing views were probably at odds with many of my biology-teacher-colleagues. These colleagues may hold more objectivist views of science and tend to adopt transmission styles of teaching. It has been pointed out by Prawat (1992: 354) that ‘constructivist approaches to teaching and learning, which many reformers advocate, are inconsistent with much of what teachers believe’. Such beliefs are generated from prior experience, but:

> teachers may not have had experiences within their own education that would foster learning empowerment. These individuals would have difficulty understanding teaching models that do not fit their own constructions of learning.

Cannella and Reiff (1994: 30)

Therefore, views I expressed publicly regarding teachers and students as co-learners in a constructivist classroom environment (eg. Kinchin 1999a) were presented in a subtle and understated fashion, otherwise I felt that they might be deemed unacceptable to the ‘practitioner press’ and its readership. A recognition of what Louden and Wallace (1990; 1994) call the ‘constructivist paradox’ followed. I gradually realised that I was beginning covertly to view the teachers involved as the major learners in the classrooms involved in this research.
However, I considered this could not be easily articulated without being perceived as a threat by my teacher-colleagues. The expressed aims of my research were to investigate teaching and learning in the classroom - implying learning by students rather than by teachers. Any shift in this focus might have been viewed as dishonest and caused the alienation of those with whom I was working. The interviews conducted with some teacher-participants with whom I was collaborating in the research suggested that the views of at least some may have mirrored my own more directly than I had assumed in considering the mismatch between constructivist goals and classroom reality (eg. Appendix 3). Subsequent references in my published work to ‘teacher empowerment’ have been consequently more explicit. Such concerns (re: constructivism) have been discussed in descriptions of case studies of teacher change (Briscoe, 1996; Tobin, 1993; Shaw and Etchberger, 1993).

It is interesting to compare the quote from Isaac Newton (above) with the following from Jarvis (1995: 21):

> ... people who think that they have the truth cannot learn and so we should not consider that we teach the truth - we should encourage learners to reflect upon the knowledge with which we provide them and try it out for themselves. If it is true, then they will discover it for themselves - but if it is not true, then they will have discovered new knowledge.

Whilst many teachers may agree with parts of this statement, the idea that they are not ‘teaching the truth’ may be found unpalatable. Even in popular T.V. culture, the idea that ‘the truth is out there’, seems all-pervasive. It is also clear that learners (of all ages) do not always ‘discover it for themselves’. This raises many important questions to investigate why not. It is interesting to speculate how Newton would have reacted to Jarvis’ quote. Whilst there are clear
differences between the two, they are not irreconcilable. Newton recognised that he did not hold the truth, though he struggled to reach it. It is not clear if he thought that others would someday be holders of the truth or whether we would always have to be contented with the 'prettier pebbles' offered by the beach. It is also clear that in the absence of understanding of 'the great ocean of truth', Newton was able to see himself as a learner.

Teachers seem quick to identify what Russell (1993: 248) has termed the science teacher's dilemma of 'curriculum versus constructivism' when the issue of lack of class time is inevitably raised. The comment is often made by teachers that 'I need to get through the syllabus', when really it is how much the students have 'got through' which matters.

5.1.6 Quantitative and qualitative approaches (surveying or mining?).

Much of the 'methodology literature' seems to describe a direct relationship between epistemological positions and preferred research techniques. Brannen (1992:15) writes:

Quantitative methods are seen as having some kind of one-to-one correspondence with positivist epistemology, while qualitative methods are associated with an interpretive epistemology directed toward the uncovering of meaning.

Similarly, Biggs (1996: 348) describes the two broad theoretical positions of objectivism and constructivism in such a way that the two are seen as linked to a certain methodology:

- Objectivism – concerned with assessment – quantitative measurement which distorts the quality of teaching and learning.
- Constructivism sees learning in qualitative terms and sees the learner as
central in the creation of meaning; not the teacher as the transmitter of knowledge.

This may be seen as promoting the 'methodological parochialism' described by Bryman (1984:86), creating 'blinkers' that restrict the choice of research tools available to the researcher. Whilst this matching of theory to method may seem unsatisfactory by restricting choice, it would seem that such combinations (objectivism and quantitative; constructivism and qualitative) are typically paired and so would be widely perceived as complementary. Indeed, changes in my epistemological commitment described above (from objectivist to human constructivist) may be linked to the evolution of methodologies described in Chapter 4 (from quantitative to qualitative). In attempting to untangle the technical and epistemological levels of discussion (concerning methods/techniques and methodology respectively), Bryman concludes that combining strategies exudes good sense and enables the research to benefit from the strengths of different approaches.

At the time I began this research, I brought with me a view of research (and of data collection and analysis) that was essentially objectivist, grounded as it was in a tradition of empiricism and quantitative analysis that I had acquired in my training and experience as both a science teacher and as a researcher in biology. As I began to work with students' views and ideas however, I became increasingly concerned that much of the value of my work was limited by the methodology that I had inherited. Just as I had begun to question the validity of my approach in the classroom (described above), I began to debate the methods by which classroom research into learning could be carried out.

The scientific approach with which I was familiar (characterised as
dominantly quantitative and largely inflexible) seemed not to be appropriate.

What has been seen as an over-dependence upon the methods of science in educational research has been interpreted by Guba and Lincoln (1989) to have had unfortunate results:

- Assessing the evaluand as though it did not exist in a context, but only under the carefully controlled conditions that are in force after a design is implemented – described as ‘context-stripping’.
- Commitment to the scientific paradigm inevitably seems to lead to an overdependence on formal quantitative measurements, with a consequent loss of ‘data richness’.
- The scientific method offers a view of a ‘truth that is non-negotiable’, having been ‘provided by nature’. It, therefore, closes out any other ways of thinking as ‘alternatives to the truth must be erroneous’, leaving a blinkered view.
- As science is putatively value-free, adherence to the scientific paradigm relieves the researcher of any moral responsibility for his or her actions.

As the work started, I began to question the assumptions of the scientific paradigm. As I became exposed to the qualitative literature my approach to research began to evolve. I provide here a description of both the objectivist and constructivist stance in relation to methods of enquiry to show how I came to make more of qualitative methodologies than I would otherwise have done. I draw on the literature to show how the personal changes that I went through satisfy the criteria of ‘definitive change’ and I argue that my development (like that of the ‘good teacher’) went from commitment to content and results to
commitment to learners and finally to commitment to values or principles (Pratt, 1992). These concepts of teaching are actually, in themselves, all statements of value, but it is the last (commitment to value or principle) that attributes value a priori to the learning commitments and teaching methodology.

It may be that my own conceptual change has followed a predictable path during the course of this research and could be mapped against stepped pathways such as those recognised by Davis et al. (1993) and Gallagher (1993). Just as students' understanding of science can be viewed as a reflection of the development of the domain. For example children's understanding of biological evolution often resembles Lamarkism before taking on a Darwinian perspective, whilst understanding of motion is often Aristotelian prior to adopting a more Newtonian view (reviewed by Wandersee et al., 1994). Similarly, my change (from objectivist and quantitative towards constructivist and qualitative) seems to mirror changes within educational research. Reasons for this change, both domain-specific and personal have been summarised by Cobern (1993: 63):

The constructivist has come to understand that the contextual factors positivist researchers seek to neutralize are in fact factors of considerable significance.

A problem that this change process has generated is in communicating findings to colleagues who have not undertaken comparable ‘journeys’ themselves. Given the express intent for it to ‘have utility and application for teachers’ [p. 1-1] the work needs to be written in appropriate language. This may need to seem ‘objectivist’ at some points (eg. in the design of the quantitative protocols) , but promote ‘constructivism’ at other points. I acknowledge this tension.
5.1.7 Prior knowledge revisited - ecology

My prior knowledge of, and interest in ecology (e.g. Kinchin, 1993c) may have made me more receptive to the notion of a conceptual ecology [2.2.3]. The present literature on conceptual ecologies is fairly 'lack-lustre’, and the potential for this notion is only apparent to me as a consequence of my earlier studies providing a fertile conceptual foundation. A rich prior knowledge provides many possible points of contact for analogous reasoning and so eases the construction of numerous conceptual links.

This also provides a common reference point for collaborating biology teachers (who share with me similar prior knowledge structures), allowing new ideas to appear more familiar and less threatening. This reflects a theme running throughout this work, that the nature and organisation of prior knowledge structures influence the trajectory and extent of future meaningful learning. This may contribute to an explanation of why the biologists in school D were more receptive to concept mapping than the chemists and physicists [5.3.2].
The methodology described in this thesis, particularly the development of the qualitative description of concept maps, has emerged in a way that resembles a Grounded Theory approach (Glaser and Strauss, 1968) in that it evolved in response to data gathered from early observations made. This is considered 'the hallmark' of a grounded theory study (Charmaz, 1995). Some qualification is made in the use of this term that has come to mean different things to different observers. The grounded approach, as originally conceived, is seen by Pidgeon and Henwood (1997) to be embedded within an objectivist epistemology because of the way in which Glaser and Strauss talk of theory being discovered from data, as if it has an independent existence. Others have reinterpreted grounded theory to fit a constructivist perspective (eg. Gregory, 1994).

In describing the essential attributes of grounded theory, Glaser (1992: 31) asserts that, 'there is a need not to review any of the literature in the substantive area under study'. When the substantive area is research methodology, this may pose something of a dilemma that can only be resolved if the methodology can be matched gradually to the practice as an integral part of an iterative research process – as is the case here. A grounded approach demands a period of ‘rich picture building’ (sensu Checkland, 1999). This gives an opportunity for research
questions to be informed by the research context while the conceptual framework, researcher and methodology all evolve through constant interaction. It is this interaction that produces the data (Charmaz, 1995) and generates ever more complex and stable agenda to guide subsequent data collection (Guba and Lincoln, 1989). The absence of 'existing theory and research' (as advocated by Glaser, 1992) from the theoretical framework model described in chapter one would have left a void. If we accept the premise of the human constructivists, that human beings are compulsive 'meaning makers' (Mintzes, et al., 1997; 1998), then the void is likely to have been filled (consciously or subconsciously) with spurious 'speculative models' (Lave and March, 1975). Maxwell (1992: 287) contends that 'all observations and descriptions are based on theory, even if this theory is implicit or common sense'. The researcher's conceptual ecology is seen as providing a 'store of sensitizing concepts' which orientate the research (Charmaz, 1990). An explicit consideration of appropriate theory, therefore, seems a necessary guide to set an initial research trajectory, with the recognition that this trajectory may change in the light of subsequent experience — the 'open-mindedness' described by Harding and Hare (2000).

Within the domain of science education research, influential writers have emphasised that a review of the literature 'must be an initial component of research design' (Gallagher and Anderson, 1999). This has been echoed by those who argue that a theoretical framework is the only lens through which data can be viewed (eg. Millar, 1998; Hodson, 1998). Pidgeon et al., (1991: 152) commented upon the researcher's role in this process:
The task of analysis is not a simple one ... it is an interpretive process in which the researcher must take responsibility for perceiving and creating order in the data which has been collected. This requires identifying both what is relevant as well as what is irrelevant in the data, while at the same time faithfully reflecting significant complexities inherent in the material.

The degree to which patterns can ‘emerge’ from data, without being ‘forced’, provides a point where grounded theorists find disagreement (not least between the two original authors – see Glaser, 1992). In his criticism of ‘emergence’, Constas (1992: 254) clearly stated his opposition to Glaser’s (1992) stance:

Contrary to what some have claimed, categories do not simply ‘emerge’ from the data. In actuality, categories are created, and meanings are attributed by researchers who, wittingly or unwittingly, embrace a particular configuration of analytical preferences.

Whilst Pidgeon and Henwood (1997: 255) stated:

... what appears to be ‘discovery’ or ‘emergence’ of theory is really the result of a constant interplay between data and the researcher’s developing conceptualisations, a ‘flip flop’ between ideas and research experience.

This has been called a ‘constructivist’ revision of grounded theory (Charmaz, 1990) and allows it to fit comfortably within the human constructivist framework (Mintzes, et al., 1997; 1998).

In order for this research to be palatable to the science education research community, and to find a niche within the existing body of knowledge, research literature and prior experience are used explicitly here to create a theoretical framework for research. This may leave some observers to describe the methodology employed here as ‘forced conceptual description’ (eg. Glaser, 1992: 5), while others may be more content to call it grounded theory (eg. Strauss and Corbin, 1997). I consider it more important to employ an approach that is appropriate to this context than to ensure an accurate fit to accepted definitions.
For simplicity, the term ‘grounded approach’ will be used throughout this work.

Emphasis in this study is on learning outcomes rather than the social processes that lead to learning, which would more traditionally be the focus of grounded theory studies. Grounded theory has been developed for field studies involving interviews as a primary data collection method. As concept mapping was originally developed as a tool to summarise and clarify interview data (Novak and Musonda, 1991), there does not seem to be any conflict.

The collection of concept maps as the primary data source is also a departure from the typical grounded theory study, which focuses on data collected from interviews. In consequence, transcription of tapes and subsequent coding of responses was not a part of this process. In particular, the reductionist approach of ‘line-by-line’ coding was seen as inappropriate here, though it is seen as a key component of the analysis of interview transcripts (eg. Charmaz, 1995). The maps themselves provide the ‘paper trail of evidence’, allowing ready access during analysis. In this research, it is not just the individual ideas that are of interest, but their arrangement and relationship with one another. Any transcription of concept maps would either have lost this information or have been so complicated as to be unhelpful. Pidgeon and Henwood (1997) have described grounded theory to be most typically well suited to the analysis of ‘broad themes’ within participants’ accounts. This is reflected in the description of concept maps’ gross structure that is developed here.

The stages described by Turner (1981) are applicable in this instance to provide a framework for analysis of the qualitative data (table 5-2). In addition, Turner (1981: 226 – 227) claims that such an approach promotes the development of ‘explanations which conform closely to the situations being observed, so that
the theory is likely to be intelligible to, and usable by, those in the situation studied'. I see this as essential if this research is to inform classroom practice.

Table 5-2 Stages in the grounded approach.

<table>
<thead>
<tr>
<th>GROUNDED THEORY STAGES (after Turner, 1981)</th>
<th>QUALITATIVE CONCEPT MAP ANALYSIS</th>
<th>WHERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEVELOP CATEGORIES</td>
<td>Spoke, chain and net categories - originally identified in a class studying reproduction in flowers</td>
<td>School B (n=32, Yr 8) See Fig. 5-2 [5.4.5]</td>
</tr>
<tr>
<td>SATURATE CATEGORIES</td>
<td>Further instances of these categories were found during trialing of photosynthesis test.</td>
<td>School B (n=40, Yr 10) [5.4.3]</td>
</tr>
<tr>
<td>ABSTRACT DEFINITIONS</td>
<td>Categories are defined in terms of their link to NC. and teachers' SoWs and in terms of students 'global' view of subject</td>
<td>See table 5-3</td>
</tr>
<tr>
<td>USE THE DEFINITIONS</td>
<td>Further incidents of these categories are seen in various classrooms.</td>
<td>School C (n = 120, Yr 10) School D (n = 75, Yr 10) UniS (n = 150, U/G) [6.2 &amp; 6.3]</td>
</tr>
<tr>
<td>EXPLOIT CATEGORIES</td>
<td>The categories are tested out in collaborative learning situations to determine influence of meaningful learning.</td>
<td>UniS (pilot) (n = 12, P/G) School E (n = 90, Yr 8) School F (n = 50, Yr 8) [6.4.6]</td>
</tr>
<tr>
<td>FOLLOW-UP LINKS</td>
<td>Implicit development from spoke to net, but what is the sequence?</td>
<td>See Fig. 7-13</td>
</tr>
<tr>
<td>CONDITIONS FOR LINKS</td>
<td>If students all start at different points, can they all progress along the same route?</td>
<td>Student diversity makes generalisation difficult.</td>
</tr>
<tr>
<td>CONNECTIONS TO THEORY</td>
<td>Relate to literature on conceptual change.</td>
<td>The importance of the ecosystems view of conceptual change.</td>
</tr>
<tr>
<td>COMPARISON OF EXTREMES</td>
<td>Identification of extreme spokes, chains and nets for relation to other characteristics.</td>
<td>See table 6-3 &amp; Fig. 6-4</td>
</tr>
</tbody>
</table>
The details of the process of category development are described below [in 5.4] and the main stages are summarised in table x. Whilst such a representation typically suggests a linear sequence, it needs to be emphasised that several stages can be running concurrently and/or may be revisited.

One outcome of such an approach is that the results of one phase of research provide the instruments and materials for the next phase [as mentioned in Chapter 4]. The appropriateness of the terms ‘instruments’ and ‘results’ are, therefore, context-dependent – changing as the research moves on and perspectives are modified by experience. In this way, the results presented here may provide the methods for future study.
5.3 The subject of research.

5.3.1 A suitable vehicle

The vehicle for this research was to be within the domain of biological education as this is where my teaching experience is located. Within this field, it was important to select an area that would support the research process by fulfilling the following criteria:

- It should be described by a significant body of literature to show the result of previous investigation on associated misconceptions. This research was not intending to add to the cataloguing of misconceptions. I wanted to move on from this point, building upon the misconceptions literature to inform classroom practice.

- It should be an aspect of the subject that is repeated at various levels in the curriculum (KS1 – 4) so that there are presumed building blocks from earlier phases of the curriculum to gauge the conceptual level of the students involved (probably Year 10).

- As a practical consideration, it would help if the chosen topic was taught in schools C and D near to the beginning of the academic year.

The topic of photosynthesis was found to fulfil all these requirements and so was the chosen vehicle for the initial experimental investigation. Students would be given a pre-test to expose areas of misconception. Test groups would then be subject to an experimental intervention. A post-test could then help to determine change in understanding and the resilience of the misconceptions.
5.3.2 Areas of misconceptions and test questions

The areas of misconception within photosynthesis are well documented in the literature along with suggested question formats (Amir and Tamir, 1994; 1995; Bell, 1985; Bell, et al., 1985; Haslam and Treagust, 1987; Hegarty-Hazel, 1986; Mintzes, et al., 1991; Smith and Anderson, 1984; Stavy, et al., 1987; Wandersee, 1984a; 1984b). In constructing a first pilot of the photosynthesis test, an attempt was made to address all the areas of misconception identified within the literature using a varied style of questioning. Overall, this test was to take 30 – 40 minutes and was piloted at School A.

This was subsequently streamlined. Key questions were identified as those to which a large proportion of students not only get the answer wrong, but also chose the same wrong answer. From the first pilot a number of changes were necessary before piloting at school B. The time available for the test was considerably reduced as pre-testing, concept map training and the production of a ‘naïve’ concept map had to be completed within a single 50 minute lesson. To leave adequate time for the mapping, testing was reduced to a ten minute slot. There was a necessary trade-off between a wide coverage of the topic and an in-depth probing of individual areas of misconception. To accommodate this the number of two-tier questions (Haslam and Treagust, 1987) was reduced. Though the test was much shorter than the original version, each key area was still covered by at least two questions.

The ‘final’ version of the test (Appendix 1) was discussed with the class teachers from the two test schools (C and D). In response to comments from one school, the font size on the test was increased as the teachers felt that some of their less-able students would simply not attempt to read ‘normal size’ type. In
addition it was agreed that teachers could read the questions aloud if they felt it would help the students, particularly those in low-ability sets. This then became a shared methodology (between teachers and researcher, as recommended by Englert et al., 1993).

There was a query on question 4 that the word ‘nutrients’ may be misleading and should be replaced with ‘minerals’. This question was tested with a class at school D with half the students having the question with nutrients and half with minerals. Inclusion of nutrients did seem to induce more wrong answers not only in the first part of the question, but also in the second. Nutrients was included in the final version given in Appendix 1

5.4 The enquiry tool

5.4.1 Investigating the ‘rich picture’.

To fulfil the aims of this study a mechanism was required that could be used to collect data from a variety of students spanning a wide range of academic abilities and levels. The method had to be quick to administer and transparent in its simplicity to teachers and students. Given that students and teachers were to invest some time and energy in the use of this tool, I felt it was important that it would be seen to benefit students and teachers from the collaborating institutions, even after the research programme had ‘been and gone’. In addition, I wanted data that could be interpreted on a variety of levels, one that would give a rich picture of students’ perceptions in which they had freedom to express the things they considered important (ie. not right/wrong or yes/no responses).

A graphical technique that did not require students to read or write large volumes of text seemed to offer most promise as this would provide the flexibility
needed to cope with the diversity of students to be encountered. A ‘free drawing’ activity was tried, but its unstructured format was considered unhelpful. After considering a number of approaches, it became clear that the investigative tool needed to have some sort of structure to facilitate evaluation and comparison. Concept mapping (sensu Novak and Gowin, 1984) seemed to fulfil all my requirements and so its potential was investigated in some depth. The concept map is described by Mintzes et al. (1997: 424) as ‘the most important metacognitive tool in science education today’.

Whilst the research literature dealing with concept mapping provides a positive recommendation for its use in science teaching (eg. Horton et al., 1993), science departments that were encountered within this research programme had little experience of its classroom use. It was, therefore, important to devise a ‘training protocol’ that could be used with the students and, to maintain transparency, be used and elaborated with the participating teachers. I felt that, in the same way that students have been found to increase their engagement in scientific enquiry when instruments become more ‘transparent’ (ie. more intelligible in the way they function) so teachers may be helped to engage in classroom research if investigatory tools are more transparent (eg. Resnick, et al., 2000). The protocol devised (outlined in the following sections) was designed for use with all the groups of students and teachers from schools and higher education. Only the level of language used and the examples employed were changed to suit the requirements of the audience.
5.4.2 Concept mapping training

The concept mapping training was developed from the descriptions given by Novak & Gowin (1984) and White & Gunstone (1992). Within such tasks, Faletti and Fisher (1996) have commented that unnamed connections limit the communicative value of each proposition and can promote ‘fuzzy thinking’. Therefore, the importance of link quality was stressed heavily during introductory sessions. Care was taken during presentations not to include any specialist terms that might influence subsequent maps.

When ‘training’ students to produce concept maps, I was aware that the presentation of too many examples could ‘lead’ the students and so constrain their creativity (sensu Marsh et al., 1996). Students, eager to please, would latch on to any terminology that they could take from the presentation and use in their own maps. All maps presented were strongly hierarchical and of a ‘net’ type structure.

The first classroom test of this training protocol was delivered to Year 8 and Year 10 classes at school B. This allowed the presentation to be refined and any ambiguous or confusing materials to be reviewed. Additional trials were undertaken with sixth form students (who were not to be part of later trials), teachers at the two school where the major trials were to run (schools C and D) and with postgraduate students at UniS.

INSET sessions for science staff were run at the two schools (C and D) involved in the main photosynthesis trials before the classroom interventions. This was a way of guiding the collaborating staff, and their immediate colleagues, through the ‘Innovation-Decision Process’ described by Rogers (1995). This process has five stages:
1) **Knowledge Stage**

Most of the teachers involved claimed to have no, or only vague, previous knowledge of concept mapping as a learning tool. Agreement to be involved in the work hinged upon me providing teachers with information at departmental INSET days.

2) **Persuasion Stage**

This involved the simultaneous 'seeding of dissatisfaction' with current practice and a suggestion of a 'way out'. This was given as a condensed personal account of my own transition [as described in 5.1] so as not to imply any criticism of the 'host institution'. Anecdotes from the first pilots also seemed to add credibility to the story.

Within the two schools, this worked in different ways:

a) **School C**

Sixth Form biology students were also invited to the session. The positive reaction of the students to the session was observed by the teaching staff and this seemed to help them form a favourable opinion of concept mapping as a classroom tool.

b) **School D**

The INSET session seemed to highlight differences in approach between the biology department in the school (who were quite eager to consider new teaching approaches) and the chemists and physicists (who seemed to adopt a more traditionally objectivist stance in which 'change' was seen as a
threat). The effect was to make the biologists even more eager
to develop their skills and divorce themselves from the other
two departments.

Whilst the intention, expressed to the collaborating teachers, was to promote
conceptual development among students, it soon became clear that the
introduction of concept mapping into the departments was also having an impact
upon the teachers involved. In anticipation of the concept mapping activities, they
were visibly and audibly making adjustments to their mental teaching preparation,
reflecting Prawat’s comment:

In moving toward a constructivist approach to teaching, teachers will
need to attend to their own conceptual change at least as much as they
attend to this process in their students.


3) Decision Stage

Both biology departments decided to be involved in the research programme.

At this point, the major constraints on access to the students were those
imposed by the schools’ timetables.

4) Implementation Stage

Concept mapping was undertaken in agreement with all the biology teachers
within the two schools with all the classes of Yr 10 students.

5) Confirmation Stage

The final stage lay outside of the timeframe provided by the research, though
it is known that one of the schools involved in the collaborative trials (E) has
incorporated the concept mapping approach into their lower school schemes
INSET sessions for staff at schools E and F were held after the classroom interventions. The collaboration for this research phase [6.4] was for a much shorter period than for the photosynthesis trials [6.2]. It also started later in the academic year so that the timing of INSET could not be fixed prior to the intervention. Additionally, staff in schools E and F had less input on the detail of the intervention than teachers in schools C and D. This has implications for their feelings of 'partnership' in the work and 'ownership' of the findings.

This highlights a weakness in the grounded evolution of the research methodology. Whilst schools C and D were a part of this process, staff at schools E and F, who joined the research programme in a later phase could not have the same detailed introduction to the work and could not be given the same amount of time to reflect on the implications for their own teaching. This could have been overcome if all phases were conducted in the same schools, but would then have put unacceptable pressures on the teachers involved to conduct all the work in the time frame available.

5.4.3 Revision practice materials decided with staff

The material that was presented to groups as 'practice material' during the concept mapping training was decided upon in consultation with the classroom teachers. This was to ensure that the subject material was familiar to the students (so that they were not learning a new technique and new material simultaneously). In this way the lesson was seen as a revision session of an earlier topic. The materials were:
For the Year 10 photosynthesis trials:

- 'Pond ecology' (School C)
- 'Circulatory system' (School D)

For the Year 8 collaborative trials:

- 'Acids' (School E)
- 'Teeth' (School F)

Details of these materials are given in Appendix 5.

Powerpoint slides and commentary for concept mapping training are given in Appendix 2.

5.4.4 Quantitative map description

A method was required to describe the contents of concept maps generated by participants in the study so that they could be compared and used to illustrate conceptual change. Differentiation between concept maps has often been undertaken quantitatively, based on the scoring protocol devised by Novak and Gowin (1984). This scheme considers the number of valid links presented; the degree of cross-linkage indicated; the amount of branching and the hierarchical structure. However, this aggregation of scoring elements creates a blurring of what the score actually reveals and can also be quite taxing on the scorer - making it unattractive for adoption as a classroom tool.

Scoring of maps was attempted using Novak and Gowin’s scheme and variations upon it. However, these had a tendency to become cumbersome and time-consuming. The generation of a final score also revealed little about the
differences between individual maps, reflecting the comment by Caine and Caine (1994: 166), that ‘it is impossible to communicate the scope and depth of a student’s abilities by means of a letter or numerical grade’. Novak and Gowin (1984: 97) were not convinced of the value of such scores themselves, stating that ‘scoring was in many respects irrelevant, for we were looking for qualitative changes in the structure of children’s concept maps’. Whilst Stuart (1985: 80) commented that ‘to rely on numerical scores is to risk missing diagnostic data used to help the pupil’. White and Gunstone (1992: 38), not only doubt the value of such scores, but also caution against the damaging effects of scoring, stating:

> giving any form of grade to a map can alter students' attitudes to them and so threaten their potential to promote learning.

I am critical of the scoring of only ‘valid’ links (as proposed by Novak and Gowin, 1984) as I see this as unsupportive of the learning process and at odds with the constructivist philosophy that underlies the use of concept mapping as a learning tool. Constructivism has been said to invite a comparison between how novices and experts process scientific knowledge (Blais, 1988), with expertise requiring a demonstration of ‘connected understanding’ (Schau and Mattern, 1997). Therefore, a qualitative approach was sought in which maps could be examined for indicators of expertise – particularly ‘connectedness’ and ‘link quality’. The scoring of only ‘valid links’ also misses the point that ‘invalid’ links may have a value to the student by supporting more valid links (sometimes temporarily) and so contributing to the overall knowledge structure that he or she is using as a basis for further learning:

> The richness of meaning that accompanies many ‘misconceptions’ is a significant part of the way we as human beings understand our world. To deny that richness of meaning is dangerous.  

Bloom (1990: 560)
The 'invalid' links in a student's map may reveal much about the thought processes that lead a student along a particular path of understanding. The definition of a 'valid link' can also cause problems as a link may be 'valid' in terms of providing a factually correct statement, but may be inappropriate when considered in the context of the core concept under discussion. In addition, problems in the consistency of scoring schemes, have been highlighted in the literature (e.g. Jonassen et al., 1997; Liu and Hinchey, 1996; Ruiz-Primo and Shavelson, 1996).

5.4.5 Qualitative scheme first identified at School B (yr 8).

The experimental approach [described in section 6.2] yielded data that informed the emergent design of the approach described in subsequent sections, and as such may be viewed as a rich picture building exercise.

The classification described below was originally recognised when reviewing reproduction in flowering plants with a group of Year 8 pupils. This topic has, therefore, been used to provide examples for initial discussion here. Subsequent studies with students of varying ages (including postgraduate students) and considering different topics in the biological sciences, have revealed the same basic types of map structure. Illustrations of the three types, denoted as 'spoke', 'chain' and 'net' are given in figure 5-2 (parts A, B and C respectively). Characteristic of these three types are summarized in table 5-3:
Table 5-3 Characteristics of map types.

<table>
<thead>
<tr>
<th></th>
<th>SPOKE</th>
<th>CHAIN</th>
<th>NET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hierarchy</td>
<td>One level only</td>
<td>Many levels, but often unjustifiable.</td>
<td>Several justifiable levels</td>
</tr>
<tr>
<td>Processes</td>
<td>Simple association with no understanding of processes or interactions</td>
<td>Shown as a temporal sequence with no complex interactions or feedback</td>
<td>Described as complex interactions at different conceptual levels.</td>
</tr>
<tr>
<td>Complexity</td>
<td>So little integration that concepts can be added without consequences for 'map integrity'.</td>
<td>Map integrity cannot cope with additions, particularly near the beginning of the sequence</td>
<td>Map integrity is high. Adding one or more concepts often has minor consequences as 'other routes' are available.</td>
</tr>
<tr>
<td>Conceptual development</td>
<td>Shows little or no 'world view'. Addition or loss of a link has little effect on the overview.</td>
<td>Integrated into a narrow world view, suggesting an isolated conceptual understanding. Loss of a link can lose meaning of the whole chain.</td>
<td>Can support reorganization to emphasise different components to appreciate a larger world view or to compensate for a missing link.</td>
</tr>
<tr>
<td>Represents</td>
<td>National Curriculum structure</td>
<td>Lesson sequence</td>
<td>Meaningful learning.</td>
</tr>
</tbody>
</table>

5 - 41
Figure 5-2

Three ‘correct’ maps describing the structure and function of flowers. The different structures are described as spoke (A), chain (B) and net (C).

As ‘invalid links’ are of equal importance to ‘valid links’ (in terms of teacher-awareness), the time-consuming (and sometimes arbitrary) process of assessing the validity of links is avoided. The simplicity of this classification scheme makes it more likely that it could be adopted for classroom use and yet it fulfils the criteria for an effective qualitative scheme outlined by Kinchin (1998). The scheme differentiates maps in terms of their complexity; resilience in
accommodating additions; the establishment of a context for the key concepts; degree of appreciation of a wider viewpoint and its relationship with the 'expert' view. This is summarised in Table 5-4.

Table 5-4 Characteristics of expert and novice concept maps.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Expert</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connectedness</td>
<td>Highly integrated structure with numerous cross-links.</td>
<td>Disjointed structure dominated by linear arrangements in isolated clusters.</td>
</tr>
<tr>
<td>Link quality</td>
<td>Appropriate linking phrases which add to the meaning of concepts, using the specialist language of the domain.</td>
<td>Links are often inappropriate – usually single words that add little to the meaning and using non-specialist terminology.</td>
</tr>
<tr>
<td>Link variety</td>
<td>A diversity of linking phrases illustrating a range of thought processes.</td>
<td>The same linking words are used for a number of links, suggestive of a narrow range of thought processes.</td>
</tr>
<tr>
<td>Dynamism</td>
<td>Changes over time, reflecting active interaction with alternative knowledge structures.</td>
<td>Stable over time suggesting a lack of active engagement in knowledge restructuring.</td>
</tr>
<tr>
<td>Concepts</td>
<td>Concentration on overarching concepts to create an overview.</td>
<td>Concentration on specific concepts indicating a limited perspective.</td>
</tr>
</tbody>
</table>

Implicit in this qualitative classification is the development of increasing integration of a conceptual framework from spoke structures towards net structures. The structure of the framework held by a student will have implications for the mechanism of further meaningful learning. If a pupil holds a spoke structure (fig. 5-2), then the addition of new knowledge will not cause any disturbance to the existing framework. It can simply be added in with a link to the core concept, but without any links to associated concepts. The result would be that the knowledge can be assimilated quickly, but only be accessed by reference.
to the core concept, not by reference to one or other of the associated concepts. For the pupil with a chain structure (fig. 5-2), the addition of new knowledge will be easy if there is an obvious break in (or premature end to) the sequence, but may be problematic if a workable sequence is already in place as the additional concept may appear superfluous. Alternatively, the addition of a concept near the beginning of the sequence may be so disruptive to the knowledge structure lower down that incorporation of the new knowledge is rejected. Additionally, understanding of a concept in the middle of the sequence may be difficult without travelling from the beginning. For the student with a net framework (fig. 5-2), access to a particular concept may be achieved by a number of routes, making the knowledge more flexible. However, this requires understanding of the associated concepts beyond their link with the core concept and so implies a wider understanding.

The occurrence of the types of map illustrated may be partially explained by the students' interpretation of the styles of 'expert' views to which they are subjected. The layout of National Curriculum orders for Science (Department for Education, 1995) where a core concept is followed by a listing of related concepts to be taught, suggests a spoke arrangement of knowledge. The links between subordinate concepts are not made explicit. Whilst the teacher will be aware of this documentation, the pupils' direct interface with the published curriculum will be through the scheme of work that is followed in class along with the accompanying textbooks, handouts and tests. These will tend to transform the spoke arrangement of the National Curriculum into a chain arrangement of a lesson sequence. This is reflected in the maps shown in Figure 5-3, which were produced by Year 8 pupils on completion of a series of lessons on reproduction in
flowers. Three of those pupils are referred to here as ‘Kelvin’, ‘Danielle’ and ‘Simon’.

Danielle’s map

Figure 5-3

Concept maps produced by Yr 8 students to express their understanding of ‘flowers’.
Kelvin’s map is dominated by a chain showing an appreciation that flowers need to attract insects for pollination, suggesting a focus on one particular section of a lesson sequence. Danielle’s map is characterised by two chains showing an appreciation of the male parts of flowers and a separate appreciation of the female parts of flowers. These are shown as distinct sequences of understanding with the lack of overlap emphasised by the positioning of the chains so far apart in her map. Whilst the interrelationship between male and female may seem obvious to the teacher, Danielle has failed to make this connection and so has missed out on one of the key points of reproduction. Martin (1994:15) has noted how often, ‘teachers teach one of the vertical hierarchies of the map, then the next one, then the next one, and so on, sequentially, failing to relate the parts to each other and failing to demonstrate the interrelationships that need to be linked’. This may explain observations made by Novak (1988) in which he describes how children in the first grade of school display little difficulty in producing hierarchical maps, but by the fifth grade some children have difficulty in organizing maps in this way and resort to the production of linear strings of concepts. This suggests that curriculum documents and schemes of work need to concentrate on the structure of information presented and the links between concepts as much as on the concepts themselves, as without appropriate links the concepts lose meaning. This will help students to put their understanding into a context that makes it more meaningful by creating potential for interaction with existing knowledge. Teachers may find it useful to include concept maps in their schemes of work to remind themselves of important links which need to be made explicit to their students and to help sequence teaching.
materials more effectively, as demonstrated by Cliburn (1986). It can be seen from Danielle’s and Kelvin’s maps that when such links are not emphasised, different students will take different elements from a teaching sequence upon which to base their individual knowledge structures.

In comparison to Danielle and Kelvin, who both have well developed knowledge structures covering certain components of the topic, Simon’s map suggests that he has really failed to internalise the details of reproduction in flowering parts in terms of sexuality or in terms of the relationship between flowers and insects. Such a simple map does not contain enough information to have its structure categorised as spoke, chain or net. It is, therefore, designated as a ‘simple’ structure, which demonstrates no development from typical pre-instructional understanding of this topic that would be expected of a much younger student (eg Hickling and Gelman, 1995).

The spoke and chain types were not described in the training sessions [Appendix 2] and arose spontaneously during the concept mapping sessions. Elements of the three patterns (spoke, chain and net - SCN) were recognised with the maps produced by one class. These map-types were also identified within the maps gained during the photosynthesis trials at schools C and D.

5.4.6 SCN collaboration piloted with PGCEA students at UniS.

The qualitative description of concept map structure described above could be exploited as a means of differentiating between students in a non-threatening and non-judgemental way. The categories of gross structure suggest ‘difference’ without necessarily implying ‘better’ or ‘worse’.

When groups of students are working together, they need to have some
focus for their discussions and this may promote greater discussion if the perspectives brought by the participants display some differences. A suggested mechanism for promoting discussion is summarised in figure 5-4.

**Figure 5-4**

*A concept map summarising the application of qualitative map classification to promote learning in collaborative groups.*
Within such a model, a variation in size of effect is anticipated, resulting from variation in the degree to which the generated cognitive conflict was expressed or acted out to activate differences in students' points of view. In describing prerequisites for cognitive restructuring, Perret-Clermont (1980: 118) considers the notion of 'minimal competence' to describe a threshold level over which the student must climb in order to benefit from social interaction, and states:

Social interaction can stimulate constructive activity only in so far as the subject has attained a level of competence sufficient to benefit from that interaction.

This minimal competence includes prerequisites for social interaction and prerequisites for cognitive restructuring. A more holistic view is taken by Glachan and Light (1982: 258) who consider the outcome of an interaction to be equal to more than the sum of the parts contributed by individual students, and conclude:

It would appear that interaction between inferior strategies can lead to superior strategies or, in other words, two wrongs can make a right.

The potential of this was investigated as a classroom intervention was investigated with a group of 12 postgraduate trainee teachers registered on the part-time PGCEA course at UniS. The participants were all training to be nurse-trainers and so all had a basic grounding in biological science. Though concept mapping has been promoted as a useful learning tool for nursing (eg. Irvine, 1995; All and Havens, 1997) none of the participants claimed familiarity with the technique. The topics used as vehicles for the tests were 'pathogenic microbes' and 'genetics' – topics with which all the participants should have been familiar at a basic level. After initial training in the use of concept maps, the trial was run in two stages:
Stage one: Participants were given a list of twenty basic concepts associated with pathogenic microbes. The list was checked against a number of nursing texts to ensure suitability. They were asked to construct concept maps individually (without reference to colleagues or to other materials). These maps were quickly assessed and each one categorised as a 'spoke' a 'chain' or a 'net' type map. The quality or appropriateness of individual links or concepts was not evaluated at this time. Maps were then sorted into groups of three, each group consisting of one 'spoke-dominated' map, one 'chain-dominated' map and one 'net-dominated' map. Each triad of students was then asked to compare their maps and produce a 'consensus map' from the group.

Stage two: was similar to stage one, but used the topic of genetics. This time groups were arranged so that similar maps were put together in triads (eg. all 'spoke-dominated' maps).

The number of acceptable propositions was then evaluated for each map and the gain score (from individual map to group map) was calculated for each student. This is shown in the graph in figure 5-5, comparing the average individual and group scores for the microbes trial (heterogeneous/mixed groups) and the genetics trial (homogenous/similar groups). The difference in average gain scores between the two groups is pronounced: +7 for the mixed groups and -0.83 for the similar groups.

The scores achieved by the heterogeneous collaborative groups were greater than the sum of the scores that had been achieved by the individuals. This reinforces Glachan and Light's claim that 'two wrongs can make a right'. It is possible that 'wrong' elements from an individual's map simply need to be re-contextualized in order for them to become 'correct'. A sharing of perspectives in
the collaborative groups may facilitate such a re-contextualization.

It may be that the group found genetics a more difficult topic than microbes, though the starting values (number of acceptable propositions within individual maps) are similar for each topic (genetics slightly higher).

![Graph](image_url)

Figure 5-5

*Graph to illustrate difference in average gain scores within a group of students (n=12) between individually-produced maps and those produced in collaborative triads.*

This result is strongly suggestive that the mixing of students perspectives within a collaborative group (as depicted by the gross structure of concept maps) promotes more effective exchange of information during collaborative episodes. However, individual variation in the effect achieved suggested a more interesting line of enquiry for subsequent studies than examination of trends and averages.
5.5 Participant interviews

It was felt important to try to gain 'respondent validation' (Silverman (1993: 156) of the interpretations made of students’ concept maps. By taking findings back to the subjects being studied, it is argued that one can be more confident of their validity. The nature of the interviews would necessarily be a compromise between what was desirable and what would be practically feasible within the collaborating institutions.

Group interviews seemed to offer a promising approach. The use of the group interview has been described in detail by Watts and Ebbutt (1987) and Lewis (1992). Two major advantages of group interviews are highlighted:

a) the challenging (and so clarification and extension) of an individual’s responses by others in the group.

b) the stimulation of new ideas.

A group interview also reflects more closely the typical working arrangement of students in science lessons, where work in small groups is the norm. It also reflects the view of science as a ‘social process’ (eg. Solomon, 1991). In addition, children may be less intimidated by talking with their peers than when talking to an unfamiliar adult on a one-to-one basis and in a less intimidating environment they may be more willing to offer their thoughts.

Interviews were audio-recorded. Kirk and Miller (1986: 55) maintain that a tape recording of the questions contributes meaningfulness to the interviewer’s notes because it provides a record ‘not of what the fieldworker thought she was asking, but of what the informant heard’.

In practical terms, groups would not have been easy to arrange within the logistical constraints imposed by the collaborating institutions. Interviews had to
be conducted within school lunch breaks, with the result that those who went home for lunch could not be included in the sample. Interviewees had to be ‘booked’ in advance, with ‘reserves’ standing by (in case of absentees). Interviews had to take place within a science laboratory with poor acoustic quality so that taping large groups would be difficult. Interviews were therefore conducted with pairs of students. Complementary pairs were arranged, by matching students with differing naïve concept map structures. These pairs were each taken from within one ability group to ensure that the individuals had been given a comparable experience of the concept mapping tasks. An established rapport between peers would help them to feel more comfortable in an unfamiliar interview setting (Solomon, 1991). Friendship groups are more common within ability groups though this was not actively considered as pairing was done ‘blind’ with reference only to concept maps.
6.1 The environment for the research

Research was conducted in a number of secondary schools in the SE of England (see table 6-1) and also within the University of Surrey (UniS). Schools were approached either directly through known contacts, or via third parties who had known contacts at the school. UniS students included postgraduates (my own teaching groups within the School of Educational Studies - SES) and undergraduates (via a staff contact within the School of Biological Sciences – SBS).

The schools included some that might be considered ‘typical’ of those in the region, ie. large, mixed comprehensive schools with pupils exhibiting a wide range of abilities. However:

.. even if one could achieve typicality in all major dimensions that seem relevant, it is nonetheless clearly true that there would be enough idiosyncracy in any particular situation studied so that one could not transfer findings in an unthinking way from one typical situation to another.

Schofield (1993: 99)

The research was conducted in a diverse range of educational institutions as it was considered that findings that emerged from the study of several very heterogeneous sites would be more robust than those emerging from a study of several very similar sites. Single sex schools (2 boys’, 1 girls’) were, therefore included in the study. Overall, the schools included those very close to the top of their respective county league tables, and one near the bottom (in addition to those more ‘typical’ institutions near the middle). The work presented is a description of sites studied rather than a general comment on schools in the U.K. Whilst similar phenomena might be observable in similar sites, no attempt will be made to make mass generalisations:
the value of a qualitative study may depend on its lack of external
generalizability in a statistical sense; it may provide an account of a setting or
population that is illuminating an extreme case or 'ideal type'.


The definition of generalizability can be expanded beyond the traditional meaning
(statistical generalizability) to include analytical generalization. This involves a
reasoned judgement about the extent to which the findings from one study can be used
as a guide to what might occur in another situation and puts the onus on the reader to
judge the soundness of the generalisation claim (Taber, 2000b).

Whilst there was some diversity in the institutions used (Table 6-1), there were
a number of factors that were uniform across the sample. Classes of students used in
this study were:

Year 10 - all setted by ability (schools B, C and D)
Year 8   - all of mixed ability (schools E and F).

Students were almost exclusively white and of middle-class backgrounds so
that the influence of ethnicity and socio-economic factors could not be evaluated. The
schools used were set in suburban environments so that the contextual influences of
inner-city or rural communities could not be examined.
Table 6-1  Schools involved in the studies presented,

<table>
<thead>
<tr>
<th>SCHOOL</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involved in</td>
<td>Photosynthesis test (p1)</td>
<td>Photosynthesis test (p2)</td>
<td>Photosynthesis INSET test (main)</td>
<td>Photosynthesis INSET test (p3)</td>
<td>Collaborative INSET Map training (main)</td>
<td>Collaborative INSET Map training (main)</td>
</tr>
<tr>
<td>Type</td>
<td>Boys selective</td>
<td>Mixed comprehensive</td>
<td>Mixed comprehensive</td>
<td>Boys selective</td>
<td>Mixed comprehensive</td>
<td>Girls selective</td>
</tr>
<tr>
<td>NOR</td>
<td>833</td>
<td>1060</td>
<td>1520</td>
<td>704</td>
<td>1845</td>
<td>357</td>
</tr>
<tr>
<td>1999 GCSE performance*</td>
<td>99%</td>
<td>27%</td>
<td>74%</td>
<td>100%</td>
<td>76%</td>
<td>78%</td>
</tr>
<tr>
<td>GCSE pos°. (England)</td>
<td>153=</td>
<td>3216=</td>
<td>775=</td>
<td>1=</td>
<td>737=</td>
<td>717</td>
</tr>
</tbody>
</table>

* 5 + A*-C grades at GCSE (source: http://www.dfee.gov.uk/)

(p1)(p2)&(p3) = pilots 1, 2 & 3 [5.3.2]
Gender was a factor that could have been explored in this study, but was not for the following reasons:

- Whilst single-sex schools were involved in the study, gender would have been difficult to separate from ability. The boys' schools (A and D) in particular were selective grammar schools catering only for very able students. Observed differences from these groups could, therefore, have been gender- or ability-related.

- Within the mixed-gender classes in the collaborative trials (school E), the unevenness of distribution of map diversity across classes was such that segregation of sexes would have made it more difficult to group students by maximising differences in map-type. The practical limitations of having to sort materials during short breaks between lessons also made the consideration of too many variables impractical.

- During exploratory studies with students to develop the training for concept mapping at school B (Yr 8) and schools C and D (6th Form), differences between the attitudes of male and female students or between the maps they produced (in terms of complexity or gross morphology) were not detected.

- Segregation of data from girls and boys supposes that each of these labels represents an homogenous group. Whilst gender is a discontinuous variable, a focus on this distinction may mask other, more subtle but equally important continuous variables that could be thrown up by the research.

A number of issues concerned with access to institutions for research have been discussed by Flick (1998) and many of these are of relevance to this study. For example, he describes how research can be disruptive to the normal pattern of events.
within an institution. To some extent, the intention of an intervention is to cause disruption by initiating change in elements that are thought to be ineffective. However, teachers are sensitive to influences that disrupt classroom time and so I had to ensure that the time I spent with students was seen by their teachers to be of potential benefit. Flick (ibid.) also warns of problems that can be created by the exchange of too much information between researcher and researched as this can lead to a perception of increased complexity in the research process. To this end, I refrained from giving the collaborating teachers information concerning the theoretical background to my research. Any questions that arose were answered, but only information of a practical nature was volunteered.

The subsequent access to individuals within an institution is also discussed by Flick (1998), who describes two problems: willingness and identification. Whilst the students seemed ‘willing’ to participate in anything that was asked (concept mapping, interviews etc.), teachers offered more resistance. There was a noticeable difference between the degree of teacher-willingness at schools C and D (teachers from D being more willing than those at C). Possible reasons for this are:

- The point of contact at School D was the head of department, whereas at School C, the point of contact was a part-time teacher within the department. The seniority of the contact teacher may influence the way other members of the department co-operate.
- The department at School C was much larger than at School D (6 teachers compared with 3). This, coupled with the timings of sessions which allowed me to sit and chat informally in the prep. room in School D (but not at School C), allowed me to establish a more intimate rapport with the department at School D. This may have resulted in reducing the perceived
threat of being interviewed by me at the end of the teaching sequence (no teachers at School C wanted to be interviewed – all three teachers at School D agreed).

- In a ‘tit-for-tat’ agreement, I taught a number of ‘extra’ concept mapping lessons at School D (Years 7, 8 and 6th Form). Not only did the teachers see this as being of benefit to the pupils, but it also helped them to cover two planned staff absences. Therefore, the teachers saw giving an interview in exchange as a ‘fair deal’.

Identification of ‘interesting individuals’ to interview was not achieved satisfactorily. At School D, all involved teachers were interviewed, whilst at School C, none were interviewed formally. Interviews with pupils were also problematic. Whilst ‘interesting’ pupils were identified from their concept maps, I was reliant upon staff in the schools to ensure that pupils were informed about the dates, times and locations for interviews. Evidently, this information was not always transmitted and received. Pupil absences also caused problems. Though ‘substitutes’ were always listed, teachers often ‘helped’ by arranging substitutes of their own so that I did not have a wasted trip to the school. In consequence, I had little control over the choice of interviewees. Even with these contingencies, I had one visit to School C in which none of the selected interviewees or their substitutes could be located.

6.2 Photosynthesis trials

6.2.1 Introduction

The initial design of the photosynthesis trials was underpinned by my assumptions about the suitability of the experimental paradigm for this investigation [described in Chapter 5] and supported by the concept mapping literature. It was,
therefore, devised as a controlled experiment in which ‘test subjects’ would be compared with ‘control subjects’. This emphasis changed during the course of this trial [as explained in Chapter 5] as the notion of statistical analysis and averaging of results revealed itself as increasingly inappropriate to the analysis of concept maps. ‘Averaging’ suggests an aim of achieving homogeneity in a rather authoritarian and objectivist tradition. In practice, concept mapping is to do with recognising the diversity of understanding and the variety of learning pathways employed by students to achieve personal meaning. Despite this shift in perspective, the quantitative data are described below.

Although a number of weak trends are suggested by the data, the enormous variation in results exhibited within classes of students indicates a need for deeper probing of the data to understand the nature of the developmental changes for individual students. The variability of results can be exemplified by the data from school C (Yr 10, N=234) in which, overall, the average gain score on the photosynthesis test for the test groups (concept mappers) was 1.12, whilst the gain score for the control groups was 0.61. This suggests that concept mapping had the effect of doubling gain scores. However, the range of results for gain scores, even within one test class was from −3 to +12. An analysis of variance confirmed no statistical significance between the results gained for test and control groups. The spread of results from the 12 classes of Yr 10 students at school C is given in figure 6-1. From this it can be seen that gain scores are not distinguishable from one group to the next, either by comparing test and control groups, or by comparing groups of different ability. The results from school D were similar, with average scores suggesting that mappers out performed non-mappers, but with such large variations between individuals that average scores become meaningless.
Figure 6-1

Graph illustrating the variation in gain scores by students at school C.
(Sets 1 – 4, test groups [T] and control groups [C])

Students in set 4 (the lowest ability group) seemed to be confused by the curriculum material and by concept mapping. The concept map reproduced in figure 6-2 typifies this confusion. The student has taken materials from the example map on pond ecology (Appendix 5) and tried to insert part of it into his photosynthesis map, possibly confusing ‘pyramids of numbers’ with ‘concept maps’?
Most of the maps produced by Year 10 students contained a number of relevant terms that indicated a certain level of prior knowledge (as would be expected from Key Stage 3. Various misconceptions are also apparent. The map from a student in set 1.2 (School C) is fairly typical and is given in figure 6-3.

The experimental approach (implicit in sections 6.2.2a and 6.2.2b) yielded data that informed the design of the approach described in subsequent sections, and as such may be viewed as a rich picture building exercise, informing development of subsequent approaches, described below, in the following sections.
Figure 6-3
A concept map of photosynthesis produced by a Year 10 pupil.
6.2.2 Qualitative (SCN) analysis.

In commenting on the need for research into students’ understanding, Sizmur (1996a: 72 – 73) is critical of the typical pre-test/post-test design of experimental studies which, he complains, tell us nothing about the process that contributes to reported gains in learning. He states: ‘There is a need for research which investigates the effect of concept mapping on learners’ cognitive organization’. The qualitative approach to concept map description developed from observations of the photosynthesis trial data is intended to investigate just that.

6.2.3 Comparison of extremes.

The final stage of the grounded approach to investigation (Table 5-2) is described as a comparison of extremes. From the 500+ photosynthesis maps that were gained from Year 10 students from schools B, C and D, a number of maps were identified as extremes:

- Spokes in which there are no developed chains or crosslinks. \( n = 14 \)
- Chains which are single and include no branches. \( n = 11 \)
- Nets which are integrated and not overly linear. \( n = 6 \)

The number of such maps is predictably small. The majority of maps may be predominantly ‘spokey’ or ‘chainy’, but with elements of other categories, suggesting a transition from one structural type to another. As conceptual change is a dynamic process, development through framework categories will be continuous whilst learning is occurring. The qualitative description of concept maps (as spokes, chains and nets) suggests the occurrence of discrete stages, but are actually only labels to describe a dynamic/evolutionary process in which intermediate/transitional stages would be the norm.
Propositions within the extreme maps identified above were all assessed according to the protocol described by McClure et al. (1999) and were also compared against the students' gain scores from the accompanying photosynthesis test. No clear trends were apparent from these quantitative measures. Even with the small number of extreme maps identified, considerable diversity was apparent in accuracy of information included and link quality, with any given map-type occurring across abilities and gender.

6.2.4 Two-tier analysis.

The qualitative SCN scheme described above has the advantage of being quick and easy to use, providing teachers with a simple starting point for concept map analysis. It has been shown, however, that most writers visualize conceptual development (or knowledge restructuring) as occurring at two or more levels (Harrison et al., 1999). I suggest that recognition and consideration of these levels in the concept mapping context will require separate methods of analysis. The qualitative 'spoke-chain-net' classification is able to describe gross changes in a concept map, indicative of radical restructuring, but is too coarse to pin-point details of weaker restructuring. Analysis of maps possessing similar gross structures (e.g. two spoke-style maps - as given in Figures xa and xb) shows that they differ in detail, particularly in the quality of the links used. In order to adequately describe these differences, a finer focus on the details of the map is required.

The quality of the links between concepts was analysed by Ghaye and Robinson (1989). Those authors devised a classification for such links and arrived at seven kinds, which they called structural; functional; locational; procedural; logical; composite and erroneous - these have been applied to the maps in Figure 6-4.
Consideration of links in this way certainly adds to the richness of the description of a concept map and would provide the teacher with a tremendous insight into the depth of understanding displayed by his/her students. However, devising classifications of this kind (which will vary from topic to topic) makes substantial demands on a teacher’s time and powers of analysis. In the absence of suitable published support materials, it seems unlikely that the adoption of such a strategy would be widespread. In the mean time, what is needed is a scheme that can be applied to any domain so that teachers may quickly gain familiarity with its use. It is most likely that a quantitative approach would satisfy this demand. Despite the disadvantages inherent in overall quantitative schemes, when assessing a single element (such as link quality) a numerical description may offer some practical advantages. In their comparison of various scoring protocols, McClure et al. (1999) have shown that the most reliable are probably those which place least strain on the working memory of the scorers. In particular they found that analysis of the quantitative evaluation of propositions within a map is least likely to tax the scorer. This focuses on the links in the map - the element over which students seem to have most difficulty, but which reveals so much about the depth of understanding. Carter (1998: 10) emphasised the importance of these map components when she stated: ‘good proposition construction is an indicator of meaningful knowledge’. The scoring protocol suggest by McClure et al. (1999) is summarised in Figure 6-5 and has been applied to the maps in Figures 6-4 and 7-3.

In combination, these two methods of analysis (qualitative analysis of gross structure and quantitative analysis of links) would seem to provide a valuable tool to highlight key characteristics of maps. This allows teachers to monitor both radical and weak restructuring of students’ knowledge over time by observing changes in successive maps and may help to establish student profiles of development.
An example of a map classified as an ‘extreme chain’ is given below in figure 6-4. Links are described according to the classification given by Ghaye and Robinson (1989) and by the scoring protocol given by McClure et al., (1999):

**Figure 6-4**
An ‘extreme chain’ concept map with indicators of link quality.
Figure 6-5

*Proposition-scoring protocol (from McClure et al., 1999)*

---

**Proposition to be scored**

- Is there any relationship between the concepts of the proposition?
  - NO: Assign a value of 0
  - YES: Does the label indicate a possible relationship between the concepts of the proposition?
    - NO: Assign a value of 1
    - YES: Does the direction of the arrow indicate a hierarchical, causal or sequential relationship between the concepts of the proposition that is compatible with the label?
      - NO: Assign a value of 2
      - YES: Assign a value of 3
6.2.5 Discussion.

There are various reasons for expecting there to be no difference between the test performances of the ‘mappers’ and the ‘non-mappers’ at schools C and D:

- The intervention was too short. Students were not given the opportunity to refine their mapping technique or reflect upon their learning. Concept mapping provides a format for presenting information with which many of the students were unfamiliar. This may have been unsettling and may have required a period of adjustment so students could become comfortable with maps as a presentation style.

- Concept mapping was introduced to pupils too late (Yr 10) in their school careers, at a time when study patterns have already been established. A number of students commented that they preferred to rely on techniques that had ‘got them this far’. Students seemed to think it was too late to try something that was for them ‘new’ and, therefore ‘risky’.

- Teachers involved may have varied in their degree of ‘student-centredness’. There was no opportunity to evaluate this during the research, but it was evident that some teachers found it difficult to let go of the urge to give their students ‘the correct map’. The element of ‘risk’ perceived by some students, was also a consideration for some teachers.

- Teachers were adding concept mapping to their normal teaching – not radically changing their approach to the topic or using concept mapping as an integrated component of their scheme of work. It was therefore, obvious to the students that concept mapping was an ‘add-on’.

- Concept maps require feedback/discussion if they are to aid meaningful learning. Such feedback was not a formalised feature of this intervention. Those
students who were subsequently involved in the interviews appeared to learn from the experience of talking through their maps as much as drawing them.

- Students require time to reflect upon their learning (individually or in groups). Whilst the notion of the spiral curriculum seemed familiar to all the biology departments in which I used concept mapping, the idea that revisiting topics allowed for reflection upon previous learning seemed less so. It seems that topics are typically revisited simple to 'add more detail'.

- Concept mapping was only introduced in biology lessons and, therefore, may have been perceived as a 'special event' rather than as a generally beneficial learning strategy that could be employed across the school curriculum. The students seemed sensitive to anything that was not 'recognised across the curriculum'. Adoption of similar techniques by other departments may have lent more credibility to the concept mapping technique.

- Concept mapping was not incorporated as an activity within tests and is not a feature of public examinations – one of the strongest motivating forces for adoption by pupils in Yr 10. The Year 10 photosynthesis test produced by teachers at school C did not include any concept mapping questions or even questions that referred to a concept map in any way (this would have been unfair to the control groups). The end of topic test was looking at understanding of isolated fragments of knowledge whereas the concept mapping was looking at the integration of knowledge - therefore, they were not measuring the same thing. Additionally, if learning is defined as 'a change in a cognitive system's stable elements' (Petri and Niedderer, 1998: 1075), then testing for elements that are being restructured and have not yet reached 'stability' may prove difficult.
Whilst concept maps show a diversity of starting points for further learning, all the students within a group were given largely the same learning environment – a consequence of the controlled, experimental approach. Teaching was, therefore, not responding to the learners’ needs in terms of weak or radical restructuring, with some students basing their learning upon a misconception and others having valid anchoring conceptions (sensu Clement et al, 1989).

Students who were in an ‘intermediate’ or ‘restructuring’ phase of their learning may be expected to exhibit a temporary deterioration in performance (Schuell, 1990). Paradoxically, a deterioration in test performance may be an indicator of meaningful learning in progress as students construct ‘intermediate notions’ (Driver, 1989: 483). Therefore, tests undertaken immediately after a teaching sequence may contribute to restructuring, with results not providing an accurate indicator of ‘final’ understanding. A lack of correlation between concept mapping and test results might, therefore, not indicate failure of the technique to support learning.

Observations of learning development in individual students using the various schemes described above for assessing map quality would require a longitudinal study [the benefits of which are described in Chapter 8]. Such an approach is beyond the scope of this work.

Teachers were not aware of individual student’s specific learning styles, re: holist-serialist (Adey et al, 1999) and so were not able to help students make most appropriate use of their concept maps - holists to focus on critical details or serialists to appreciate a wider perspective [as described Chapter 3].
6.3 Collaborative mapping trials

6.3.1 Introduction

For collaborative learning episodes to promote learning in individual students presumes the occurrence of a 'mutual construction of understanding', resulting in convergent conceptual change (sensu Roschelle, 1992). However, the synergy present during group does not always carry over into post-test assessments of individual students' understanding (Lumpe and Stayer, 1995), confirming that not only do individual students bring different experiences to a collaborative endeavour, but that they may also achieve various and individualised outcomes. This was acknowledged by Vygotsky when he developed his notion of the 'zone of proximal development'. He hypothesised that children would be able to solve problems with assistance from an adult or 'more capable' peer before they could solve them alone. He concluded that learning consists of the internalisation of social interaction processes. This is emphasised by Scott (1996: 326) who makes the point that 'Learning ... involves a process of internalisation in which concepts are first rehearsed between people, prior to being developed within the learner as an intramental feature'. Hodson and Hodson (1998:40) summarise this as 'social acts become internal processes'. This process of internalisation is seen not simply as the transfer of concepts to the individual, but also their reorganisation and reconstruction by the individual. Webb (1989) states that one of the things the researcher must know in order to understand the effectiveness of collaborative elaboration is whether or not a student can and does internalise it. As an additional complication, Rafal (1996: 282) suggests that 'the learning fostered by interaction does not always take place during the interaction itself', but may result from later reflections upon the process.
Science learning can be viewed as more than a product, but also the process of students’ interactions, in ways ideas are introduced, debated and related to personal and shared experiences (Richmond and Striley, 1996; Woodruff and Meyer, 1997).

Webb (1989: 29) considers elaboration as a 'critical feature of peer interaction'. However, she goes on to say that 'Analysing only the level of elaboration ... is not sufficient to understand students' experiences in the group that lead to increased understanding and higher achievement' (ibid: 35). Earlier work by Mugny and Doise (1978:182) described three points that should be observed to facilitate students’ progress during collaborative interactions:

1) that interactions take place during the elaboration phase of a notion.
2) that verbal communication is essential
3) that the structure of the group influences progress.

One of the major conclusions drawn by Sizmur and Osborne (1997) is that greater elaboration within a group is more likely to result in the incorporation of a particular proposition in the final piece of work. This shows considerable overlap with the conclusions drawn by Hirokawa and Johnston (1989: 513):

as group members communicate private cognitions to others, they receive feedback from those others regarding the validity and relevance of those cognitions. This feedback is subsequently relied upon to modify private cognitions to make them more consistent with the perceived views and sentiments of other members of the group. The result of this process of consensual validation is the creation of 'common points of agreement.'

Other authors have also discussed the distinction between individual knowledge and social knowledge and the requirement for a consensus to establish the latter (eg. Carley, 1986). However, group work is often not organised with the intention of optimizing group structure:

where opportunities were given for pupils to work in groups. eg. on practical tasks, these were rarely organized in such a way as to encourage substantive discussion of the science involved.

(Newton et al., 1999: 567).
Indeed, it is suggested by Sands (1981) that the major reason for arranging students into groups is more to do with organising ‘bodies’ within the classroom than as a specific teaching strategy. I was, therefore, sensitive to the reactions of the teachers concerned to my intention to ‘organise minds rather than bodies’ as a strategy to improve learning.

6.3.2 Results

It was suggested in Chapter 3 that comparison of students’ concept maps with expert-generated maps may provide a method of evaluating the development of students’ understanding of a topic. Teachers in schools E and F were reluctant to offer concept maps of their understanding of modules taught to Year 8 students. However, one physics specialist from school E did volunteer such a map (figure 6-6). The Head of Science (also a physics specialist) subsequently verified this as being a fair representation of the material that the students should understand by the end of the module. This summary is also shown as a list of the 27 propositions that can be extracted from the concept map (in table 6-2).

159 maps from 53 students across three mixed ability Year 8 groups (School E) were analysed to determine the degree of overlap with the ‘expert view’ at three stages after instruction of the material was completed: individually (pre-collaboration), collaboratively in groups of three and again, individually (post-collaboration). The pre-collaboration maps were constructed under test conditions in the classroom, the post-collaboration maps were produced as a homework activity.

The collaborative groups of three students were constructed on the basis of the gross structure of their pre-collaboration map (re: ‘spoke-chain-net’). This was arranged so that some students were deliberately teamed with students who had produced complementary map structures (ie. a student with a spoke-style map was
teamed with a student with a chain and a student with a net). These are heterogeneous or 'different' groups. Others were deliberately arranged so that the group members all had very similar map structures (i.e. all spokes or all chains or all nets) and are termed homogeneous or 'same' groups. Only gross structure was considered here. There was no determination of link quality or validity of concepts included.
Figure 6-6
Expert concept map of Year 8 sound module constructed by a teacher from school E.
Table 6-2
Propositions extracted from the ‘expert map’ of sound given in Figure 6-6.

1. SOUND is made by VIBRATING OBJECTS
2. SOUND is a PRESSURE WAVE
3. SOUND has a QUALITY
4. SOUND is useful to COMMUNICATE
5. VIBRATING OBJECTS cause a PRESSURE WAVE
6. The PRESSURE WAVE is LONGITUDINAL
7. The PRESSURE WAVE has a WAVE FORM
8. The PRESSURE WAVE has different AMPLITUDES
9. The PRESSURE WAVE has different FREQUENCIES
10. The WAVE FORM affects sound QUALITY
11. AMPLITUDES correspond to VOLUME
12. FREQUENCIES correspond to PITCH
13. FREQUENCIES are measured in Hertz
14. VOLUME is measured in DECIBELS
15. VOLUME is picked up by the EAR
16. PITCH is picked up by the EAR
17. PITCH that is too high to hear is ULTRASOUND
18. Hertz of between 20 - 20,000Hz are within the HEARING RANGE
19. The EAR has a HEARING RANGE
20. Too many DECIBELS cause NOISE POLLUTION
21. NOISE POLLUTION causes STRESS
22. The EAR can be damaged by NOISE POLLUTION
23. The EAR helps to COMMUNICATE
24. The EAR cannot hear ULTRASOUND
25. ULTRASOUND is used in CLEANING jewellery
26. ULTRASOUND is used in RANGE FINDING in submarines
27. ULTRASOUND is used in SCANNING during pregnancy
Comparison of student pre-collaboration maps with the expert map shows very little direct overlap (Fig. 6-7), with an average of only 1.3 expert propositions per student map.

![Graph showing the average number of propositions exhibited within students' (n=53) concept maps of 'sound' – indicating the number shared with the teacher's 'expert' map and those that are not shared (ie. non-expert).](image)

It is noted that 'non-expert' does not equate with incorrect. For example, a number of students included the idea that sound cannot be heard in a vacuum (a valid, but non-expert proposition), whilst others referred to 'molecules of sound' (an incorrect proposition and so necessarily 'non-expert').

The growth in the number of expert propositions from the pre- to post-collaborative scores is found to be statistically significant at the 1% level of significance using a student t-test. This is particularly significant when it is considered that there was no teacher-input to the collaborative episodes. As a percentage of total
propositions within the students' maps, the average proportion of 'expert' propositions rose from 10.57% in the pre-collaborative maps to 17.8% in the post-collaborative maps. Whilst the total number of propositions rose from 13.6 to 15.9 – indicating some convergence with the expert view.

Consideration of sub-groups within the sample of students adds to our understanding of what is going on in the learning process. The average gains in the number of expert propositions (from pre- to post-collaboration) in these groups is shown in table 6-3. The high variability in the small sample results in a lack of statistical significance. Too few net-type maps were produced to allow different and same groupings to be compared.

Table 6-3 Increase in expert propositions in collaborative groups.

<table>
<thead>
<tr>
<th>MAP STRUCTURE</th>
<th>GROUPING</th>
<th>n =</th>
<th>Mean increase in expert propositions (mean for total pop(^n = 11))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOKE</td>
<td>DIFFERENT</td>
<td>6*</td>
<td>0.7 (SD 0.9)</td>
</tr>
<tr>
<td>SPOKE</td>
<td>SAME</td>
<td>13</td>
<td>1.9 (SD 1.7)</td>
</tr>
<tr>
<td>CHAIN</td>
<td>DIFFERENT</td>
<td>7*</td>
<td>1.3 (SD 1.2)</td>
</tr>
<tr>
<td>CHAIN</td>
<td>SAME</td>
<td>4*</td>
<td>0 (SD 0)</td>
</tr>
</tbody>
</table>

*Low numbers due to 'non-returns'.

The performance of the subgroups indicated in Table 6-3, suggests that Spokes promote learning and Chains hinder it, though the numbers involved and the variation recorded mean that such a generalisation has to be tentative.
6.3.3 Discussion

Items in the top two levels of concepts from the expert map (particularly ‘pressure wave’; ‘wave form’; ‘amplitude’; ‘quality’ and ‘longitudinal’) were almost totally absent from the students’ maps. Students tended to concentrate on the concepts that appear lower down the expert map (particularly ‘volume’; ‘decibels’ and ‘ear’). This shows that those concepts that define the overall structure for the teacher do not fulfil the same role for the students. Their map structures tended to be dictated by more familiar notions, such as ‘music’, into which they tried to fit the ‘more scientific’ ideas. This reflects the comments made by Gott and Johnson (1999) that our curriculum is constructed from the perspective of established science rather than from the needs of the students. The result is that personal relevance is lost.

Research studies into children’s understanding of sound have shown confusion in children’s discussions of sound properties that are consistent with those suggested above (eg. Driver et al., 1994; Mariano, 1998a; 1998b).

Interpreting the graph in figure 6-7, one might have anticipated the overall increase in propositions from the pre-collaborative maps to the collaborative maps (136 to 1795) as the students pooled information and explored each others ideas. Some of this information then appears to have been ‘filtered’ in the production of the post-collaborative maps with students discarding ideas with which they were not happy (the total number of propositions dropping slightly from 1795 to 159). More surprising is that the number of ‘expert propositions’ included did not fall in the same way, but maintained a slight increase. This suggests that students were reflecting upon the ideas presented in their maps and this may have helped them to recall information from their lessons on sound.
6.4 Microbiology evaluation

6.4.1 Introduction

This investigation was conducted in the context of a 1st year undergraduate microbiology course, between September 1998 – December 1999. This is a generic course, catering for students (n ≈ 150-180) who will follow various degree tracks in their 2nd and 3rd years – including nursing, nutrition, biochemistry, medical microbiology and environmental science. The course was structured as four blocks of lectures (microbial diversity; environmental microbiology; medical microbiology and industrial microbiology).

Even though marks gained on this course were generally good, the motivation for this investigation arose from lecturer-dissatisfaction in the students’ ability to appreciate microbiology as an integrated body of knowledge that has implications for numerous other branches of biology. The course co-ordinator had a genuine desire to gain a better understanding of the students’ perspective on the course and try to identify potential difficulties and misconceptions so that this could inform teaching in subsequent years. The enthusiasm of such a key staff member was seen as crucial for the success of the project.

Concept mapping was considered by the course co-ordinator as appropriate for use as the main tool for this research. Previous studies have shown it to have a dual role as a device that can both promote and assess conceptual change in a higher education setting (eg. Gravett and Swart, 1997; Jonassen et al., 1997).

The investigation was run over two years with successive cohorts of students. The methods used evolved during this time and can be recognised as two stages, described here as phase one and phase two. Phase one was seen as exploratory in which the data gathered was instrumental in defining the method for phase two. This
may be regarded as a 'rich picture building phase' (sensu Checkland, 1999), providing
the data upon which phase two would be grounded.

Students involved in phase one were given a 1 hour introduction to concept
mapping [5.3]. The session ended with a summary of seven 'golden rules' for concept
mapping:

1. Concept labels are written in boxes
2. Major concepts appear at the top of the page and more specific concepts appear
   lower down
3. Each concept can only be written in one place on the map
4. Links have arrowheads to show the direction in which they should be read
5. Links must have labels (words or phrases) to give them meaning
6. There can be any number of links coming from or going to a concept box
7. Do not include so many concepts that the overall structure becomes unclear.

The generation of such 'rules' was in an attempt to standardise map format to ensure
enough commonality between them to allow comparisons to be made. Students were
then asked to draw a concept map with 'microbiology' as the top concept. The choice
of other concept labels was completely free. This was considered to be the ‘pre-
instructional map’ and represented the students’ starting points for further learning.
Time for subsequent maps to be drawn was given at three points in the course, in
15 minute slots at the end of lectures. Maps were handed in immediately after
completion and were not returned to the students.

An example of one student’s pre-instructional map is given in Fig. 6-8. This
map was typical in the way that the concept labels ‘bacteria’, ‘viruses’ and ‘fungi’
determined the overall structure. It is also typical in its inclusion of ‘disease’ and in the
lack of diversity of the linking phrases. A total of 542 first phase maps were analysed
by reference to link quality, hierarchy and connectedness, from which a number of patterns emerged. These patterns had implications for the development of the approach to phase two.

6.4.2 Key findings from phase one and responses

Consideration of the maps suggested a number of possible improvements to the course. Acceptance of some of the possible innovations would have required members of the teaching staff to undergo a radical restructuring of their conceptions of teaching and learning, away from the whole-class, teacher-centred, non-interactive mode of lecturing that dominates university science teaching (Bodner et al., 1997). Whilst the course organiser was keen to adopt a more student-centred approach, local constraints meant that only minor alterations to the course structure and mode of delivery were possible in the short term. As Christianson and Fisher (1999: 696 – 697) have pointed out ‘Lecture teaching is as resistant to change as many students’ naïve conceptions’. The economic benefits of having one lecturer addressing 160 students gives the method a real advantage over other approaches that may be more costly in terms of staff time. Other factors were identified that could be addressed without being perceived as a threat to the teaching status quo:

6 - 30
Figure 6-8
An individual student's concept map of 'microbiology'.
The pre-instructional maps gained were dominated by a taxonomic perspective of microbiology, with ‘bacteria, virus and fungi’ determining gross map structure for the majority of students (eg. Fig. 6-8). This had been inadvertently reinforced by the sequence of introductory lectures on microbe taxonomy that had been intended to provide the students with the necessary terminology that they would meet in subsequent lectures. However, this sequence seemed to have acquired the function of an advance organiser and was used as a ‘course route planner’ by the students.

Emphasis on microbial taxonomy may have also triggering a cognitive switch between conceptual frameworks (sensu Palmer, 1999), as the general taxonomic terms (eg. bacteria, virus, fungi) have associations with non-scientific contexts within which they are commonly used. Microbiology is such a general topic that its informal understanding is influenced by numerous popular and non-scientific sources. When this is recognised, understanding of key concepts at the beginning of the course was likely to exhibit qualitative differences among students and between students and lecturers. Prosser and Trigwell (1999: 165) point out that ‘prior experience need not be conceived of as stable entities that students and teachers bring with them to learning and teaching situations, but as dynamic entities related to their present situation’. Therefore, the taxonomic introduction that activated particular prior knowledge, needed to be divorced from the main body of the course to emphasis that it was not intended to indicate the overarching framework upon which to hang subsequent concepts.

Once locked into the ‘taxonomic view’, it appeared that students found it difficult to radically restructure their maps. Subsequent maps were refined and included additional concepts, but consistently adopted the same overall structure. This is in agreement with the findings reported by Pearsall et al. (1997) who found that
radical restructuring of superordinate concepts at the highest level occurred more frequently in the early part of a course. It is clear from this that not all prior knowledge is helpful for further learning in a particular context, as summarised by Pintrich et al. (1993: 170):

*a paradox exists for the learner; on the one hand, current conceptions potentially constitute inertia that resists conceptual change, but they also provide frameworks that the learner can use to interpret and understand new, potentially conflicting information*

It is therefore, vital to activate the appropriate prior knowledge for a given context. To achieve this in the second phase:

- Concept labels would be given to the students (excluding key terms ‘microbiology, bacteria, virus, fungi’)
- The separation of the introductory lectures on microbe taxonomy from the main body of lectures on microbial processes would be emphasised by the inclusion of an interim test.

The lack of an explicit guiding framework meant that students were unclear as to how to structure their maps. The headings of the four lecture blocks might have suggested some key concepts, but this was not picked up by the majority of students. During the repeated mapping exercise, many students showed little commitment to any organising principle in the choice of higher order concepts, as exemplified by maps produced by ‘Julie’, a biochemistry specialist:

[TOP CONCEPTS that appeared directly below MICROBIOLOGY]

**Map 1:** Technology, Medical advances, Food Production, Cells

**Map 2:** Viruses, Bacteria, Fungi, Protists (=VBF & P)

**Map 3:** Micro-organisms, Environment, Bioremediation

**Map 4:** Environmental issues, Industry, Medical advances, Studying VBF & P.
The initial organising principles in Julie’s map 1, seem to have been corrupted by the introduction of microbial taxonomy at the beginning of the course (map 2). Subsequent coverage of environmental microbiology (map 3) requires a reorganisation of these ideas with a reintroduction of some of the initial ideas in map 4 as the material is covered at the end of the course. Julie, like other students, is not clear how to integrate VBF & P with the rest of her map.

From this it is clear that the course lecture schedule is not used as an advance organiser for the course. Production of a more explicit framework as an advance organiser might have reduced the amount of restructuring that students such as Julie had to cope with during the course.

There are a number of procedural factors, which may have contributed to our perceptions of the problems described above, and may have prevented the students from revealing in their concept maps what they really understood. These include a lack of time for adequate reflection; a lack of motivation to engage in the activity and a lack of opportunity to discuss their thoughts with others. These problems required consideration before implementing phase two:

The time given for concept mapping at the end of a lecture was probably not enough to allow students to reflect upon earlier maps. This may have encouraged them to reproduced earlier versions without much modification or consideration.

- **Students would be given several weeks to produce maps at their own pace.**

The mapping activities in phase one were not formally assessed and did not contribute to the students’ final grade for the course. Neither was any feedback given to the students as it was felt that the mental effort involved in the act of producing the map was of key importance rather than the awarding of any summative grade. This created some unease among the students and the motivation to complete maps declined.
during the course. It was, therefore, felt necessary to provide greater incentive for active participation in concept mapping activities, and the easiest way to achieve this would be to link it to course assessment. Therefore, in phase two:

- The concept mapping assignment would contribute 20% to the final course grade.

Given the large size of the class (~160 students) individual feedback provided by lecturers on students’ maps was not possible and this was seen as a weakness in this course. Previous studies have shown that the key benefits of concept mapping are concerned with improving the process of learning and in providing formative feedback through discussion and debate over maps within collaborative groups (eg. Regis et al., 1996; White and Gunstone, 1992). I agree with Lord (1998) that students need time to discuss their thoughts and ideas so that they can test their assumptions and correct misinterpretations in a non-threatening learning environment. It was felt that if students were given the chance to discuss their maps in peer groups, they might be able to develop and reorganise their ideas more effectively. The experience of the previous year’s cohort suggested that the majority of students would not spontaneously engage in discussions based on their concept maps – the teacher’s desire that this collaboration should take place would have to be made explicit. Therefore, in phase two, concept mapping would be focussed in:

- One formal collaborative exercise, indicated on the course schedule.

6.4.3 Second phase task

Course development continued into a second year, with a new cohort of students. Students involved in phase two, were given the same 1 hour introduction to concept mapping as students in phase one, but were not asked to draw a ‘pre-
instructional' map of microbiology. Students were informed that there would be an assessed concept mapping assignment given to them later in the course and were advised to experiment with the technique before then by producing concept maps that summarise textbook chapters or the content of lectures.

A collaborative concept mapping exercise was devised in response to the findings from phase one (summarised in the five bullet points above). The intention was to ‘wean’ students away from the taxonomic model of microbiology as it was not considered to be the focus of the course; the application of microbial processes was seen as being of greater concern. The students were allocated to groups of five. The allocation was alphabetical by surname. The groups were given a list of 20 concept labels (shown in maps 6-9 to 6-12) that had to be included on a single map that summarised the content of the course. None of the taxonomic concepts that had dominated student maps in the previous year were included in the list. In this way, it was intended that the students would be forced to reconceptualise microbiology in terms of processes and interactions. Groups were requested to write a paragraph of explanatory notes to annotate each link in their map with annotations referring to microbial processes and named examples. This assignment was set after the taxonomic introduction and associated test were completed and was to be submitted just before the end of the course. This was considered to be a challenging activity as the ‘answer’ could not be found in any textbook and, in any case, there was no single correct or best answer. Students were given 6 weeks to collaborate with their peers, reach a consensus and produce a group map and supporting comments for submission.
The maps that were submitted raised a number of issues. These are discussed below and are illustrated by reference to the examples of group maps given in figures 6-9 to 6-12.

Whilst scoring of maps was not seen as the main purpose for the activity, it was felt necessary to provide students with an extrinsic motivator for engagement with the task. As Novak and Gowin (1984: 97) pointed out: ‘because we live in a numbers orientated society, most students want to score concept maps’. In order to provide a score out of 20 for the final assessment, a maximum of 5 marks were awarded for overall structure (hierarchy, clarity and integration); 10 marks for links and annotations (the annotations generally ran to several pages of typed explanation) and 5 marks for absence of mistakes (glaring omissions and misconceptions). All marks were awarded by the course organiser. The assessment scheme was made explicit to the students.
Figure 6-9
A collaborative group's concept map of 'microbiology'
Figure 6-10

A collaborative group's concept map of 'microbiology'
Figure 6-11
A collaborative group's concept map of 'microbiology'
Figure 6-12
A collaborative group's concept map of 'microbiology'
6.4.4 Results

A number of maps generated in phase two were considered to be well-organised, exhibiting a clear and logical structure (eg. Fig. 6-9). In such maps, the clusters of concepts are appropriate, interconnected and the hierarchy within each sequence appears justified. Even within such maps however, there are usually criticisms that can be made of the detail. In figure 6-9:

- A number of similar links (‘affected by’) could have been elaborated for greater clarity. The link between ‘agriculture’ and ‘plant pathogens’ has been augmented by the inclusion of ‘adversely’. Others were clarified in the annotations provided.
- The role of ‘nutrients’ seems unclear from the map, suggesting that the function of agriculture is to provide nutrients for invertebrates.

The overall arrangement of some other maps was much less clear or logical. An extreme example is shown in Fig. 6-10. Here, linking phrases were not included on the map though each link was numbered (not included here) for reference to the annotations provided. The propositions within the map do not follow on from each other in logical sequences and so are effectively representing isolated ideas. The mass of links going in all directions gives the map a chaotic appearance and suggests that the arrangement of concept labels is inappropriate. Whilst a connection from any concept to any other concept in this map may be justifiable as they are all related by the ‘umbrella’ of microbiology, the group demonstrates an inability to identify and highlight important links that may clarify understanding. The apparent arrangement of the map into three chains is purely cosmetic, with ‘human waste’ isolated near the top of the left-hand chain and the central chain is broken between ‘organic matter’ and ‘infectious disease’. The implied hierarchies in these ‘false chains’ are not justifiable and were not clarified in the annotations provided by the group.
Overall, the group maps from phase two indicate a higher level of integration than most individual maps produced in phase one. An exception to this is the map shown in Fig. 6-11, which is suggestive of a limited perspective of the subject. This map is dominated by a central chain and exhibits a lack of diversity of linking phrases – variations on ‘needs’ account for three of the seven links in the central chain. Both of these characteristics are indicators of a lack of expertise. This map was actually produced by an individual student who failed to collaborate with the other members of his group. The difference between this map and the other group maps illustrates the benefits to be gained from collaboration with peers who may bring an alternative perspective to the debate for consideration.

Whereas ‘carbon cycle’ was omitted from the map in Fig. 6-11, the group who produced the map in Fig. 6-12 selected it as their top concept. Whilst this is a different starting point to that selected by the majority of student groups (or anticipated by the course organiser), the overall structure of the map is seen as clear and logical with appropriate clustering of concepts. Although ‘human health’ is placed in a lower hierarchical position than in most group maps, it is still employed as a key concept with more links than any other concept label in this map. The choice of the top concept was expected to be one of the factors that influenced map structure. Of the 32 group maps that were submitted in phase two, over half (17) had ‘human health’ as the top concept. This was in agreement with the course organiser’s perception of the course. Other choices were ‘organic matter’ (4); ‘carbon cycle’ (4); ‘enzymes’ (2); ‘water/food quality’ (2); ‘invertebrates’ (1); ‘agriculture’ (1) and ‘nutrients’ (1). Whilst some of these are seen as more appropriate than others, the choice of an appropriate top concept is not a guarantee that the rest of the map will be well-organised (eg. Fig. 6-10). Equally, some less popular top concepts can provide the starting point for a valid and
clear map of the domain (eg. Fig. 6-12), demonstrating that alternative perceptions can be equally as valid as the course organiser's view.

One surprise was that no specific examples (ie. names of microbes or specific processes) were used in any of the group maps to anchor subordinate concepts. This was in spite of the fact that it was suggested during the introduction to concept mapping and that so much lecture time was devoted to detailed description of specific examples. This function may, however, have been subsumed by the detailed annotations provided by the groups.

The placing of ‘less popular’ concept at the top of the map by some groups (such as Carbon cycle) indicates that it is quite possible for there to be ‘alternative correct answers’. Views on the appropriateness of a top concept may have depended upon the students’ intended specialism in subsequent years.

Links used in the maps may describe complex ideas in one or two words. The selection of appropriate terminology may be used by the students to disguise a lack of understanding It was, therefore, important to probe the meaning of links by discussion or by annotations. For example: links such as ‘improve’ soil quality, but what does this link mean? How is soil quality improved? Equally, ‘has an effect on’ is ambiguous – is the effect positive or negative?

6.4.5 Discussion

The diversity of the maps received during both phases emphasises the distinction between ‘information’ and ‘knowledge’ (sensu Blais, 1988). Whilst all the students were ‘given’ the same information, this was translated into various knowledge structures reflecting the range of conceptual ecologies (sensu Strike and Posner, 1992) within the student population.
Producing a map without using either the central concept label (eg. 'microbiology') or labels with meanings in other contexts (eg. 'virus', 'fungi') forces the mapper to reconceptualise the topic rather than just regurgitate ideas associated directly with the central idea. This demonstrates a distinction between concept mapping and 'Mind mapping' (Buzan and Buzan, 1993). Whereas mind mapping helps rapid brainstorming of ideas and formation of simple associations with related concepts, concept mapping is a more reflective process and emphasises the 'how' and 'why' of such links. The two tools may, therefore, be seen as complementary.

As the final maps were a group effort, there can be no guarantee that individual students share a common framework of understanding that it may represent. This is not the point. The fact that students were able to engage in a discussion to consider the connections between major concepts from the course is seen as much more important. This is something that previous cohorts of students were not given the opportunity to do. Individual differences and idiosyncrasies in understanding are not intended to be extinguished by this process, but should be offered for comparison with other perspectives brought by students with different conceptual ecologies, in order to promote conceptual change or consolidation.

It is possible that certain concept labels do not feature within the students' 'microbiology' framework. For example, 'food quality' and 'nutrition' may be filed under Nutrition whilst 'carbon cycle' and 'biological control' may be filed under Ecology. These would not then be activated by the stimulus provided by the course title and so not appear in students maps even though they may be present within an individual’s conceptual ecology. Nutrition and Ecology may be 'pigeon-holed' by students at A-Level, emphasised by modularization of their courses. Therefore, prior understanding is not helpful here as it is not evoked by the microbiology context.
Reflecting on the maps produced, it would seem that some of the concept labels in the list of 20 given to the groups were inappropriate because they were too general. In particular, the labels 'enzyme' and 'nutrients' are seen as all-pervasive in biology and are therefore difficult to assign a single position within a concept map. This was highlighted in a comment volunteered by one of the groups as a preface to their annotations:

The top concept was debated and it was eventually agreed that we would each build two concept maps one with nutrients as the top concept and another with human health. Human health was chosen because it appeared to be effected either directly or indirectly by the majority of concepts in the list. Nutrients were chosen — because everything living, from microorganisms to human beings have a common need for nourishment.

At the third meeting, it was decided, by a majority vote, to use nutrients as the top concept. Enzymes were considered briefly, because they seemed to feature in all three of the main themes we had identified [medical, industrial and environmental microbiology]. Industrial provided some good links between the other two. We had several different concept maps to integrate; most were very complex with many different links. Following much debate and with some compromises, the group were very satisfied with the concept map produced.

The students are describing a process in which individually generated maps act as the 'grounded' data used in the construction of an aggregated map, by providing a device for facilitating negotiation, as anticipated by Eden (1988).

The choice of an all-pervasive concept such as 'nutrient' to go at the top of a map may lead to a 'flat hierarchical' structure — similar to the 'spoke' arrangement described above. This happens as the mapper tries to show how it links to all the other concepts. This process results in obscuring the major links and the hierarchical relations between the other concepts. In addition, this group recognised the importance of considering multiple perspectives to enrich their ideas:

'On balance, the team was stronger for having members who were ultimately studying different subjects, each member managing to broaden the perspective of another.'

Unfortunately, the follow-up interviews that had been intended to contribute to respondent validity in this case were not possible as a result of logistical constraints that were beyond my control.
7.1 Quantitative analysis.

Overall, the quantitative analysis of concept mapping data presented here has demonstrated the inadequacies of reducing the results from a concept mapping exercise to a simple numeric value. Observed changes are complex and varied, indicating much about the individualised process of learning. Like other authors, Morine-Dershimer (1993: 20) has commented on this:

Because concept maps are graphic devices for displaying relationships among concepts and elements, an analysis confined to numbers clearly loses something in its translation of results.

However, the literature offers few practical alternatives and has tended to concentrate on improvement points and gain scores as indicators of change, calculated using variations on the scoring protocol devised by Novak and Gowin (1984). In the much cited meta-analysis given by Horton et al. (1993), there are three papers (that I described in Chapter 4 as the most significant from that study's sample, Lehman et al., 1985; Heinze-Fry and Novak, 1990 and Schmid and Telaro, 1990) that are revisited here. The problems associated with the quantitative analysis of concept maps were rather overlooked in those papers, and can now be evaluated in the context of the work described herein. Papers such as these inevitably guide the construction of further research, but may offer a flawed platform from which to progress.

* elements from this chapter have been accepted for publication as:

The assumption that a quantitative approach to concept map analysis is the most appropriate is implicit in the style of those papers and the comments within them. When improvement marks for concept maps are awarded on the basis of Novak and Gowin's (1984) scoring protocol [figure 3-7], it is not possible to see how the improvement has been achieved solely on the basis of the score awarded. A large improvement in score may be attributed to a small change in the map and *vice versa* (Fig. 7-1). If students have been told that cross-links are particularly valued, some of them may be 'playing the system' by concentrating on these in preference to other possible additions and so boosting their scores disproportionately.

*Figure 7-1*
*How Novak and Gowin's (1984) scoring protocol can mask the quality of change within a student's concept map. Changing one element from the map on the left can change the score from 8 to: 9 - by adding one extra link 14 - by adding one layer of hierarchy 18 - by adding one cross link.*
The scoring protocol developed by Novak and Gowin (1984) also gives weighted credit to the hierarchical structure presented in a map. Whilst this seems theoretically justified, in practice intended hierarchical relationships are difficult to interpret from students’ maps (Figure 7-2):

Figure 7-2
*Problems with interpreting hierarchy from concept maps.*

Maps 1 and 2 in figure 7-2 are structurally the same, but because two of the subordinate concepts are placed on a lower level than the others in map 2, this is counted as an extra layer of hierarchy and so awarded an extra five points. In practice, students will separate concepts in this way to make their map look less cluttered and to leave more room for linking labels across the line of their page. Maps 3 and 4 are also
structurally the same: the angle of the link from the bottom right hand concept box
implying a hierarchical link (in map 3), but a cross link in map 4. The hierarchical
nature of the link can only really be confirmed by the nature of the language used in
the link. Novak and Gowin (1984) only consider the validity of each link rather than its
quality – a property that has been shown to exhibit considerable variation (eg. Ghaye
and Robinson, 1989; McClure et al., 1999), and to be an important indicator of
understanding (Carter, 1998). In this way, much of the Novak and Gowin scoring
protocol is based on the quantity of knowledge presented rather than the quality.
Structurally similar maps can be seen to be qualitatively very different. The two maps
of ‘sound’ in fig 7-3 have a similar gross structure, but the links within them suggest
differences in the quality of understanding that is represented. This can be illustrated
by applying the scoring protocol for link quality given by McClure et al. (1999). This
results in a score of 6 for the top map and 13 for the lower map.

Figure 7-3
*Differences in link quality can be used to separate structurally similar maps*
These problems are illustrated below by some examples taken from the collaborative mapping exercises with Year 8 students at School F:

**First Case: Xiao**

Xiao was a bright pupil. Her first language was Chinese and she clearly had difficulty in expressing her thoughts in English. When I spoke to her in class, she was frustrated at not being able to explain her ideas to me. The textbook that the class was using was not helping her – she knew many of the key ideas, but was unable to cope with the English explanations.

![Figure 7-4](image)

*Figure 7-4*  
Xiao's first concept map

Xiao's first map (Fig. 7-4) was quite simple. Some of the links are not labelled and so it is difficult to see what she really understands. Her final map (Fig. 7-5) shows a number of developments.
Figure 7-5
Xiao's final concept map
Xiao’s final map provides a more detailed structure and would provide a better focus for a student-pupil discussion about her understanding.

- There are some duplications within the map: the section leading from ‘air’ could be moved across to join with the section leading from ‘lung’.
- Her inclusion of ‘resparation’ requires some exploration as the link (‘needs’) does not suggest a clear appreciation of the link with breathing.
- The role of energy seems very confused in this map. Xiao (like many other students in this class) has linked smoking to a lack of energy. Whether this was her idea or something she had picked up from her peers is not clear, but the widespread existence of this misconception among the students needed to be addressed.

Upon production of her final map, Xiao appeared to be more confident in talking to me about her understanding of the topic, using her map as a support and indicating where an idea should go when her spoken English let her down. In a school with a large number of overseas students, concept mapping seems to offer a way of explaining complex ideas without writing large blocks of text. Xiao had been grouped with students offering different maps structured for the collaborative exercise.

**Second case: Gemma**

Gemma was an average ability student. Like many students’, Gemma’s first map (Fig. 7-6) was dominated by chains. Novak (1988) considered such structures to be indicators of rote/verbatim learning, and this seemed to be the case with Gemma who seemed to have a large array of ideas that were poorly arranged without any notion of hierarchy. Some of Gemma’s links are quite elaborate and may reflect her ‘chatty’ personality.
Figure 7-6
Gemma’s first concept map
Gemma’s second map retains the domination by chain structures (she had been grouped with students who also had ‘chainy’ first maps). There are, however, a number of differences within her final map (Fig. 7-7) that may be significant:

![Diagram of Gemma's final concept map]

**Figure 7-7**
*Gemma’s final concept map*

Gemma’s final map has been simplified from her first effort. Such a simplification may be a necessary prerequisite to restructuring (sorting the wheat from the chaff). Other developments include:
• Her two chains seem to offer a distinction between anatomical structures and the
gasses involved in breathing, though she has still not produced any links between
the two strands.
• There is a suggestion that she has started to organise some thoughts in a more
hierarchical fashion – with oxygen and carbon dioxide now placed on a common
level (nitrogen appears to have been discarded as not important).
• Smoking has been omitted. It is not clear if this is a conscious decision, or if she
was simply too lazy to draw it all out again.

All of these changes require a dialogue between teacher and pupil to really evaluate
their significance, but they do offer a route into a discussion.

**Third case: Becky**

Becky was a very able student who’s initial concept map suggested a highly
structured and organised framework for ‘breathing’. In her first map (Fig. 7-8) she has
produced an approximately hierarchical structure with a cross link from the gasses
involved (on the right) to the structures involved (on the left). However, even in this
map, Becky has not really explained breathing in terms of gaseous exchange. She has
got side-tracked into telling us what she knows about the circulatory system and also
indicates a typical lack of understanding concerning the place of ‘energy’ in her map.

In her final map (Fig. 7-9) she has:
• attempted to explain the relationship between energy and respiration
• she has reduced the discussion of the circulatory system
• she has included the problems associated with smoking.

This brief illustration of three students’ development serves to illustrate the variety of
starting points and developmental pathways exhibited by students in a single class.
Figure 7-8
Becky’s first concept map.
Figure 7-9

Becky’s final concept map.
Scoring the maps produced by Xiao, Gemma and Becky would not have indicated the sort of subtle changes that are described above. However, if Novak and Gowin's scoring protocol is applied to extreme spoke, chain and net type concept maps, it can be seen that implicit in this scoring scheme is a progression from spokes, to chains towards nets (fig. 7-10). This is evident from the increasingly weighted scores given to links (1), hierarchy (5) and cross-links (10) respectively.

![Diagram](image)

**Figure 7-10**

*Scoring maps A = 11, B = 42, C = 44.*  
*(scores given have assumed that all links and hierarchies are valid).*

Whilst in this instance, many of the hierarchical levels indicated in the chain (B) are not valid (eg. 'male parts' are not superordinate to 'female parts'), it can be seen, none-
the-less that two qualitatively very different maps could achieve very similar scores. The teacher would have to reflect on the scores and decide if map C is really 4 times as ‘good’ as map A, or is this difference only an artefact of the scoring system?

Scoring in this way emphasises the learning that has been achieved and does not indicate an amenability to develop. If map C is more robust, it may also be less flexible and hence a less valuable starting position for future learning.

In addition to the problems created by Novak and Gowin’s scoring protocol, some other key features from the three ‘significant’ papers from Horton’s meta-analysis are identified and explored here. Horton’s analysis concentrates exclusively on studies that offer quantitative data – probably for ease of comparison in the meta-analysis and possibly reflecting a bias toward ‘traditional, experimental’ research designs. However, the quantitative results given in the three papers are inconclusive, with two concluding no statistically significant difference between control groups and test groups (Lehman et al., 1985; Heinze-Fry and Novak, 1990) and one only showing significance for certain types of students when responding to certain types of question (Schmid and Telaro, 1990). Despite this, average results were seen to be better for mappers than for non-mappers and these results are seen as ‘indicators of a tendency toward an effect of the experimental treatment’ (eg. Lehman et al., 1985: 670). In all three papers, the most positive elements of their conclusions are derived from more qualitative and intuitive observations.

None of the three papers discussed gave in-depth consideration of the environment for learning with concept mapping being ‘tacked on’ to lessons rather than being indicative of an overall approach or underlying epistemological belief. For example, Schmid and Telaro (1990: 80) explain how

the instructor introduced the content in the normal fashion [mainly lecturing] and, at the appropriate point, set aside time for each student to create a map of a specified concept.
The possible conflict that this could generate between constructivist and objectivist traditions is not mentioned by Schmid and Telaro, nor is the influence of the concept mapping tasks on the teachers' perceptions of their students' learning. Indeed, the impact of teachers is not only poorly discussed in these papers, but is seen as irrelevant to the research process:

Because ... the teachers were all of similar experiences and ability ... [they] were not considered significant influences in this study.

(Lehman et al., 1985: 669).

This should raise a query. If teachers are not significantly influencing what goes on in their classrooms, what are they doing there? Through their personalities and classroom performances, teachers are one of the strongest influences in the science classroom (eg. Reiss, 2000).

In striving to conduct controlled, laboratory-style experiments, these authors have attempted to neutralize (or ignore) contextual factors which may have had most influence upon their results (Cobern, 1993). Overall, these papers can be criticised for focusing on a single element of the total classroom milieu to the exclusion of other factors – precisely the criticism that can be leveled at the general quality of science teaching and assessment which concentrates on isolated fragments of understanding, extracted from the context that provides meaning. Such a reductionist stance is incompatible with the holistic or ecological perspective that is a product of a concept mapping approach.
7.2 Interpretive / qualitative analysis.

The discussion of the data gathered continues here in a more qualitative manner as this is seen to provide a more informative picture of the students' learning. Use is made of the 'spoke-chain-net' interpretation that has been described in Chapter 5.

7.2.1 Progression in a spiral curriculum

The research literature has demonstrated repeatedly, that it is difficult to overestimate the contribution of individuals' prior knowledge to their future learning. It also shows that whilst the amount of prior knowledge that a learner has about a topic may directly impact upon learning, there are other characteristics that may also influence learner outcomes (reviewed by Dochy et al., 1999). The common assumption that prior knowledge exhibits certain qualities (that it is complete, correct, accessible and well-structured) is seen to be false (Dochy, 1992). Concept mapping readily demonstrates the gaps and misconceptions in students' prior knowledge and the lack of an appropriate knowledge structure. This may cause problems for progression through the National Curriculum for Science in which, for example, knowledge of KS3 material is expected to form the 'prior knowledge base' for students studying at KS4. The analysis of students' conceptual frameworks through the qualitative description of concept maps (as described in Chapters 5 and 6) can be used to illustrate the potential problems for students' progression from one Key Stage to another.

The National Curriculum has been described as representing knowledge as being composed of a series of chunks of unrelated or de-contextualised information (Education and training board of the Institute of Biology, 1998). This could be likened to a 'bag of marbles', in which related ideas are loosely aggregated, but links are not forged between the individual elements. This would allow students to add more 'marbles to their bags' as they progress through the Key Stages: re-visiting topics and
adding to their collection of facts. However, not all ‘marbles’ are of equal value in terms of providing an organizing principle for other ‘marbles’ (figure 7-11).

Figure 7–11
Concepts acquired in later stages of learning (white circles) may be subordinate to the existing structure and so be added to the base of the map structure (top row), or they may represent a ‘superior organizing principle’ that requires radical restructuring to facilitate their accommodation near to the core concept (lower row).

A ‘spiral curriculum’ is intended to facilitate conceptual development by the progressive selection of subject matter to extend the learners’ interests and competencies. This, according to Tanner and Tanner (1975: 430), ‘calls for a curriculum synthesis on both vertical and lateral planes’ – referring to the extension of
knowledge to higher levels and the to the necessary interrelationships of knowledge, respectively. There has been a considerable amount written on the subjects of continuity and progression within the National Curriculum (eg. Jarman, 1990; Naylor and Keogh, 1993). These have concentrated on the development of ideas at different key stages, but have not considered the structural evolution of the conceptual framework in which these ideas are embedded.

Progression has been defined by the National Curriculum Council (1993: 6) as, 'development in learning, such as the way a particular pupil moves from one understanding to another deeper or broader understanding'. The complimentary notion of continuity is defined as resulting from, 'a clear and logical sequence of work between and within key stages'.

In an integrated model of progression (such as that proposed by Qualter et al., 1990), the 'extension of knowledge' is indicated, but the 'interrelationships' (ie. structure and integration) of this knowledge are less well represented (eg. Fig. 7-12).
This model of progression can be considered in relation to the structure of students' understanding suggested by the qualitative description of concept maps described in Chapters 5 and 6. Qualter's model of progression would be viable if the students carried a conceptual framework described by a 'spoke' style concept map structure. Within such a structure, the accommodation of new information does not cause any disturbance to the overall framework and so transition from one key stage to the next should not be problematic. However, it was suggested above that teaching promotes the transition of students' conceptual frameworks from 'spoke' arrangements towards
‘chain’ arrangements as the result of teaching which concentrates on one sequence of ideas after another without demonstrating the links between them (Martin, 1994). In this way, teaching at KS 3 would be expected to result in students constructing a chain framework composed of ‘KS 3 level ideas’ (fig 7-13):

![Diagram showing possible pathways for building upon a simple structure of prior knowledge. Additions can be connected directly to the core concept to form an elaborate spoke, or may be related to more subordinate concepts to produce chains.]

Figure 7-13

Possible pathways for building upon a simple structure of prior knowledge. Additions can be connected directly to the core concept to form an elaborate spoke, or may be related to more subordinate concepts to produce chains.

Such a structure would be lacking any ideas that are not introduced until KS 4. The problem then arises at KS 4 when the new ideas at that level are introduced. The teacher would be anticipating the students to bring with them a structure of
understanding that would allow new ideas to be embedded in the existing framework, brought from the previous Key Stage. But chain structures are seen as rather inflexible and resistant to disruption [Chapter 6]. Students’ existing chain structures may therefore, not be able to accommodate the new ideas and may need radical restructuring. Teaching at Key Stage 3 can therefore create work for students at Key Stage 4 by encouraging the premature development of chain structures (Fig. 7-14).

If this is the case, it may be better to discourage the development of chain structures in the lower years of secondary school and instead encourage the elaboration of spokes. This would facilitate the accommodation of material in the upper school and the ultimate development of a more integrated knowledge structure that would be more helpful for students being tested at Key Stage 4 and/or moving on to the demands of Key Stage 5.

**Figure 7-14**

*Comparing progression through the Key Stages of the National Curriculum and the restructuring involved for students who develop chain structures and those who maintain spoke structures*
When students exhibit a diversity of spoke and chain structures for any given topic then a mixture of evolutionary (continuous) and revolutionary (discontinuous) development is required - increasing the demands made upon the classroom teacher. If spoke structures could be encouraged in the early secondary years, teaching could then focus more on evolutionary conceptual development within the classroom. This might be promoted by 'mind-mapping' or 'brainstorming' activities that take students away from the linear representations of knowledge that are typically represented in textbooks and other teaching materials.

Concentration of the quantity of understanding has appeared to be unhelpful in promoting progression from one National Curriculum Key Stage to the next (eg. Ofsted, 2000). When considered through the perspective provided by the qualitative description of concept maps, progression becomes concerned with more than the gradual accumulation of increasingly complex facts, but also a progression in the complexity and integration of conceptual frameworks that are promoted by classroom practice.

Within the delivery of the National Curriculum, there is an implicit obligation to take students to a state of preparedness for their next Key Stage and not just a state that allows testing of their present Key Stage. To facilitate this, there is a need to include suggested 'goal frameworks' within Programmes of Study in which concepts could be embedded at each Key Stage.

A close analysis of progression within a topic in the National Curriculum may indicate developmental patterns that may be exploited by teachers to enhance their students' learning. Conversely, patterns may emerge that might cause problems when moving from one Key Stage to the next. The literature provides little consideration of progression of concepts within topics from Key Stage 1 – 4. One exception is given by
Barker and Slingsby (1998) who have undertaken an analysis of progression of ecological concepts throughout the Key Stages (Fig. 7-15). Their summary of ecological topics, and the model that they go on to develop, provide only implicit links between topics which do little to add to the perception of ecology as a holistic discipline. Transforming the table provided by Barker and Slingsby (1998) into a concept map makes the overall structure and the links between elements easier to visualise (fig 7-16). It can be seen from this map, that ecology can be viewed from the perspective of ‘the local environment’ throughout the key stages to provide a continuity of focus.
KS1  naming and grouping living things
recognising similarities and differences between living things
that there are different types of living things in the local environment
the differences in the local environment affect the living things found there

KS2  identifying and grouping locally occurring animals and plants - use of keys
adaptation of different plants and animals to different habitats
how plants and animals in two different habitats are suited to their environment
feeding relationships/food chains
microbes recycle

KS3  variation - environment and genetic
classification of plants and animals into main groups - use of keys
adaptation to habitat, daily and seasonal change
pyramids of numbers
food webs, bioaccumulation in food chains
predation and competition - effect on populations
survival of the fittest

KS4  species distribution explained by adaptation
competition, predation, impact of human activity
quantitative approach to pyramids, energy flow
microbes in carbon and nitrogen cycles
food production and efficiency of energy transfer

Figure 7-15
Progression of ecological concepts in the current science National Curriculum* of
Figure 7-16
Progression in ecological concepts in the National Curriculum (through Key stages 1 – 4).
Concepts that are ‘repeated’ at different stages are only indicated at the lower key stage on the map. It also need to be noted that understanding of the concept behind the label will change as other ideas are added. For example, understanding of ‘adaptation’ at Key Stage 2 will be much more simple than understanding of the same idea once ‘genetic variation’ has been introduced at Key Stage 3.

Some apparent anomalies are also highlighted by this mapping process (eg. ‘food chains’ (KS 2) appears before ‘interactions’ (KS 3). This may simply reflect my own interpretation of the programmes of study and may not represent a conceptual problem for the students. However, such anomalies that may be encountered in other topic areas may be more problematic.

A similar mapping exercise was undertaken for ‘plant nutrition’ across the four Key Stages (summarized in fig. 7-17). Again, this is only my interpretation of the material and it has to be acknowledged that there are many ways of representing the same information within a concept map. However, the basic role of CO₂ (indicated by its high position on the map) is not introduced until Key Stage 3. Key Stage 2 concepts concentrate on the role of roots and the absorption of ‘nutrients’ from the soil. This suggests that an ‘unsympathetic’ introduction of Key Stage 2 concepts would do little to confront the ‘food gathering’ misconception held by so many students. Whilst the National Curriculum specifies what should be taught at each Key Stage, it is clear that ‘many teachers in upper Key Stage 2 teach aspects of science drawn from the Key Stage 3 Programme of Study’ (Peacock, 1999: 9). In his survey of 51 primary schools, Peacock found that 70% of teachers teach that ‘plants need carbon dioxide to grow’ even though this is exclusive to the Key Stage 3 Programme of Study. This suggests that these teachers would agree, as stated in my concept map of progression, that CO₂ is a major concept that contributes to a ‘scientific’ understanding of plant nutrition.
Figure 7-17
Progression in concepts of plant nutrition in the National Curriculum (through Key stages 1 – 4).
Movement of material between key stages is an example of teachers relying upon their ‘authority of experience’ to make decisions about teaching and having the confidence to make their own choices and judgements about interpreting the curriculum. This phenomenon is described by Wildy and Wallace (1995). However, this flexibility now seems under threat with the production of ‘specimen schemes of work’ by the Qualifications and Curriculum Authority (QCA). Such schemes have been criticized as diminishing teachers’ professionalism by eliminating choice (Monk, 2000).

The omission of such key elements may seem less important if students (and possibly teachers) hold conceptual frameworks where such gaps in their knowledge are explicit. Where these are arranged in a hierarchical, network style, such omissions may be accommodated (though this in itself may cause student frustration at not having the ‘whole picture’). However, when students construct ‘complete structures’ out of the fragments available to them, and where these fragments are linear in structure, the omission of a key element will not be apparent and students will create a ‘functional framework’ that may perpetuate or generate misconceptions.

Whether explicit (as concept maps or schemes of work) or implicit (as unspoken mental models), the programmes of study will be interpreted by teachers, and this will colour the way they teach a topic and the emphasis they put on particular concepts. The map of ‘sound’ produced by the physics teacher from school E (figure 6-6) can be compared with my interpretation of the National Curriculum structure for that topic (given in fig 7-18). The teacher’s map is dominated by the concept of a ‘pressure wave’. This is a Key Stage 4 concept, but is used by the teacher to organise his own understanding of the topic being taught to a Key Stage 3 group. The teacher and students are, therefore, unable to share a ‘common organising principle’ for the
Figure 7-18
Progression in the concept of sound in the National Curriculum (through Key stages 1 – 4).
topic and the consequence would seem to be a mismatch between the expression of student understanding and of teacher expectations. This emphasises the call from Gott and Johnson (1999) for a curriculum devised from the perspective of one who ‘does not yet know’ rather than being devised from the expert’s perspective. The problem faced by the teacher is that the key stage 3 concepts of ‘frequency’ and ‘amplitude’ can only be given any relevance in the context provided by ‘waves’. His rearrangement therefore seems appropriate and logical, but needs to be somehow shared with his students so that students’ and teacher’s frameworks do not exhibit such fundamental differences that communication between them breaks down.

The problems created by using KS 4 concepts to organise teaching for KS 3 students may be explained by reference to the work by Johnson and Gott (1996) on the problems of accessing children’s ideas. They refer to a ‘translation interface’ between the different frames of reference held by teachers and students which casts doubt on whether they can understand each other and establish meaningful communication. They use the rather passive term ‘neutral ground’ to describe that in which a largely (but never completely) undistorted communication takes place between teacher and student. Whilst Johnson and Gott argue against the use of the term ‘common ground’, that term seems intuitively more informative. I would, however, acknowledge that the implied ‘equivalence’ cannot be claimed because the structure of common/neutral ground can only be interpreted by its connections to the rest of the framework of reference – different for teacher and student. I have chosen to call this area of overlap the ‘active interface’ as it is here that a joining of the two frames is achieved by active negotiation (figure 7-19):
Figure 7-19
*The translation interface (modified and redrawn from Johnson and Gott, 1996)*.

Whilst the active interface is shared by teacher and student, they will each have individual interpretations of it based on the connections they have with the rest of their frameworks. The teacher’s ‘expert’ framework will make different connections compared with the student’s ‘novice’ framework.

The structure of the active interface may be inferred by reference to student and teacher concept maps. From these overlap can be tentatively identified. The qualitative difference in the rest of the framework held by student and teacher can be inferred by the ‘organising principles’ or ‘key concepts’ used by each. Incompatible key concepts may reduce the effectiveness of the active interface. To avoid this, teachers need to use appropriate key concepts that are a part of the students’ conceptual ecologies in such a way that conceptual development can be guided. A reorganisation of the teacher’s
map, using suitable KS 2 key concepts, may help to promote meaningful
communication at the active interface and facilitate students’ conceptual development.

This raises a question about the ‘appropriateness of expertise’ when teaching
abstract concepts at this level. The ‘expert’ (ie. physicist in the case of ‘sound’
described above) cannot help but organise his/her understanding in an ‘expert
structure’, using key concepts that may not be available to the students. In contrast, a
‘non-expert’ (eg. a biologist in this instance) may not possess an expert structure. The
non-expert’s key concepts may represent a lower level of understanding, but as a
consequence, may allow him/her to develop a more effective active interface with the
students. A distinction is therefore made between ‘subject expertise’ and ‘pedagogical
expertise’, with the subject expert having to rearrange his/her thoughts (in response to
the needs of the students) in order to demonstrate pedagogical expertise.
7.3 What is learning?

At this point it may be helpful to revisit the concept of learning in the context of the work described so far. I have concentrated on ‘meaningful learning’ in this work as this is seen in the constructivist literature as more valuable than ‘rote’ or ‘surface’ learning, which tends to lack permanence or adaptability. Novak (1998: 19) gives three requirements for meaningful learning:

1) **Relevant prior knowledge**: That is, the learner must know some information that relates to the new information to be learned in some non-trivial way.

2) **Meaningful material**: That is the knowledge to be learned must be relevant to other knowledge and must contain significant concepts and propositions.

3) **The learner must choose to learn meaningfully**: That is the learner must consciously and deliberately choose to relate new knowledge to knowledge the learner already knows in some non-trivial way.

Novak’s insistence on the non-trivial nature of meaningful learning may cause some questioning of the relative merits of continuous and discontinuous progression (as described above). Interpreting Novak’s conditions in the context of qualitative concept map description, discontinuous progression [chain → chain in figure 7-3] would be described as meaningful because the learner must go through a period of cognitive conflict in which the ‘new’ material must compete for position with the ‘old’ before the whole structure is reassembled. The process of continuous learning can, however, be totally trivial in that new information can be added to the existing knowledge structure without any restructuring and only interacting with the existing structure on the most superficial level (Hashweh, 1986).
This again exposes Novak's narrow focus on a snapshot of understanding, without standing back to survey the eventual 'global' consequences of an immediate 'local' change. A 'trivial' change in a concept map may represent a small variation in current structure, but may be a fundamental prerequisite to a more significant change, necessary for progression along the novice $\rightarrow$ expert continuum. Therefore, triviality may not be a valid descriptor of a local change in a map, but may be better as a description of the resulting associated change in the learner’s perspective. For example, adding CO$_2$ to a map of plant nutrition is a prerequisite for a student to change from the ‘food gathering’ model of plant nutrition towards the ‘food production’ model [see figure 7-17 showing progression of concepts of plant nutrition]. It is a small change, but cannot be considered trivial if it results in a major shift in student understanding.

7.4 Model testing

7.4.1 Conceptual change or contextual switch?

So far in this chapter, I have chosen to equate conceptual change with learning (as is done in much of the research literature). Nevertheless, I have also shown that:

- Learning is difficult to describe and measure
- Different types of conceptual change may be considered meaningful or trivial learning events, depending upon the measures of learning that are used.

Here I add another layer of analysis by describing a potential conflict between what I choose to call ‘conceptual change’ and contextual switching’. In conceptual change, the structure of an active framework is modified, whilst in contextual switching, the learner ‘turns off’ one framework and ‘turns on’ another in response to contextual cues, but no structural change in either framework is implied. I introduce these ideas
not as an attempt to discredit that which I have already argued (since I believe my reasoning will show it to remain substantively correct), but because 'another way of looking' at qualitative concept map analysis reveals still more about learners' conceptual development than is shown by quantitative measures.

So far I have argued that:

a) progression is likely to be facilitated by learners' conceptual models that are based on SPOKE rather than CHAIN structures because new ideas and information are likely to be incorporated easily with prior knowledge.

b) that learners for whom prior knowledge and information is represented by conceptual CHAIN models are likely to need periods of radical conceptual restructuring in order to progress from one Key Stage of the National Curriculum to the next.

c) LEARNING may be defined in a variety of ways so that whilst a) and b) above appear to suggest that SPOKE models promote easy development (and hence learning), a definition of learning that emphasises NON-TRIVIAL INTEGRATION of old and new ideas as part of conceptual change actually suggests that changes to chain structures constitutes learning where simple addition to spoke structures does not.

It has been proposed [in chapter 2] that within a student's conceptual ecology, s/he is able to hold conflicting conceptions simultaneously (i.e. a misconception and a scientifically acceptable conception). These may well have points of overlap, or '... common elements that are simultaneously embedded in and serve as activation links between and among related communities of concepts' (Jones et al., 2000: 141). The student can then choose between them depending upon the context by using an
‘if...then...’ type of reasoning that links the two (Lubben et al., 1999; Palmer, 1999). This has been described as ‘opportunistic differentiation among contexts of interpretation’ by Caravita and Halldén (1994: 89). Within a given topic area, there may be two (or more) competing frameworks, many of which are described in the literature (eg. Driver et al., 1994). An ‘alternative framework’ may represent the dominant viewpoint among students in a class, particularly if they share formative out-of-school experiences or cultural traditions that help to reinforce it. Concept mapping can reveal the structure of the conceptual framework in which a particular conception is embedded, with some structures appearing to be more receptive to change than others. Such change that is recorded may, however, be an artefact resulting from a restricted focus of the observations made. Students may be simply ‘switching’ from one framework to another in response to contextual cues, but the individual frameworks may remain unchanged (Fig. 7-20) Correct answers given might, therefore, not be an indicator of conceptual development, but rather of appropriate switching. This switching may be reversed if original cues are restored, giving the illusion of ‘conceptual decay’ in which understanding is observed to revert to previously held conceptions, as described by Georghiades (1999). Both ‘change’ and ‘switching’ can be considered as meaningful learning, depending upon the context. As Lemke (1990: 187) has asserted, ‘Making meaning is the process of connecting things to contexts.’
The identification of the structure and locus of critical nodes forming such a contextual switch within a student’s conceptual ecology is, therefore, worth investigation as it may:

- **Provide a focus/target for effective teaching**
- **Explain apparent inconsistencies in student responses**

### 7.4.2 The contextual switch in photosynthesis

When conceptual frameworks are made explicit by concept mapping, critical nodes, or keystone concepts, associated with any given misconception may be
identified. These should provide the focus for teaching, as the direction of subsequent learning is dependent upon their appropriate organisation.

Within photosynthesis, the two main opposing frameworks can be described as the ‘food-absorption model’ and the ‘food-production model’. The locus of the contextual switch between these two, I suggest, occurs between the concepts of ‘food’, ‘absorption’ and ‘production’ (figure 7-21):

![Figure 7-21](image)

Figure 7-21

Possible locus of a contextual switch for the comprehension of photosynthesis in which use of the terms ‘food’, ‘absorbed’ and ‘produced’ may cause switching from the scientific to the non-scientific frameworks within certain contexts.

These key terms are commonly confused and misinterpreted by students in a number of ways:

- ‘Food’ is often confused with ‘energy’ and ‘nutrient’ (e.g. Leach et al., 1996).
- The process of ‘absorption’ often features in the links near top of concept map on photosynthesis, referring specifically to water and CO₂ (e.g. Kinchin 2000). If these are considered by the student as food items, then ‘plants absorb food’ follows logically and the switch is made – following the typical zoocentric model that is
consistently adopted by students within the classroom (eg. Kinchin, 1999). Within certain non-scientific or domestic contexts, the absorption model may provide greater utility than the more scientifically acceptable ‘production model’. This ensures that it will remain viable within the student’s conceptual ecology and will be activated in response to appropriate cues.

- Students may consider food production, not from the perspective of the plant needing food to support its own metabolic processes, but from an anthropocentric viewpoint of food production for the human population.

### 7.4.3 Implications

If teaching is to proceed with the express aim of promoting conceptual change, then this needs to be monitored at an appropriate (ie. ecosystemic) level of magnification so that contextual influences can be recognised. Future research needs to build on the enormous literature concerned with ‘alternative frameworks’, ‘misconceptions’ or ‘children’s science’ so that research can be used to help teaching by promoting greater focus on the key concepts which form the switch between contexts. The teaching effort spent on key concepts needs to reflect their importance in developing an acceptable framework. If concepts at critical nodes are not understood (ie. contextualised), time spent on teaching subordinate concepts is unlikely to be fruitful.

Students need to be aware of opposing conceptions and the appropriateness of each within a range of contexts. It may be impossible (and even undesirable) for students to completely abandon misconceptions that are supported by social or cultural interactions, but they must be guided in the recognition of suitable contexts for their expression. In reviewing the literature on conceptual change research, Duit and
Treagust (1998: 11) conclude that 'there appears to be no study which found that a particular student's conception could be completely extinguished and then replaced by the science view. Most studies show that the 'old' ideas stay 'alive' in particular contexts.' In attempting to address this problem, Linder (1993: 298), who concluded that less emphasis should be put on:

"efforts to change segments of students' existing repertoires of conceptualizations and more efforts on enhancing students' capabilities to distinguish between conceptualizations in a manner appropriate to some specific context.

Evaluating conceptual development can then be viewed in terms of the changing extent to which alternatives are selected over time as the learner develops both the conceptual frameworks themselves and judgements about the contexts in which they are best applied (Taber, 2000a). For meaningful learning to occur, that which is to be learnt needs to have personal relevance to the learner (eg. Reiss and Tunnicliffe, 1999). However, the context associated with the student's alternative framework may be perceived to have greater personal relevance than that associated with the scientifically accepted framework. This would hinder development of the accepted framework and possibly consolidate the alternative framework. In such instances, the teacher's perception is likely to be of a misconception that is resistant to change. If switching is to be promoted it needs to be accompanied by increased 'conceptual appreciation' (sensu Linder, 1993), which involves the ability to differentiate between contexts. It is, therefore, suggested that the contextual appreciation needs to be probed as much as the conceptual understanding. In reviewing the evidence gathered from inspections of secondary schools in England between 1993 and 1997, Ofsted (1998) concluded that:

Inspection evidence ... has shown that, whereas their knowledge of the material in the Programmes of Study has improved, pupils' understanding of underlying scientific concepts frequently remains insecure, and they are insufficiently able to apply their knowledge in new contexts.
Perhaps teaching should aim to increase overlap between competing frameworks so that switching is made easier for the student. In this case it would be necessary to make opposing frameworks explicit – possibly through concept mapping. Understanding needs to be probed through a variety of contexts to gain a picture of the variety of perspectives that are held as discrete frameworks within a student’s conceptual ecology. Bloom (1990; 1992) has suggested that teachers construct ‘context maps’ to try and identify different perspectives and has suggested a typology of contextual components that includes (a) knowledge; (b) mental processes; (c) interpretive frameworks and (d) emotions.

There are times when change would be more desirable than switching (and *vice versa*) depending upon the student’s conceptual starting point and the instructional goal. Where change is desirable, teaching and learning needs to build upon pre-instructional conceptions that are compatible with the accepted view. Fundamental restructuring is not necessary. Where switching is desirable, radical restructuring is required and may be triggered by the generation of cognitive conflict. Duit and Treagust (1998) have termed these two learning pathways respectively as *continuous* and *discontinuous* (terms that would sit comfortably within a biology teacher’s conceptual ecology). In either case, it is essential for the teacher to have an understanding of the prior knowledge that students bring with them so that its development can be supported by the most appropriate approach. This may require that teachers reappraise their own referents for teaching – demanding from them either change or switching!
7.5 Participant feedback

Development of the arguments presented here has been influenced by numerous conversations with teachers and students during my visits to participating schools. To formalise some of this feedback, interviews were conducted with three teachers from school D. These were carried out individually so that teachers could not influence each other's responses or feel pressurised in the presence of a senior colleague. The teachers were:

**Teacher 1:** Female 15 years' experience (Senior pastoral responsibility).

**Teacher 2:** Male 22 years' experience (Head of Biology).

**Teacher 3:** Male 12 years' experience.

Teacher 1 proved to be the most articulate and so the teacher feedback is presented largely through her words, reinforced as appropriate with comments from teachers 2 and 3. There were no comments that conflicted from one teacher to another.

Teachers from school C felt unable to participate in formal interviews, but comments from informal conversations allowed for the formation of a general picture of their perceptions. Views from teachers at schools E and F were also obtained during informal discussions and staff INSET sessions. Additionally ten Year 10 students were interviewed in pairs (from schools C and D).

The over-riding conclusion that can be drawn from the interview data is that, whatever other claims may be made for concept mapping as a classroom activity, it does seem to have the effect of making learners (students and teachers) think about the learning process.
7.5.1 The teachers' perspectives

Arguments presented above describe a spiral curriculum, in which ideas are revisited at different levels so that concepts can be built upon the knowledge that was constructed at previous stages. This supposes that students are internalising this knowledge and bringing it with them, ready to apply it in subsequent lessons. Comments from a number of teachers indicated that the 'pre-instructional' concept mapping showed this not to be the case:

They come to a lesson with like a 'blank head', and we think we are delivering a curriculum that's building on past experience, but that isn't where they're coming from. They come in with a 'well what are we doing today?'. And you might start off by saying, 'well, you remember last week ...', but you have to do that for them. They don't come in thinking, 'oh, last week I had some starch and amylase and I noticed that the starch disappeared when they were mixed - I wonder what else I could find out'.

They don't bring with them the knowledge that you are expecting them to have. Now I think it's in there, but it's sort of been filed away.

They simply didn't bring that with them. Not at the front of their minds, so I need a way of getting it.

(Teacher 1)

This particular teacher was clearly frustrated by the weaknesses she perceived in her own classroom practice. The concept mapping activities had reinforced some of her concerns. The technique had suggested a way of addressing her concerns, but had also thrown up additional questions. The value of pre-instructional maps had been recognised and was being expressed in Ausubelian terms:

[I think I would change by] trying to find out where they were before I started.

(Teacher 1)

This teacher also recognised that it was not just knowing 'what they knew' that was of value, but also knowing 'how they learn'. The information about concept mapping was being transmitted to students in a fairly objectivist style, and there was concern that this may be producing some conflict with their existing classroom strategies (as suggested by Armstrong, 1995). This she expressed as:
You were trying to overlay something on a process that they did already.

(Teacher 1)

All of the teachers involved in the various research programmes described in this work considered that concept mapping should be introduced as early as possible in the students' school careers. Year 10 was considered to be too late as students were often very fixed in their study strategies and were too preoccupied with GCSE examinations to consider new techniques (reflected in the students' comments below).

Teachers 2 and 3 reiterated these comments and felt that concept mapping should be taught as part of a school-wide study skills programme in Year 7. Dismay was expressed that study skills were only taught to the sixth form by a senior member of staff, and it was not seen as a joint venture with the rest of the teaching staff:

Whoever does it, doesn't tell the rest of us what they're doing.

(Teacher 2)

Just as science needs to be taught in an integrated manner so that students can make links across the subject, so too, the teachers felt, a more holistic approach to the 'whole school experience' should be adopted. They felt that for concept mapping only to be introduced in biology may have an isolating effect from the rest of the curriculum and from teaching colleagues. However, they felt that resistance from other departments would make such an approach very difficult to organise.

Teacher 1 also recognised some of the implications of concept mapping in the classroom. She was concerned about the way in which concept mapping would relate to her teaching in general. Concept mapping was seen by her as a first step towards adopting a 'meaningful learning approach' within her classroom, and recognised the concept map as a starting point for learning rather than an end product of it:
To be very useful, the teacher's then got to do something with it. You can’t just say ‘oh, I’ve done a concept map!’ ‘Oh good, let’s pat you on the back!’ It's a can of worms. If you open it, you’ve got to do something with it. Otherwise you’ve got the danger of reinforcing mixed messages and confused concepts.

(Teacher 1)

She also acknowledged that the ‘can of worms’ would still be there even if it was not opened for scrutiny by concept mapping. She thought it was better to address this by bringing problems out into the open, rather than ignoring them. The teacher recognised that concept mapping is a communication tool, and to leave a concept map with out discussion is analogous to leaving a student’s question unanswered:

The problem is, to address the concerns of a concept map, you probably need a dialogue and that's what's really tough – to find time for that.

(Teacher 1)

Although this was a teacher with 15 years of classroom experience, she had felt disempowered by the concept mapping experience as it had raised a number of questions for her and she felt that she had neither the time or resources to answer them to her satisfaction. She ended her interview by indicating an interest in knowing more:

I would like to know about experiences elsewhere.

(Teacher 1)

This suggests that there would be a demand for INSET that concentrates on the teaching and learning experience. When describing the benefits for the teacher, one member of department commented:

I can be a bit cynical here. It makes them [teachers] actually prepare their thoughts before hand ... especially those who have been teaching for a while – sometimes I find myself doing that. I rely to my previous things and I find myself doing the same thing again and again and it becomes a bit tedious, boring. But when I think 'oh, I'll use the concept mapping technique today', so have to think about what sort of ideas do I present to the boys. How do you trigger them, how do you make them think? So at least from that point of view it helps.

(Teacher 3)
This suggests that in addition to the ‘can of worms’ that concerns the quality of student learning and the ways in which misconceptions are addressed in class, there is a second can of worms concerning the professional development of teachers. Raising the lid on this can may be more problematic, but may help to address the apparent routine nature of delivering an objectivist curriculum. Concept mapping may provide a first step in promoting classroom creativity and revitalising teacher enthusiasm for teaching by initiating a transition towards a more constructivist approach to students’ learning.

7.5.2 The Students’ perspective

With the benefit of hindsight, most of the teachers involved thought that Year 10 was probably too late to introduce concept mapping. I had anticipated that the majority of the teaching in schools C and D would be concerned largely with the transmission of information in preparation for GCSE examinations. Within such an objectivist teaching ecology, I had expected difficulty for the constructivist application of concept mapping to find a suitable niche. Some students expressed reservations about the ‘new’ technique:

I came in here thinking ‘I dunno, concept mapping - a bit dodgy?’. At first everyone was just like ‘oh, extra work’, ‘new things to learn’, ‘extra tests’, but in the long run it probably has helped us, we just didn’t know it ‘cos we weren’t too keen on doing it.

(Girl – School C)

A number of students commented that they were able to see the benefits of concept mapping in helping them to learn, but were equally positive that were unlikely to use it on a daily basis in their studies. The following comments are typical:

It did make you think, but I don’t think I’ll use it again.

(Girl – School C)
I guess it was helpful, but I shouldn’t think I’ll use it because it does take some
time to think about it and do the map, and to be honest, I’m quite lazy.

(Boy - School D)

This does seem to reinforce the teachers’ views that their students prefer to be ‘spoon-
fed’ information and are more concerned with getting the correct answer written down
to memorise, rather than any concern for the generation of understanding. Some
students were concerned with getting the ‘right map’ and failed to see the possible
benefits of ‘displaying their ignorance’ to their teacher. When asked if she would use
concept maps again, one girl said:

I may do, it depends how easy I find the topic, ‘cos if I find the topic fairly
easy, I can do them, but if it’s something I didn’t understand much, I don’t
know whether I would.

(Girl - School C)

The possibility that there could be more than one acceptable ‘answer’ seemed quite
unsettling for some of the students. They appeared unfamiliar with developing an idea
and more used to having a complete perspective given to them:

I found it quite useful, but sort of confusing at the same time ... trying to
change my views, but not having much luck.

(Girl - School C)

This may provide a comment on teaching that places a premium on ‘getting the right
answer’ rather than showing ‘how to get to the answer’. Harlen (2000: 21) comments
on the benefit of the latter approach:

If children are taught science in a way that reflects the tentative nature of all
theories, it will seem natural for them to adapt their own ideas as new
evidence is presented.

The value of using concept maps as a focus for teacher-student discussion can be
highlighted by the passage below. This is taken from an interview between myself and
two students (L and R) from school C in which we were discussing their pre- and post-
instructional maps of ‘photosynthesis’:
Ian: Now you’ve got carbon dioxide in there, and you’ve got glucose in there. You haven’t linked the two directly.

Student L: No.

Ian: Should there be a link? … Or is there a link between the two.

Student L: Yeh, I suppose there is because I’d say everything on this page is linked together … even if only very distantly. But um … no but CO₂ is something that’s needed for photosynthesis and glucose is a product of photosynthesis, yeh, so I suppose yeh it is. I don’t know how to connect those two, but they are linked, but just in a very round about way.

Ian: O.k., ‘R’ can you add to that? Can you identify a link between CO₂ and glucose?

Rachel: Um.

Ian: In either map. [pause] No?

Student R: No.

Ian: It doesn’t matter. O.k. Can I ask you why CO₂ is important in photosynthesis? We’ll start with ‘R’. Why is CO₂ needed, what’s its purpose?

Student R: Um … well because it’s got … um … partly oxygen, it’s going to be needed to produce more oxygen. Um …

Ian: What about the other part?

Student R: Um … not sure really. Helping other reactions happen? I don’t know.

Ian: ‘L’, can you add anything to that?

Student L: Not particularly. Apart from, it is one of the requirements for photosynthesis. But that’s all I can add.

Ian: Let’s imagine this bench is actually a wooden bench [knock, knock], therefore, wood is a hard material and it comes from a plant. What would be the main chemical in wood?

Student L & Student R: Carbon.

Ian: O.k. Where did that carbon come from.

Student L & Student R: Carbon dioxide

Student L: Oh wow! [giggles]

Ian: O.k. so you’re telling me that the hard stuff in a tree, comes from the invisible stuff in the air? Is that what you’re telling me?

Student L: After certain processes, yeh.

Student R: Yeh.

Ian: So what’s the role of carbon in carbon dioxide? Back to that first question.

Student R: To produce the … I dunno to produce the plant, I suppose.
And the plant is made of ... Car-bo-hy-drates like glucose, and what's glucose made of chemically? What three elements are in glucose?

Oh, um ... carbon, hydrogen ... oxygen?

and oxygen [nodding].

Yeh [pleased]

So there's carbon in glucose, and that comes from the carbon dioxide in the air. That's why there should be a link between CO₂ and glucose [pointing to map].

Aahhh, yeh, I see.

Such a focused conversation addressed a key misconception and its structure and guided by the students' concept maps. The focus of the conversation would not have occurred to me (as a teacher) without the map to act as a trigger, and the questions would not have occurred to the students as they were unaware of their misconception.

In another interview at school D the issue concerning the source of carbon was addressed, but the conversation came to a different conclusion:

So where does the plant get the carbon to make the wood?

Um ... from dead animals in the soil? Or just the minerals ... carbon from the soil. Through the roots - it's able to gather up.

Do you agree with that, 'A'?

Yes. Absorbed through the roots from the soil, yeh.

This may indicate the value of pairing students who offer opposing (or at least differing) perspectives to generate cognitive conflict. Here the two students shared a misconception, and so appeared to reinforce each other's view. Whilst both students were very able and could explain the nature of photosynthesis in a way that would get them credit in an examination, they still held the underlying belief that plants acquired their food from the soil, reflecting Cobern's (1996: 592) summation, that 'Comprehension does not necessitate apprehension'.

7 - 49
8.1 The environment for effective concept mapping

I suggest that concept mapping *per se* does not, of itself, improve learning, but may fill a niche within an appropriate 'teaching ecology' in which the constructivist application of concept mapping activities may support and encourage meaningful learning of science. This is achieved by providing a focus for sharing understanding. This reflects Hyerle's (1996: 105) comment that:

No one can guarantee that students will reflect on a visual display any more or less than with other modes of communication. Metacognitive activity often depends on teachers asking the questions that will facilitate students' reflective thinking.

This builds on the assertions of the Human Constructivists (eg. Mintzes, Wandersee and Novak, 1998) who describe the importance of well-prepared classroom teachers in providing what Caine and Caine (1994) call *orchestrated immersion in compelling experiences*. Such experiences promote learning that is seen as *meaningful* (Novak and Gowin, 1984) or *natural* (Caine and Caine, 1994). An 'appropriate teaching ecology' develops from a combination of factors:

a) The preparedness of teachers

b) The motivation of students

* elements from this chapter have been accepted for publication as:


c) Conditions in which teachers and students communicate effectively as partners within an active learning community.

8.2 Recognition of student diversity
Not all students (even in the same class) may benefit from concept mapping in the same way, depending upon:

a) compatibility with students' existing and developing study strategies
b) students' motivation for learning
c) the starting point of student understanding, re:

i/ quantity - how much prior knowledge.
Those students with a greater quantity of prior knowledge will have more resources within their conceptual ecology from which to draw and so are more likely to construct appropriate connections between 'existing' and 'new' knowledge.

ii/ quality - structure of prior knowledge.
Different structures of existing knowledge are likely to be more receptive to new knowledge and more able to accommodate it within an existing framework. Those students with an existing 'spoke' arrangement may have a more flexible platform for future learning whilst those with a more linear 'chain' structure may find restructuring more problematic.

8.3 Barriers to the adoption of concept mapping
The greatest barriers to the extensive adoption of concept mapping as an integral component of typical classroom strategies are seen as the epistemological beliefs and values of classroom teachers (the 'gatekeepers' of classroom practice) and the curriculum that they are asked to deliver:
8.3.1 Teachers

As pointed out by Hyerle (1996:45), ‘if the teacher is more interested in “correcting” or editing ideas to fit a lesson, the whole point [of mapping] has been lost’. This echoes Hoyle’s view of the centrality of teacher-development in the success of curriculum innovation [p. 5-12] and suggests that more staff INSET time should be devoted to the fundamental issues of teaching and learning that underlie daily practice, at the expense of time spent on more transient reform initiatives.

Teacher development (towards a more constructivist stance) has been described from a personal perspective in Chapter 5 and can be related to literature describing teachers’ conceptions of teaching. For example, Larsson’s (1987) work, based on interviews of 29 serving teachers, reported four different conceptions of teaching skill and its development. When a teacher has taught for some time:

a) There is a change in focus of attention from the teacher’s own acts and/or plans, to the students’ thinking.

b) The teacher collects knowledge about the way different pieces of teaching work and is able to choose amongst those pieces.

c) There is a change in what kind of knowledge to transmit, from large quantities of facts toward a reduction of quantity and a concentration on a few principles or ways of thinking.

d) Work becomes routinized and, in consequence, the teacher does not use his/her full capacity and becomes less effective.

Collectively, these conceptions of how teachers learn from experience suggest an evolution of practice that moves from a narrow focus of attention (a) and a portrayal of teaching as if the sum of the part equals the whole (b), to a more efficient transmission of ‘essential’ information (c), and finally a loss of interest in teaching
resulting in routines that do not utilise the full capacity of the teacher (d). Prior to this research, I would recognise my own position as a type-(d) teacher who felt ‘routinized’, and have recognised this in many of the teachers who participated in the studies described herein [eg. see the comments made by ‘Teacher 3’ in Chapter 7]. Such routinization and boredom among teachers is likely to have a negative impact on their classroom performance and consequently upon their students’ learning.

The influence of teachers’ beliefs on students’ learning outcomes has been discussed by Kember (2000) and his model is summarised in Figure 8-1. Whilst Kember’s model is concerned with the influence of teachers’ beliefs upon students’ learning, it can also be interpreted as describing the influence of students’ beliefs upon teachers’ learning – emphasised by the inclusion of double-headed arrows in many of his links. ‘Learning outcomes’ is left ambiguous by the omission of ‘teachers’ or ‘students’ and can be measured for either. This interpretation of the model highlights at least one glaring omission – a link from ‘learning outcomes’ to ‘reflection upon practice’. This suggests a limitation of a linear model in describing a cyclical process.
Figure 8-1

A model showing how teachers’ beliefs can influence student learning.
(modified from Kember, 2000)
Teachers’ reflection upon their professional practice as a step towards a more constructivist stance can be initiated by the very tool (concept mapping) that can be subsequently used to support students’ learning within a constructivist classroom (e.g. Leino, 1996; Shymansky et al., 1993). Such constructivist teacher development is seen as the way forward by Bell and Gilbert (1996) and by Kroll and LaBoskey (1996), to encourage teachers to see themselves:

a) **As learners:** to reflect on themselves as learners as they learn to teach – seen as a lifelong construction process.

b) **As teachers:** to become passionately involved in their specialist content area.

c) **As researchers:** to see their own teaching and learning and their students’ learning as issues for enquiry.

When discussing the importance of students’ prior knowledge [as explored in Chapter 2], a mismatch between espoused theory and theory in use (*sensu* Argyris and Schön, 1978) has been identified by West and Fensham (1974: 62):

> Despite the obviousness of prior knowledge as a major factor in learning science and its wide acceptance intuitively by science teachers, they proceed to ignore it in so much of their regular practices.

This suggests that some external factor prevents teachers from developing their practice towards a more constructivist perspective, and accusations for this have been leveled at the UK National Curriculum (e.g. Hacker and Rowe, 1997; Donnelly, 2000).
8.3.2 Curriculum and its assessment

A curriculum that is designed to be learnt by rote (as argued by Gott and Johnson, 1999 for the UK National Curriculum for science) provides little incentive for teachers to encourage their students to engage in more meaningful learning. Such an approach has been condemned by Schmeck (1988:321):

A surface approach to learning leads to a learning outcome that is essentially a literal reproduction of the words of textbook authors or instructors. Furthermore, the surface approach does not include perception of the holistic structure of information, but instead atomizes it into disconnected bits and pieces that are memorized through repetition. Thus, individuals taking a surface approach are likely to have a quantitative conception of the process. If the outcome is organized at all, it is merely a stringing together of memorized bits and pieces of information.

Within such a regime, constructivist learning tools (including concept mapping) may be seen to offer little utility and will be perceived by teachers as an additional and unwelcome complication (eg Prawat, 1992).

Critics of the teaching profession could argue that the National Curriculum may be viewed as a convenient ‘protective shield’ that can be used by teachers as an excuse for everything that is wrong in their classrooms. However, in their recent report on progress in Key Stage 3 Science, (Ofsted, 2000: 2) make the statement that:

Some of the best teachers inspected ... were less constrained by the Programme of Study; they adjusted the content, teaching approach and pace of lessons to meet the needs of their pupils.

All teachers should have the confidence to respond flexibly to the National Curriculum; they need to be reassured that the responsibility for making decisions about how the National Curriculum is applied in the classroom is still theirs.

Whilst this would seem to confer upon teachers the power that they want is designing a more student-centred curriculum, the assessment regime leaves less room for such interpretation, and is seen as the main driving force behind the development of departmental teaching schemes, particularly at Key Stage 4 (Nott and Wellington, 1999).
8.4 A synthesis

The model summarised below in Figure 8-2 (The TLC cycle), is seen as a development of that given by Kember (2000) (see also Figure 8-1) and represents a synthetic conclusion to the work presented in this thesis. The major distinction between Kember’s model and the TLC cycle is that in the latter ‘learning by teachers’ and ‘learning by students’ are not viewed as separate entities. I consider ‘learning’, within an appropriate teaching ecology [described in 8.1], as equally applicable to teachers and students, with teachers’ learning an essential component of effective teaching. This is compatible with the Government’s stated aim for ‘teaching to become a learning profession’ (DfEE, 2000: 3). Essentially, teachers and students are both seen as learners, promoting mutual change. The model can be read in either direction, starting at any of the three points (T, L & C) within the cycle.

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**Figure 8-2**

*The Teaching, Learning, Change (TLC) cycle.*

*(R&R = Research and Reflection)*
The components of the cycle are continually monitored by research of and reflection on practice (R&R). It is here that concept mapping may have a key role in monitoring teachers' evolving conceptions of effective teaching (eg. VanLeuven, 1997). I also suggest that the promotion of reflection upon teaching and learning that can be stimulated by concept mapping activities, may help teachers to avoid the long term dip in effectiveness and accompanying 'routinization' of their role (eg. Shymansky et al., 1993; Leino, 1996; Nichols et al., 1997) by promoting their role as a learner. However, if the switch to such a teaching approach requires radical restructuring of the teacher's conceptions of teaching, then a short term dip in performance may be a consequence. This is analogous to the dip in students' performance that accompanies radical restructuring of subject knowledge (Schuell, 1990).

There is a difference between change that is initiated by the teacher in response to an intrinsic need, and change that is imposed by an external agency in response to extrinsic factors that may not be of direct interest to the teacher. This is because intrinsic motivation is likely to be linked to core beliefs whereas extrinsic motivation may not be.
The TLC cycle is seen as a cycle within a cycle. As teaching and learning initiate change in the learners, then the nature of the teaching ecology will change (from 1 - 4). Therefore, ‘teaching’ in step 1 may not mean the same as ‘teaching’ in step 4, depending upon the degree of change that has been achieved.
The way in which teachers conceptions of teaching change in response to increasing appreciation of constructivist science teaching (Louden and Wallace, 1994) was described in Chapter 2. This teacher-change impacted upon the implementation of the experiments described in this thesis. Whilst approaches were focused on students’ learning, it is apparent that the context of this learning was changing as the teachers were reacting to what they observed (analogous to the researcher-change described in Chapter 5). The teachers involved would each have constructed their own personalized interpretations of what they observed (eg. Bell, 1998), and because any change that was initiated would have unique ‘starting points’ for each teacher (depending upon existing notions of what constitutes an ‘appropriate teaching ecology’), then the notion of a ‘controlled experimental procedure’ evidently becomes untenable. Though it was not explored in this study, it might be anticipated that some teachers involved could have been described as 'change-ready’ and ‘others’ as ‘change-resistant’ (sensu Lasley et al., 1998). If these groups reacted differently towards the classroom innovations (concept mapping trials), it may have resulted in a polarizing effect upon student performance – contributing to the variance observed between classes.

Whilst there has been considerable time and effort spent on the development and implementation of new curricula in the UK, I would argue, along with Russell (1993: 250) that:

Curriculum development is not the central issue facing science education, whether it proceeds on constructivist principles or not. How we teach and learn, in science classes and in programs of science teacher education, is the issue of importance.
8.5 In Summary

- Typically, only a small proportion of a student's conceptual ecology consists of 'expert knowledge' with students having difficulty in distinguishing between expert and 'non-expert' knowledge.

- Competing theories may be held as discrete or overlapping frameworks within a student's conceptual ecology – each activated by contextual triggers.

- Frameworks may contain deeply rooted misconceptions that are reinforced culturally or linguistically.

- The structure of students' conceptual frameworks impact upon future learning (that may be facilitated by spokes and impeded by chains).

- Teaching for a Key Stage may impede progression to later Key Stages (by premature formulation of linear structures of understanding that are resistant to change).

- The structure of the National Curriculum for science and its associated methods of assessment neither promote meaningful learning nor recognize how knowledge is integrated with links between concepts. It has been noted by Reiss (2000: 92) that in Year 9 science SATs:

> credit is almost never given for imaginative or creative thinking or for linking ideas from different areas of science

As a result, the widespread promotion and development of constructivist teaching principles, that help promote diversity in thinking, seems unlikely.

- Key concepts determine the structure of understanding for a topic. These key concepts may not be shared by teacher and pupils – leading to a loss of personal relevance and a failure of students to construct an expert knowledge framework. Appropriate advance organizers providing an overall framework of key concepts
may help students to organize less inclusive concepts in ways that will offer
greater utility in test/exam situations.

- The organization of concepts (re: progression and their introduction at different
  key stages) may offer tacit support to student misconceptions through errors of
  omission.

- Problems in students’ understanding can only be recognized if there is a flow of
  information from students to teachers: this can be facilitated by concept mapping.
  Such a flow will only occur if teachers recognize the importance of the pupils’
  perspectives. It may be impeded by a constant flow of information from teacher to
  student that results from a content-heavy curriculum.

- Schemes of work should be specified within a given belief system in order for it to
  make sense and to guide its interpretation. Constructivist teaching tools within
  such a scheme may be corrupted for use in objectivist lessons and will
  consequently promote rote learning instead of meaningful learning (eg.
  memorization of a ‘correct’ concept map for revision).

- Misconceptions are common across a range of abilities, but students of higher
  ability are better able to ‘read the context’ and answer test questions correctly.
  Higher ability students also tend to have better language skills and so are better
  able to use appropriate terminology that may suggest understanding, but which
  may mask underlying misconceptions. Therefore, concept mapping may be a good
  indicator of understanding, but poor predictors of test performance, particularly
  when tests concentrate on recall of isolated fragments of knowledge.

- The most significant contribution of concept mapping to the development of
  meaningful learning may be through its influence on teachers’ beliefs about
teaching and learning. It may, therefore be seen as a tool to promote teachers' continuing professional development.

- Meaningful learning may be promoted by conceptualizing teaching in terms of the TLC cycle.

8.6 Future research

Conclusions offered in this chapter are of two types: those that attempt to provide answers to the original research questions, and those that raise further questions that are presented as a result of the work described above. Elements described in this section indicate the flexibility of concept mapping and the ease with which it can be adapted and developed to suit emerging needs. This is seen as a strength of concept mapping, supporting its adoption in ways that will reflect local circumstances. It also suggests a number of avenues for further research, all of which could be considered in the context of wider studies into learning styles, gender differences, ability, ethnicity etc.

8.6.1 Consideration of a limited range of map characteristics.

The style of concept map that has been considered in this work has been influenced by the science education literature, in turn dominated by the format described by Novak and Gowin (1984). This has resulted in a focus on the language used in the links and concepts of the maps, but a rather limited range of other map characteristics. In his discussion of ‘visual language’, Horn (1998) describes a range of ‘visual topologies’ that will influence interpretation of the material presented within a map (figure 8-4). Horn (1998: 81) considers that such topologies ‘communicate meaning’ because they are based on the Gestalt principles of human
perception – something that has also been explored by Wallace et al. (1998) in the context of concept mapping. Horn considers that the words used in a concept map cannot be evaluated separately from the incorporated images and shapes. He describes 'making meaning' from the integration of these elements as 'semantic fusion'. Wallace et al. (1998) have shown that application of Gestalt principles to concept mapping can help recall and retention of information.

Figure 8-4
Variation in radial spoke topology.
(modified and redrawn from Horn, 1998).
8.6.2 Combining maps with other tools (eg. concept cartoons).

Concept cartoons were developed by Keogh and Naylor (1999), in a search for strategies to help bridge the gap between constructivist models of learning and classroom practice. In these, characters are drawn in familiar settings where they express commonly held, but conflicting views about a scientific phenomenon (Figure 8-5). This is then used as the starting point for discussion.

Figure 8-5
A concept cartoon with complementary concept map fragments that illustrate two common views of photosynthesis.
The addition of concept maps to the use of concept cartoons may enhance such a tool. The map fragments shown in Figure 8-7 may be used as a starting point for students who could each choose to elaborate upon one or other of the maps by adding concepts such as energy, water and carbon dioxide. Alternatively, students could be asked to complete concept maps for each of the students' views shown (A and B) and then consider the differences and similarities. Graphic organizers to guide students through such a compare-and-contrast-activity are provided by Parks and Black (1990).

There are some advantages in combining the benefits of concept cartoons with the benefits of concept mapping - both of which are classroom tools that can help to reveal students' beliefs and underlying assumptions about natural phenomena. It enables the 'concept mapper' to re-direct any responsibility for incorrect links onto the cartoon character during discussions and so remove the fear of getting it wrong. When map fragments are added to the cartoon (as in Figure x) it helps to break down the ideas encapsulated within the speech balloons into manageable chunks that are easier to manipulate mentally during a discussion. Adding the concept maps helps to show 'the story behind the headline' that is summarized in the balloon. This is valuable as students with similar 'headline beliefs' may exhibit differences in the detail of their understanding - with consequences for future learning.

8.6.3 Selection of concept labels (using competing theories).

At times when students are using complex active frameworks that are in opposition to the accepted scientific viewpoint, it may be helpful to make explicit elements of the accepted framework (that may be present, but inactive) prior to the concept mapping exercise.
When teaching photosynthesis, it may be argued that within a typical classroom there are two competing theories vying for acceptance: the naïve ‘food absorption model’ held by many students and the scientifically valid ‘food production model’ which represents the ‘goal framework’. These theories can be broken down to their constituent arguments for presentation to the students. Students could then be asked to select from these constituents for subsequent incorporation into a concept map. They could be stimulated to do this by being presented with a number of key statements along with a supporting and a counter-argument, such as the examples offered below:

**Photosynthesis converts sunlight into starch**

**A.**
No. Sunlight is a form of energy whilst starch is a chemical composed of molecules containing carbon, hydrogen and oxygen. It is, therefore, impossible to change one directly into the other because they are made of different things. It would be like trying to convert ‘happiness’ into ‘peanut butter’!

**B.**
Yes. Sunlight is absorbed by chlorophyll which converts it into starch. This can be identified by adding iodine which turns starch black. Large amounts of starch can be obtained from a variety of foods (eg. wheat and rice) which form the basis of many people’s diet.

My choice: A. 〇 B. 〇 (tick one)

**Plants get some energy from the soil**

**A.**
No. Plants only absorb water and minerals from the soil. These are vital for the health of the plant, but they do not provide any energy. That comes from the sunlight.

**B.**
Yes. Soil is a plant’s food. Energy-rich nutrients (such as those found in fertilizers) are absorbed by the roots and these allow the plant to grow.

My choice: A. 〇 B. 〇 (tick one)
Selection of one or other arguments effectively provides the student with propositions to incorporate into his/her concept map.

8.6.4 Annotating maps to probe links.

When assessing concept maps, the quality of the links has been shown to be an important indicator of understanding (eg. Carter, 1998). However, in reading concept map links, there is an assumption that the idea intended by the students is the same as that interpreted by the teacher [see the discussion of the ‘translation interface’ in Chapter 7]. Some links can subsume a great deal of understanding that may benefit from further probing. In particular, links that summarize processes may be a shorthand representation of a complex sequence of events. Able students often have the ability to use scientific vocabulary to conceal a lack of real understanding, particularly for concepts such as photosynthesis, conservation of matter and energy transfer (Barker and Slingsby, 1998). The annotation of concept map links may help to reveal detail of the student’s understanding of each link (figure 8-6).
Figure 8-6
Annotating concept maps with 'how' and 'why' questions.

The concept map fragment shown in Figure 8-6 includes five links, of which four indicate processes involved in photosynthesis. This fragment is drawn with speech balloons (described as 'callouts' in MS Word) each containing a 'how' or 'why' question to be addressed by the student. Adequate answers to the questions would require reference to processes such as respiration, osmosis and transpiration. This is also a reminder that even within such a simple fragment of a concept map, a great deal of prerequisite knowledge is required in order to make complete sense of the whole structure so that it can be embedded in a wider conceptual framework.

Answering the questions in this map may be a suitable homework activity, with the questions acting to direct the students’ reading of their textbook (page references could be added to the speech balloons). In such a case, the concept map is acting as an interface, helping to translate the linear structure of the textbook, into a
network structure that may be more representative of the students' conceptual framework [as described in Chapter 3].

8.6.5 Teaching and assessment

I agree with Sizmur (1996a) when he is critical of experimental studies which reveal little about the processes that contribute to reported gains by learners, but I would interpret 'learners' to include teachers and students. The learning that goes on in a classroom results from the interaction between students and between students and teacher, with teachers having a pivotal role in the student-centred classroom.

If the promotion of meaningful learning is the goal of classroom concept mapping activities, then it makes sense that they should be complemented with meaningful assessment methods. Testing understanding with short 'atomized' questions will tend to reinforce rote learning approaches (Black, 1998). The challenge is, therefore, to develop practical assessment tools that do not conflict with constructivist teaching aims and that are accessible to teachers within the normal classroom situation. As assessment seems to be a major driver of curriculum development, particularly at Key Stage 4 (eg. Nott and Wellington, 1999), then perhaps this should be the focus of change, after which change in classroom practice will follow.

When considering concept maps, a combination of 'macro' descriptors for gross morphology (spoke-chain-net) and 'micro' descriptors (eg. for link quality) may be helpful in providing a profile of concept map quality. This would be a development of earlier schemes that only used quantitative assessments of 'micro' map attributes (eg. Malone and Dekkers, 1984). This may provide a mechanism for describing individual learning pathways and may enable the development of a typology that
could help teachers to make more informed choices about appropriate teaching strategies. It would also illuminate the relationship between micro and macro changes in a student’s map over time.

8.6.6 Longitudinal / qualitative studies

Few of the studies reported within the literature on concept mapping have described longitudinal studies in which the development of individuals has been mapped over time. Exceptions are those by Novak and Musonda (1991) and Helldén (1998). In both of these studies, the major use of concept maps was for the transcription and summarising of interview data. The structure of maps presented was therefore, a researcher’s interpretation of the structure intended by the student, rather than a direct representation of it.

The dominance of quantitative, ‘experimental’ research within the science education literature may reflect the researchers’ desire to categorise students who they do not know well enough to describe in more meaningful terms. Such descriptions can only be achieved after the sort of prolonged interaction that can be achieved by teachers, but rarely by researchers:

> When the pupils had flooded into their science laboratory for their first science lesson I had had a sudden irrational feeling that there weren’t any important differences between them. By the end of Year 7 it seemed remarkable to me that I could have felt like that. The pupils had become 21 individuals to me.

(Reiss, 2000: 43)

Recognition of the complexity of the learning process, has led to increased emphasis on qualitative approaches to research (eg. White, 1998). Significant conceptual change is a long-term process, often taking months or years (eg. Driver and Erickson, 1983; Pintrich et al., 1993; Smith et al., 1993). Recording such change during the
course of a short course of instruction therefore seems rather optimistic. It would seem logical to elucidate long-term educational processes through long-term research projects (eg. Arzi, 1988), though the logistical problems created by such work makes it an impractical proposition for a doctoral thesis.
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Appendices

Appendix 1:
Photosynthesis test administered to Yr 10 students at schools B, C and D.

Appendix 2:
Powerpoint slides and commentary used in concept mapping training.

Appendix 3:
Specimen interview transcript (Teacher 1, School D).

Appendix 4:
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Appendix 5:
Revision topic materials developed as part of the training at schools C, D, E and F.
Appendix 1:
Photosynthesis test administered to Yr 10 students at schools B, C and D.
QUESTION BOOKLET

Photosynthesis

Instructions to students

The following page contains 4 questions. Each question has two parts: a multiple choice response followed by a multiple choice reason. You are asked to make one choice from the response section and one choice from the reason section for each question.

Answer all the questions in the answer booklet in ink.

Special instructions for questions 1 - 4:

1. Read each question carefully.

2. Take time to consider your answer.

3. Record your answer in the correct box on the answer sheet

   eg. Question 5. 2 Reason

4. Read the set of possible reasons for your answer.

5. Carefully select a reason which best matches your thinking.

6. Record your answer in the correct reason box on the answer sheet

   eg. Question 5. 2 Reason

7. If you change your mind about an answer, cross out the old answer and add the new choice

   eg. Question 5. 2 Reason

Do not write on this booklet.
1. What gas is given out in largest amounts by green plants in the presence of sunlight?

1) carbon dioxide gas
2) oxygen gas

The reason for my answer is because:

a) This gas is given off in the presence of light energy because green plants only respire during the day.
b) This gas is given off by the green plant because green plants only photosynthesise and do not respire in the presence of light energy.
c) There is more of this gas produced by the green plant during photosynthesis than is required by the green plant for respiration and other processes, so the excess is given off.
d) This gas is a waste product given off by green plants after they photosynthesise.

2. Which gas is taken in by green plants in large amounts when there is no light energy at all?

1) carbon dioxide gas
2) oxygen gas

The reason for my answer is because:

a) This gas is used in photosynthesis which occurs in green plants all the time.
b) This gas is used in photosynthesis which occurs in green plants when there is no light energy at all.
c) This gas is used in respiration which only occurs in green plants when there is no light energy for photosynthesis.
d) This gas is used in respiration which takes place all the time in green plants.
3. The most important benefit to green plants when they photosynthesise is:

1) Removal of carbon dioxide from the air.
2) Production of carbohydrate.
3) Production of energy.

The reason for my answer is because:

a) Photosynthesis provides energy for plant growth.
b) Photosynthesis uses energy from the sun to produce compounds such as sugars and cellulose.
c) Carbon dioxide is taken into the leaves through stomata during photosynthesis.

4. Nutrients from the soil are:

1) Necessary for plant health, but do not provide energy.
2) Necessary for plant health and are a source of energy.
3) Not necessary in the presence of sunlight.

The reason for my answer is because:

a) Plants get energy only from the soil.
b) Plants get energy only from sunlight.
c) Plants get energy from soil and from sunlight.
Question 5.

Look at the equation for photosynthesis given below:

\[
\begin{align*}
1 \quad & \text{Carbon dioxide} \\
2 \quad & \text{Water} \\
3 \quad & \text{sunlight} \\
4 \quad & \text{chlorophyll} \\
5 \quad & \text{Oxygen} \\
6 \quad & \text{Glucose}
\end{align*}
\]

By writing a number from 1 - 6 in the box below, indicate where you would expect to find most energy:

I would expect to find most energy at point number
Question 6.

The following statements about plants may be true or false. Tick the appropriate box opposite each answer:

<table>
<thead>
<tr>
<th>Statement</th>
<th>TRUE</th>
<th>FALSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Plants make food using photosynthesis</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>b. Gases are involved in making plant food</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>c. Leaves store the food that the roots have absorbed</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>d. Photosynthesis makes protein</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>e. People can give plants energy-rich food (e.g., fertiliser)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>f. Leaves change sunlight into food</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>g. Plants change water into sugar</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>h. When a plant grows, the extra material comes from the air</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>i. Plants use photosynthesis instead of respiration</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>j. Photosynthesis makes carbohydrate</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>k. Energy is produced in photosynthesis</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>l. Leaves drink in rain and dew</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
Question 7.

A small tree is planted in a meadow. After 20 years it has grown into a big tree, weighing 250Kg more than when it was planted.

Where did the material for the extra 250Kg come from?

Explain your answer as fully as you can.
Appendix 2:
Powerpoint slides and commentary used in concept mapping training.
What do we mean by ‘concept’?

For our purposes, a concept can be described as an idea that can be represented by a word, phrase or symbol, which can be related in a meaningful way to another idea.

To start, only the word ‘animal’ is revealed and the students are asked to think about the idea represented by the word, and to think what is the next idea they have that is related to it.

Responses usually include ‘dog’, ‘cat’, ‘sheep’, ‘cow’, (and many other animal examples, but will also often include, ‘plants’, ‘zoo’, ‘farm’, ‘hunting’, ‘vegetarians’, ‘animal rights’. The point is made that all of these responses are correct. Different people will respond in different ways and organise their knowledge in different ways - depending on their likes and dislikes, experiences and beliefs.
The point is then made that not all words represent concepts. For example, 'the' does not usually conjure up any image that can be viewed as an idea. Such words (and phrases) are useful, however, as linking words and phrases to help string concepts together to make meanings clear.

It is often noted that some links could be concepts in a different context (even within the same map). 'Results' could be a concept, whilst 'results in' may be used as a link.
The usual way that we link ideas is by constructing propositions.

Discussion of the first proposition in the slide usually reveals uncertainty about how many concepts are represented within the proposition, 'fire engines are red'. Some students will consider 'fire' and 'engines' to be distinct ideas. Others will suggest that the whole thing can be summarised by one concept, 'red fire engines'.

The discussion goes on to say that we could ask the students to list all their understanding as propositions in this way, but the list would be unhelpful as it would not have a structure by which we could navigate to find a particular element in our understanding.
By rearranging the simple proposition 'fire engines are red', basics of a concept map can be revealed and built upon.

The previous ambiguity regarding the numbers of concepts represented is now overcome as concepts are always bounded by a box. These are linked by an arrow (showing the direction in which to read the proposition) and the arrow is labelled with a linking word or phrase to make the meaning of the link explicit.
Additional concepts can then be added without having to re-write the proposition. Here the concept of speed can be incorporated by the addition of an extra concept box, linked by a labelled arrow.
Further concepts can be added in this way.

Here the idea of a 999 call is added.

Once this concept is included, it is suggested to the students that an additional concept (on the same level as 'fire engines') might be incorporated as it is not only fire engines that can be summoned by a 999 call.

Typically, the students will suggest either 'police cars' or 'ambulances' could be added.
With this slide I tell the students that my brain is obviously working in the same way as their because I thought of adding 'police cars'.

I tell them that once I have 'police cars' and 'fire engines' together, I feel that I need something else to make the set complete - 'ambulances'.

Then. Once I have 'police cars', 'fire engines' and 'ambulances' in a row my mind immediately wants to put them in a group together with a name that we could put in the empty concept box at the top.

The students all come out with 'emergency services' (or sometimes 'rescue vehicles'), and I say that we have now constructed a simple concept map of emergency services that we could elaborate if we wanted to: 'helicopters', 'coast guard' etc.

It is also stressed that sometimes we don't start a map with the 'top concept', but that emerges during the map's construction.
A simple concept map of gardening is then presented as 'someone's' view.

The map is described in terms of two strands of information: what goes on in the garden and what goes on in the greenhouse. It is then stressed that these two strands are not unrelated.

The cross-link from 'seedlings' to 'garden' illustrate how different strands can be related. The analogy is then made to their lessons and how one sequence of lessons (eg. the heart) may be related to another sequence (eg. the kidney) by a common link (eg. blood). This is also true across subjects (eg. Biology and Chemistry; Biology and Geography; Biology and Mathematics).

The value of cross-links is emphasised.
A simple concept map of 'animal' is then displayed to emphasise the hierarchical nature of many ideas in biology (i.e. there are big ideas which have smaller components, with specific examples to anchor them).

Students are told to aim for a hierarchical arrangement in their maps so that when they read down any sequence of links, an idea is always more specific (smaller) than the one above it.

Students are also told that a strict hierarchy is not always possible to achieve in a map, depending upon the subject material and that if they cannot construct theirs hierarchically - not to worry.
Emphasis is made on the absolute need to label the links so that their meaning is clear and unambiguous.

Using this slide, only the top (unlabelled) proposition is revealed and the students are asked what the link might be.

They will make several suggestions and I tell them that they are all correct (revealing the labelled propositions below).

I emphasise that the context of the map is important - a sweet shop owner may give one response and a dentist a different one.
Golden rules for concept mapping

1. Concepts are written in boxes
2. Major concepts appear at the top of the page and more specific concepts appear lower down
3. Each concept can only be written in one place on the map
4. Links have arrowheads to show the direction in which they should be read
5. Links must have labels (words or phrases) to give them meaning
6. There can be any number of links coming from or going to a concept box
7. Do not include so many concepts that the overall structure becomes unclear

A summary of some key point to remember is given. This was not given as a slide to all the groups. I felt that younger students may find such a list of ‘rules’ a little daunting.
DNA

The double helix structure of DNA was discovered by Watson and Crick in 1953. Each molecule consists of two strands of nucleotides that are wound round histone proteins. A nucleotide is made of phosphohoric acid, a pentose sugar (deoxyribose) and an organic base. The bases are of two types, purines (Adenine and Guanine) and pyrimidines (Cytosine and Thymine). The bases form complimentary pairs (A=T & C=G) by hydrogen bonding. This maintains the molecule's double helix structure.

All student groups were asked to construct a map on a topic with which they were familiar (at a suitable level for the age and ability of the class).

Often a piece of text was given and the students were first asked to read the passage and highlight any concepts they found.

Using this list of concepts, students were asked to organise the ideas into a concept map by ranking and clustering them. The text structure is such that this is not a free response.
When the students have had sufficient time to construct a map, a completed version (stressed not to be the only right answer) is revealed.

This may be given with the linking labels omitted so that the students can complete the map.
What does DNA mean to you?

CONCEPT MAP (FREE COMPOSITION)

Some groups are given a blank sheet with only the top concept indicated. They are free to select any ideas they wish to incorporate in their map.
While students are constructing their own maps, this slide is left in view to reinforce the importance of the linking labels.

Students will sometimes draw a map without linking labels and proclaim that they have finished. They were congratulated on the structure of the map and then asked what some of the links meant.

I explained that I needed help to understand each link and could they label the links as they were on the example maps.
Appendix 3:
Specimen interview transcript (Teacher 1, School D).
Ian: O.k. This interview is a chance for you to say whatever you want, however positive or negative.

T.: Alright.

Ian: It's up to you. If I can start by asking, if before I came in, had you been previously aware of concept mapping as a technique?

T.: No.

Ian: So you'd never used it or seen it used before?

T.: No.

Ian: O.k. When I was doing it and you were then teaching the kids who were doing it, what were your feelings about the concept mapping?

T.: Good! They always respond to any new sort of initiative, because it's different. So sometimes it's quite difficult to decide whether they think it's a useful activity in itself or whether they just think it's useful because it's different. But yes, certainly I felt that all of the groups I've seen were giving it a go. They weren't going to dismiss it out of hand, they were prepared to listen and to try it out. I'm different to Richard and Yasin because I didn't do your INSET day so I was only seeing it for the first time with the students.

Ian: So you were getting a 'students' eye view'.

T.: I was getting a students' eye view.

Ian: Was there anything negative? Anything that you didn't like?

T.: Not that I didn't like. One or two of the kids subsequently said, um 'why did I need to do that?' And I think that tends actually to be the bright kids. And I think that's because they were doing that anyway, but they didn't realise it. 'Cos they were the ones who could make links between even one week and the next let alone one topic and another. And so they were being asked to think in a way that they were kind of doing anyway, and um ... and so they said 'why did I need to do that?'?

Ian: Did they find it easy?
Well interestingly, I don't think they did because it was like ... you know we both have reservations about when you need a concept map ... well in a sense that was what was happening to them, because they subconsciously learnt to make links and so an artificial way of doing it was being put on top of what they did anyway. And so I think they felt uncomfortable with that rather like we feel uncomfortable if we're given a concept map about photosynthesis to deliver. I think that's what was happening, that you were trying to direct him in a way of thinking that was obviously not going to be identical to the way that he was thinking anyway ... or they were thinking ... there weren't very many, but there were perhaps three I think. I can think of two and I have a feeling there was another one. It was a minority. But I think that's what the problem was. You were trying to overlay something on a process that they did already.

And they didn't like it.

Well, they felt ... one of them said he felt threatened by it, and I think the other two well it was so blindingly obvious that it was a waste of time... really.

What about the majority?

The vast majority I think have found it useful. The greatest feedback I've had is from a VIth form group who I did a workshop with a blank piece of paper on um, the cell. And we tried to do some concept mapping. We just first of all, all tried to throw up words and then try and link them all together ... with the cell. What was the one you did with them?

I did the cell with one group.

It might not have been the cell itself, but a ... but I think it might have been processes that take place within the cell ... or something, it wasn't identical to the one that you'd done. And I could see there that they were finding that quite useful ... linking all the bits together. I think that’s its greatest use, because what we started from, is they come to a lesson with like a ‘blank head’. And we think that we are delivering a curriculum that’s building on past experience, but that isn’t where they’re coming from. They come in with a ‘well what are we doing today?’; and you might start off by saying, ‘well you’ll remember last week’, but you have to do that for them. They don’t come in thinking, ‘oh, last week I had some starch and amylase and I noticed that the starch disappeared when they were mixed - I wonder what else I could find out’. For example, at the moment we've got a two-week window in Year 10. We've been doing digestion and we want to do a catalase practical, but we don’t want to start that ‘till after Easter. We’ve been trying to think of something to fill the window so we looked at the Year 11 syllabus, well what we normally do in Year 11. And we thought, well we’ll do the kidney and Richard was
saying, 'well that’s got nothing to do with digestion, they can’t do that’. But they don’t think like that. I’m sure they don’t think like that.

You think that at the end of the lesson, it’s sort of filed away?

Yes. Yes I think so. And while that enables us to have the flexibility that I’ve just described, it can also be frustrating because they don’t bring with them the knowledge that you are expecting them to have. Now I think it’s in there, but it’s sort of been filed away. [Then we finally saw the time] when in Year 10 we’re revisiting say, respiration or circulation, when I’m expecting them to have, ‘cos they did it in Key Stage 3, some knowledge of ‘lungs - heart - body - heart - lungs - heart - body’, and yet they look at me blankly. Now another year, I think I might start off with, before we do this subject - rather like we did the photosynthesis, let’s just see where you’re at. Yes I think I will actually do that because I’ve had in the last two weeks precisely this. I want to go straight into digestion involving amylase and starch and I’m expecting them to bring with them the model gut; the fact that starch is a large molecule that needs to be broken down before it can be absorbed into the blood stream, and they simply didn’t bring that with them. Not at the front of their minds, so I need to find a way of getting it.

So you have to activate their memories?

Yes.

And put it into context for them?

Yes. And I guess the concept mapping might be a way of doing that. You know, ‘let’s just establish where you are at’. ... One of the problems with a concept map is that they do get it wrong. I know you say that it can’t be wrong ‘cos it’s your idea, but if their idea is that ‘photosynthesis makes energy’, I mean that’s a wrong idea. So if you ask them, one of the reservations I had is if I say ‘right we’re going to do digestion, or some more work on digestion, let’s have a look at where you are now, sometimes by writing down something that they’ve actually got backwards, instead of that actually reinforcing that it’s right, and if they write these concept maps down and they’ve got the wrong idea, I gonna have to go through each concept map with a tooth comb and look and see where...

I mean I suppose I could do one of two things with it: I could either mark it and actually say well, lots of good ideas here but this one’s confused and that one’s backwards or where do you think that fits - that sort of .. or I could use it as a teaching aid for me to see where the problems lie.
Ian: I think you’re right. There is a worry about pupils writing down things that are wrong and reinforcing that idea, but I think the counter argument would be, well they’ve got that idea anyway and all they’re doing is making it available for you to see.

T.: Yes that’s true, yes.

Ian: And if they don’t make the concept map, the idea is still there, they just haven’t told you.

T.: Yes, that’s very valid. Yes, absolutely right, you’ve got to address this, and if you don’t know about it, it’s just going to stay there. Or they’re just gonna get confused because you’re just gonna put another concept layer on top which is inconsistent with the one that they’ve got. It’s unlearning.

Ian: That’s right. O.k. Did you get any other feedback from the students, either things they liked or things they didn’t like about it?

T.: Well I took away the ones that ... you did a lesson for me on the kidney.

Ian: On homeostasis, yes.

T.: Yeh. And I wasn’t there, and I looked at those. And I actually used those as a starting point, ‘cos I hadn’t actually taught them the kidney at all. So what I did was, I read them through and on each one ... I didn’t actually correct things that were wrong, ‘cos I don’t think they actually got very much wrong, more the problem was that it was incomplete. They hadn’t made the link between drinking water, and urine ... you know. So I sent them back and said ‘could you put an arrow in here?’, ‘where does this go?’, um ... and they then did that. And I didn’t think they did it because I told them to do it ... so it wasn’t ... it was indirect feedback, in the sense that they wanted to continue to do it – they wanted to build on that. And again, I used the concept map ... this is not actually quite answering your question, but ... I also took the concept maps that we did with Year 7 to a parents’ evening, because it was about solutes and solvents, I think. They’d done their own maps on solutes and solvents ... and it ... was actually a very useful diagnostic tool for sort of the understanding of that particular scientific process. And also I used it as evidence for divergent thinking, because I had some guys who just had a straight arrow-arrow-arrow in a line, and they weren’t branching anywhere; and other guys who were making links between temperature and stirring and mass and all that sort of stuff. And I actually ... they’d done them on A3 I think so it was quite nice, and I actually, once or twice, brought them out and said this shows how well they’re relating all these concepts and how they are able to use them. And that conversely, this shows how he ... I
interpreted it in some cases a lack of confidence, that they’d come across these words and
they were just very nervous about using them in a wider context. And I actually used
them for parents’ evening. So I’ve actually done quite a lot, I mean I’ve marked the Year
11 ones, and I’ve used it …

Ian Did you find marking them easy?

T. No, but fascinating. I think I must, I can’t remember but, I’m sure I must have corrected
some things that were actually wrong. I think I probably scribbled through a line and
said, ‘talk to me about this’ or ‘where do you think this goes?’. But again it showed up, as
if I didn’t know already, but it showed up my really good boys … um … so it is a very
useful di… I mean diagnostic tool, and what was revealed by Year 7, way back in
November when we did it, it has proved true.

In terms of …

T. In terms of their continuing science progress.

Ian So you could use them as a predictor, you think, of the way they’re gonna develop?

T. Yeh. … I would like to look at that. I would like to look at that. Give them something
very early on, I mean November. I mean you’ve got to somehow give them all a level
playing field, because you can’t hit them as soon as they come because you don’t know
the varied experience they’ve had in the past. And it might not be a processing thing, it
might be a confidence and knowledge thing … um, so about then, about November for
Year 7, who I am teaching three times a week. I mean another thing, my Year 10 group, I
am only teaching once a week – I’ve probably actually only taught … 25 times. You see.
Whereas you can get through 25 times by the second half of the Autumn term. So um,
yeh, I’d like to look at that.

Ian How did the parents react at the parents’ evening to the concept maps?

T. Very impressed.

Ian They didn’t have any problem understanding them or seeing what you were talking
about?

T. Um, difficult to tell. Um …
They smiled and nodded?

They smiled and nodded, and thought well, she probably knows what she’s talking about. Yeh, so I’ve actually used them quite a lot. I’m just thinking on my feet now, about having taught that Year 10 now, you know for the same number of hits, um whether now would be a good time to do something with them. They’ve done the photosynthesis one, you see. They’ve now done starch/amylase experiment, as a filler, we’re gonna do the kidney for a couple of weeks and then we’re gonna go back to hit catalase as an assessed practical. So the idea of ‘enzymes’ and what they do might be just the ticket.

You’ve actually seen Year 7; Year 10 and the Vith Form doing this.

What stage do you think is the best stage to introduce this.

And I’ve seen Year 10 as well, of course. ... Year 7.

Was there less resistance with the Year 7s than there was with the other groups?

Difficult to tell ‘cos they’re very compliant anyway. If you told them to stand on their heads, they’d do it, but their just so enthusiastic ... um ... I mean you’ve had interviews with the Year 10s, and given that they’re polite boys so it’s difficult to tell, what’s your impression – did they find them useful?

The majority of boys from here that I’ve interviewed in Year 10, have said that they acknowledge that it is useful and it’s helped them to make links and see the overview, but they qualify that by saying that they don’t really want to make too many because they’ve admitted either that they are too lazy or that they’ve got other techniques that they use for revision which have served them well up ‘till now and so why do anything else?

Right. So that suggests then that it’s something that we want to introduce as a tool, that they can have in their toolbox (to use the jargon), earlier on. So that that might be one of the techniques that they use.

And I think as well, the more maps you make, the better you become at mapping. So if they were already competent mappers by Year 10, they probably wouldn’t think twice, they’d just produce them and think that’s normal. ... Do you intend to use the concept mapping in the future ...
T. Yeh.

Ian And in what way, do you think – either in the classroom or planning for yourself or what?

T. Um, I do it anyway, I think ... not in such a formal sense ... um, but it's the way I operate anyway. I actually think biology's quite good at linking ... you know, it's a strength you have to have in order to be a competent biologist. And given that of all the boys that we are teaching, only a minority will ever go on to become competent biologists, you expect some of them to have a pre-disposition for linking. Or to learn it and enjoy it. Biology's a circle, isn't it, or a jigsaw, or whatever you know. I mean I suppose a lot of subjects are. It's only when you get to the end of the story ... it's like my Year 11 group at the moment, they're happy because suddenly all those bits and bobs from all over those years are all coming together. And that gives them a sort of ... you know, while they were on the journey it was sort of ohhh, you know, 'where's it all going?', and you have to try and keep them with you until the end when it all sort of makes sense. I don't know, I'm not qualified to talk about other subjects. I can imagine in history, you learn a bit about the Tudors and then you have to take the same techniques and learn about post-war England, but does it all form a pattern at the end? I can't imagine that it does, necessarily. I mean there might be recurring themes.

Ian So do you see this as a problem in biology teaching, then? The fact that until you see the whole story, your gonna be dissatisfied.

T. Yeh. I thinks it's um, it's nice when it happens at the end. It's the guys that you lose en route that's the problem. Like I said to you this morning, this guy, this dopey guy, who's done nothing for five terms was doing genetics and said to me "I can do this". And um, I'm not suggesting that if I gave that to him at the beginning of Year 10 he would have been able to do it. I think it took all those five ... I know genetics is a different subject, a different topic to digestion and the heart and everything else, but it's about a way of thinking, isn't it. I think he's been trained over four terms so that when I finally give him genetics to do, he knew how to do it. It was like the concept, it was a concept that he was comfortable with. ... because he'd travelled all those concepts before, I think. I need to find ... it's what's the most useful, whether it's useful to teachers as a diagnostic tool. It's useful to the students if they get it right. The big question is, how useful is it if they do it and it's got confusion in it. What do you do then?

Ian Do you not think that confusion needs to be highlighted so that you can tackle it in whatever way you think?
Yes so that means again that you're using concept maps as a means to an end. And not as an end .. I mean it can be a useful summary, but .. so its got to be in the middle hasn't it. I think you've got to give a bit; you've gotta do a concept map, but you can't just leave it there. You can't open that particular can of worms and say 'fine', you have to take that forward because otherwise you leave them. But because it's such an individual thing, it raises all sorts of individual problems – it's whether you've got the time or commitment to sort those out, I mean that's the major stumbling block.

Time in the classroom. Or lack of time in the classroom.

Yes. I mean you're talking here about a very individual thing, and um, so it's got to be dealt with as an individual. There's no point in getting up and saying, 'Oh most of you got this bit wrong', it invalidates the whole thing, doesn't it? It was what you did as a person ... that's the problem.

Is there anyway that we can actually treat them as individuals though, given the time constraints?

Well ... yes. Um ... that has to be possible. We treat them as individuals when they do coursework. I mean at the moment, what happens here is that if they're doing a particular investigation, which they've just done on heart rate, everybody will write a plan, a draft plan, then they hand it in and we will go through with post its - all sorts and write on it' 'you need to explain this a bit more', 'can you give an equation for respiration here', 'but why does the muscle need more oxygen?', 'are you gonna do any replicates?', ... that way you communicate with the individual, but that involves you using time out of the classroom and then giving it back to him and for him probably to digest in his own time... the problem is, to address the concerns of a concept map, you probably need a dialogue and that's what's really tough. To find time for that.

Is there anything that appeared in the students' concept maps that surprised you?

I was disappointed ... I think ... but not surprised about their confusions with energy. They really have got a problem ... haven't they. And if these really bright boys can't get their heads around that, then what the hell else is going on out there. You know ... the concept of energy is a worry.

Have you mentioned that to anyone in the physics department?
T. No.

Ian Do you think they would be aware of it being a problem?

T. No. I think that they look less for problems. They all just assume that it's O.K. As you know we're teaching chemistry this year, and we keep saying to the chemists, well ... why are you doing it like that? Or what's the expectation, or suppose they don't do it like that. And the chemists are saying ... they're absolutely amazed because it's never occurred to them that someone might not be able to do it. Which is the useful thing about somebody else coming in because you see the problems. But yes, the energy thing was a bit of a worry.

Ian I've done this in a variety of schools, and I reckon probably something like 90% of the kids I've seen are completely confused about energy. In terms of photosynthesis, they just don't know why it's there, and where it's there and how it's there.

T. Or even respiration. They talk about, um, respiration producing energy.

Ian O.K. Is there anything that's happened, anything you've experienced during the concept mapping sessions that would lead you to change your teaching of that topic next year?

T. Yes, I think I would change it by, as I indicated earlier, trying to find out where they were at before I started. Now the easiest thing to do, which I admit freely that I do do, is to say effectively 'O.K. guys, let's start with a blank sheet of paper - can I assume you know nothing?', because that way ... but of course that isn't the reality. They are bringing prior knowledge and concepts and um, in order to differentiate adequately, I really ought to look to see who's where. 'Cos you're going to be boring to death the people who already know what you're on about. It's very demanding ...

Ian On the teacher

T. Yes. Very demanding. But I certainly um ... I'd like to look at the concept mapping as a diagnostic tool. I'm quite interested anyway in looking at how these kids are learning and where the problem is. You know, do they have a problem with learning with what they see; do they have a problem with what they hear. Where do the mixed messages come from? Where do they get these confused ideas from? Is it what they hear on the telly; is it what happened at primary school. I think it would be better if you knew what they knew before you try and get them to learn something different. And I think, what makes a good teacher is that they don't say 'I'm gonna teach them this', but 'they are gonna learn this'. 
And um, a hugh number of people, even here, don’t understand that. They’ll say, ‘well, I’ve taught them’. And what they mean is, they stood up and did it. But they just don’t know what the kids have learned or how they learned. There’s got to be some opportunity for concept mapping in the learning process. I do some study skills in PHSE, and ...

Ian This is with which year groups?

T. We do PHSE with every year group, but I specifically do some study skills with Year 7 and Year 10 do some study skills as well, although not delivered by me. But it could be introduced in any year, I mean we have a lesson a week in Years 7, 8 and 9 and ... 20 hours a year in Year 10. So we could look at concept mapping as a whole ... you know, just go in and do concept mapping about ... how you learn, I suppose, or ... how dinner time works, or something, just as a sort of learning tool.

Ian You mentioned about how you learn, do you think anybody in the school really takes the time to discuss or to talk to the kids about how they do learn?

T. Well I do. But I don’t know if anybody else does. Because I know that there are kids here who are failing because they are not learning, and I try and work out what it is that stops them from learning.

Ian It’s not to do with them not being bright?

T. Well no. They’ve got here. With all the failings of the eleven plus, they had to jump the eleven plus hoop. You can be trained to do that and we probably get down to a couple at the sixty percentile, and maybe a couple at say sixty five. Most of them will be in the top thirty. So they have got ability, but they don’t perform here, they don’t reach our expectations. As a head of year, this is what I’m up against. Guys who have got here, but don’t then deliver the goods. So why? Is it because they can’t get themselves organised? Almost certainly. Is it because they don’t understand the learning ... a grammatical problem when the teacher says ‘I want you to watch a video and take some notes’, they didn’t understand what that meant? Um, is it because they can’t express themselves in prose? So they can’t write ant any length. I dunno. But I don’t know who to ask. But I would have thought, having seen how useful it was diagnostically for my Year 7 scientists, there’s some mileage here.

Ian O.K. (inaudible question about teaching strategies)

T. I did have a look at it briefly.
You may want to talk about different year groups, you may approach different year
groups in a different way.

Now, 'which is the one that you would ideally like' [reading]. It was 'D' I think. Teacher
focused ... It was 'D'.

That's where you would like to see yourself most of the time?

Yes.

And what's the reality?

You're right, different year groups, um, vary. I try to do 'D' within Year 7 ... as much as I
can. Effectively with Year 7 it's 'C'. [Bell goes for end of lunch break]. Certainly with
GCSE, um, it's 'B'.

And what's the reason for you having to opt for 'B' ...

Time. Time and pressure of curriculum content.

O.k. Time is pressing so if we move on quickly ... if someone came from another school
and said, 'should I do concept mapping?', what would you say?

Yes.

Why?

Because it treats the kids as individuals and just for once they've got the opportunity to
express themselves in a non-threatening way. They don't have to produce something that
is the teacher's ideal. And they're not necessarily being judged up against everybody
else. It's useful for providing them a way of expressing where they're at. But to be very
useful, the teacher's then got to do something with it. You can't just say 'oh, I've done a
concept map', 'oh good, let's pat you on the back!'. It's a can of worms. If you open it,
you've got to do something with it. Otherwise you've got the danger of reinforcing mixed
messages and confused concepts.

Is there any other comment that you'd like to make before we finish. Anything that we've
not touched on?
Well I would like to know about experience elsewhere, and I’d like to think of some ideas of using it in a study skills context rather than a biology teaching context, or science teaching context.

O.k. Thank you

Thank you for your time, including with the kids.

Thank you very much.

11th March 1999.
Appendix 4:
Material developed by teachers in school E for incorporation in their scheme of work.
Concept Mapping in Year 7 Science

Each module in biology, chemistry, and physics contains one Concept Mapping exercise. Details are below. Copies of the resources for these tasks are attached.

<table>
<thead>
<tr>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic 7A.1:</strong> Cells in Organisms</td>
<td><strong>Topic 7A.1:</strong> White</td>
<td><strong>Topic 7E.2:</strong> Energy</td>
</tr>
<tr>
<td>Map title: Living things</td>
<td>Map title: Dissolving</td>
<td>Map title: Electricity</td>
</tr>
<tr>
<td>Task: Fill in the missing concepts and links</td>
<td>Task: Fill in the missing concepts and links</td>
<td>Task: Students make their own map individually, possibly after a class discussion. They are then grouped and asked to form an agreed map from their group Suggested time 1 lesson in lesson either at the start to extend the students' prior knowledge, or as revision at the end of the topic.</td>
</tr>
<tr>
<td>Two versions are provided - one includes the missing words. Judge which each student should have</td>
<td>Two versions are provided - one includes the missing words. Judge which each student should have</td>
<td>Two versions are provided - one includes the missing words. Judge which each student should have</td>
</tr>
<tr>
<td><strong>Extension:</strong> add extra concepts and more links Suggested time 5-10 minutes in lesson 7</td>
<td><strong>Extension:</strong> add extra concepts and more links Suggested time 5-10 minutes in lesson 7</td>
<td><strong>Extension:</strong> add extra concepts and more links Suggested time 5-10 minutes in lesson 7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic 7A.2:</strong> Classification and plant reproduction</td>
<td><strong>Topic 7A.2:</strong> Solids</td>
<td><strong>Topic 7E.3:</strong> Electricity</td>
</tr>
<tr>
<td>Map title: Flowers</td>
<td>Map title: Solids and glasses</td>
<td>Map title: Electricity</td>
</tr>
<tr>
<td>Task: Fill in the missing concepts and links</td>
<td>Task: The concepts are given in boxes, and direction arrows are shown. Students choose the words for the links, and add an arrow head to show the 'direction' of the concept. Extension: add extra concepts and more links. Suggested time 20 minutes in lesson 2</td>
<td>Task: The concepts are given. Students add links, remembering to pay careful attention to their choice of words. A help sheet is available for those with difficulties. Extension: add extra concepts and more links. Suggested time 30 minutes in lesson. As part of revision eg lesson 14</td>
</tr>
<tr>
<td>Two versions are provided - one includes the missing words. Judge which each student should have</td>
<td>Two versions are provided - one includes the missing words. Judge which each student should have</td>
<td>Two versions are provided - one includes the missing words. Judge which each student should have</td>
</tr>
<tr>
<td><strong>Extension:</strong> add extra concepts and more links Suggested time 10 minutes in lesson 7 or start of 8</td>
<td><strong>Extension:</strong> add extra concepts and more links Suggested time 10 minutes in lesson 7</td>
<td><strong>Extension:</strong> add extra concepts and more links Suggested time 10 minutes in lesson 7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic 7A.3:</strong> Sexual reproduction &amp; breathing</td>
<td><strong>Topic 7A.3:</strong> Materials</td>
<td><strong>Topic 7E.4:</strong> Electricity</td>
</tr>
<tr>
<td>Map title: Smoking</td>
<td>Map title: Materials</td>
<td>Map title: Electricity</td>
</tr>
<tr>
<td>Task: Students make their own map individually, possibly after a class discussion. Suggested time 20 minutes in lesson 11 (or other lesson on smoking)</td>
<td>Task: Fill in the missing concepts and links. Two versions to choose from. Extension: add extra concepts and more links. Suggested time 10 minutes in lesson 8</td>
<td>Task: The concepts are given. Students add links, remembering to pay careful attention to their choice of words. A help sheet is available for those with difficulties. Extension: add extra concepts and more links. Suggested time 10 minutes in lesson 8</td>
</tr>
</tbody>
</table>

**Resources - contents**

- Living things concept map - version 1: page 3
- Living things concept map - version 2 (missing words given to help): page 4
- Living things concept map - answers*: page 5
- Flowers concept map - version 1: page 6
- Flowers concept map - version 2 (missing words given as help): page 7
- Flowers concept map - "answers": page 8
- Dissolving concept map: page 9
- Dissolving concept map - "answers": page 10
- Materials concept map - version 1 (concepts missing): page 11
- Materials concept map - version 2 (missing words given as help): page 12
- Materials concept map - version 3 (links missing): page 13
- Materials concept map - answers: page 14
- Electricity concept map: page 15
- Electricity concept map - hint sheet: page 16
- Solids, liquids and gases concept map - version 1: page 17
- Solids, liquids and gases concept map - version 2: page 18
Task:
Copy and complete this concept map. Use these words and phrases to help you.
Cells are the building blocks of Chloroplasts Cell membrane Animals can be are made of plant all have
Nucleus, Cytoplasm, Cell wall, Vacuole
Task: Fill in the missing words and links. Use these words to help you:
sugar, water, soluble, insoluble, solutes, consists of
are, dissolves in, sea water,

Dissolving - A Concept Map

- SOLUTION
  - is an example of
  - consists of
  - SOLVENTS
    - is a
    - dissolves in
  - SOLID
    - that dissolves
    - that doesn't dissolve
  - LIQUIDS

- SOLUTION
  - is an example of
  - consists of
  - SOLVENT
    - dissolves in
    - is a
    - that dissolves
    - that doesn't dissolve
  - SOLUBLE
  - INSOLUBLE
  - SOLUTES
    - are
  - LIQUIDS
    - sugar
    - water
Materials Concept Map

Tack
Copy this concept map into your book. Fill in all the gaps and missing labels

Materials Concept Map

Tack
Copy this concept map into your book. Fill in the gaps and use these words to help you understand:
- hard
- animals
- rocks
- come from
- products
- malleable
Task: Add your own labels and links to this concept map.

Task: Add your own labels and links to this concept map.
Appendix 5:
Revision topic materials developed as part of the training at schools C, D, E and F.
Circulatory System

The circulatory system is made of three main parts: a heart, blood and blood vessels. The heart pumps the blood which travels through the blood vessels.

The heart is made of muscle. It is made of four chambers (called atria and ventricles) which are separated by valves.

The blood contains a fluid called plasma which carries dissolved substances such as sugar. It also contains three sorts of blood cells. Platelets help in blood clotting. White cells help to fight against disease. Red cells carry oxygen to the tissues that need it (such as the brain and liver).

The blood vessels are of three types. Capillaries travel through the tissues. There are also arteries (eg. the Aorta) and veins (eg. the Jugular vein).
**Pond Life**

The things that live in a pond can be drawn in a diagram called a pyramid of numbers. In this diagram, plants (which are also called producers), are drawn in the bottom level. An example of a pond plant is duckweed. Herbivores (which eat plants) are drawn in the middle level. An example is the pond snail. Carnivores (which are also known as predators) usually eat the herbivores and are drawn in the top level. An example of a carnivore that lives in ponds is the dragonfly nymph. It is important to remember that the bottom level of the pyramid is usually the largest and the top level is usually the smallest.
Acids

Acids can be weak, with a fairly low pH, or they can be strong, with a very low pH.

Acids can be neutralized by bases (such as sodium hydroxide) which have a high pH.

The pH is shown by using universal indicator.
ACIDS

WEAK
- fairly low

STRONG
- very low

NEUTRALIZED
- high
- shown by

BASES
- eg. sodium hydroxide

UNIVERSAL INDICATOR
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.281x166.
I BACTERIA I
ACID
I 4 TYPES I
incisors
canines
pre-molars
molars
I TEETH I
ENAMEL
BRUSHING
I FOOD I
BACTERIA
ACID

incisors
canines
pre-molars
molars
Teeth and decay

Do you have healthy teeth? Then make sure you brush good and feel good. Your teeth are important and you should remember to take care of them. They chew food up into small pieces before you swallow it. Imagine trying to swallow an apple whole!

a) Which foods could you eat if you had no teeth?

Types of teeth

b) Look at your teeth in a mirror.

- When you are an adult you should have 32, but you won’t have them all yet.
- Look carefully for the 4 types of teeth.
- Write down what you think each of them is used for.
- Your teacher will give you a diagram of a set of teeth.

c) Shade in the ones in which you have fillings and cross out any that are missing.

Parts of a tooth

The part of a tooth that you can see in your mouth is covered with a white layer of enamel. Enamel is the hardest substance in your body.

c) Why is it found here?

Un-enamel is the living part of your tooth which is made of dentine. This is softer than enamel.

c) In the middle of each tooth is the pulp cavity which contains nerves and blood vessels.

c) When do you have a tooth out? Why does it bleed and feel sore?

Do you brush your teeth properly?

- Find out how you should brush your teeth.
- Your teacher will give you a chart.

Remember, you can keep your teeth and gums healthy by:

- Brush your teeth twice a day.
- Avoid sugary foods and drinks.
- Floss your teeth.
- Rinse your mouth after each meal.
- Visit the dentist regularly.

Under attack

Teeth decay can erode your bone and cause pain.

- Bacteria grows on the food (especially sugar, food and form plaque).
- Food collects in the cavity, bacteria makes it worse. This acid attack the enamel and the cavity gets larger.
- The bacteria makes acid. This is the process for the formation of a cavity.
- Once through the enamel the cavity starts to spread down the dentine to the pulp. The nerve is now affected. It can be very painful.

Plaque attack

How effective are different toothpastes at killing bacteria?

- Take an agar plate with harmless bacteria growing on it. Bacteria has been cut out for you in the jelly.
- Using a marker pen, number each hole on the underside of your plate.
- Then mix the lid carefully fill each hole with a different toothpaste, making a note of what is in each hole.
- Place the lid and fix it down with adhesive tape.
- Place your agar plate in a warm incubator at 35°C for 2 days.
- Wash your hands with soap and water.
- After 2 days, measure the diameter of any clear areas.
- Sketch your results on a copy of the diagram.
- Do not open the plate. When you have finished, return the plate to your teacher.

Which toothpaste do you think is best to use and why?

Many toothpastes are alkaline. How does this help them fight tooth decay?

- Copy and complete:

  1. Copy the diagram of a tooth and shade in the parts of the tooth that are affected by plaque.

  2. If you have a toothache, try brushing your teeth with a hard toothbrush. This will help to remove the plaque and food particles that are causing the pain.

  3. Take a piece of cloth and wrap it around your tooth. Gently, but firmly, apply pressure to the area. This will help to reduce the pain and swelling.

Things to do

- Write down what you would do.