Conceptual Change: An Ecosystemic Perspective on Children's Beliefs about Inheritance

by

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Abstract

The work reported in this thesis involved the exploration of 12 year old children's conceptions of inheritance. Results derived from interviews and from videotaped recordings of small group discussions, indicate that children's conceptions of inheritance are well developed before they are formally taught these notions in school. A series of open-ended problem solving tasks were designed to elicit student's conceptions and to facilitate group discussion. Results suggest that children's conceptions of inherited characteristics are heterogeneous and 'organized' in a highly flexible way. A research model, based on the notion of conceptual ecosystems, was developed to provide a framework for data analysis. Features of conceptual ecosystems are described. It is suggested that such systems are characterised by their 'openness', adaptiveness and resilience. Results suggest that the heterogeneity, flexibility and fluctuating character of such ecosystems confer on conceptions the ability both to transform well and to resist change well. The study describes how these characteristics of resilience and adaptiveness are displayed in the cognitive and social interactions of individual students. A theory of conceptual change is advanced which considers learning as a series of continuous qualitative changes made by the learner to existing personal conceptions. The significance of these 'metatransitions' is discussed in the light of existing teaching and learning strategies. It is suggested that conceptual change can be facilitated by helping students to make their existing conceptions...
explicit, co-active and interactive within conceptual ecosystems. The social and cognitive consequences of conceptual conflict, disagreement and consensus are described. It is proposed that an ecosystemic view of children's conceptions may help explain and overcome the difficulties experienced by students when they try to reconcile scientific concepts with their existing conceptions.
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Chapter 1

Literature Review

1.0 Introduction

The following discussion will review our present understanding of children's beliefs about inheritance and will examine the ways in which it is thought that student's conceptions might change under the impact of teaching and learning.

The initial discussion will focus on the specific difficulties associated with teaching and learning genetics. What emerges from this initial review is that children's conceptions play a significant part in the problem. However, research into children's beliefs about inheritance and investigations into the nature of conceptual change must be located in a multi-dimensional 'space' occupied by numerous constellations of interactive ideas about the nature of scientific concepts, learning, conceptual change and cognitive research. What I have tried to do in this review is to follow a route through this matrix, using three different notions of what constitutes a 'concept'. I will discuss these three concepts of a 'concept' in terms of their epistemological underpinnings, the cognitive psychologies which have informed them, the notions of conceptual change that they convey and the teaching and learning strategies which they are associated.
1.1 Genetics – Pedagogic Problems and Perspectives.

There is a general consensus of feeling amongst biology teachers and their students that genetics is a 'difficult' topic. Research studies have supported this impression whilst illuminating the teaching and learning problems which underpin it.

Johnstone and Mahoud (1980) carried out a survey of topic areas within the Scottish Certificate of Education Higher Biology syllabus. Senior students, teachers and first year university students were asked to score fifteen biology topics in terms of their perceived difficulty. Both teachers and students placed genetics high on their list. In a similar study by Finley et al. (1982), genetics concepts were described by teachers as being difficult but important elements of school biology. These findings provide an interesting counterpoint to the work of Shayer (1974) which suggested that the genetics content of the Nuffield 'O' level Biology syllabus was inappropriate for students at that stage of cognitive development, i.e. the conceptual demand, in Piagetian terms, was too high for students of 'O' level age. Shayer (1980) recommended that the genetics component of the 'O' level syllabus should be abandoned. This proposed 'solution' to the difficulties associated with genetics concepts fails to recognise and consider the curricular significance of genetics. In a society increasingly preoccupied with prenatal diagnosis, genetic counselling, biotechnology and molecular genetics, it seems at the very least short-sighted to consider genetics as an expendable part of the biology syllabus at any level. If we are to have 'science for all'
then there is a powerful argument for the retention of genetics concepts within the syllabus and more research into the difficulties associated with the topic.

1.2 Research Perspectives on the Difficulties Associated with Genetics.

The character of school genetics, particularly Mendelian inheritance, is largely based on problem solving and the assumption that students learn genetics concepts during problem solving activities. Stewart (1983) examined the strategies used by American college students when they attempted to solve genetics problems. This study revealed that many students solve inheritance problems successfully, but use ritualised problem solving algorithms, rather than genetics concepts and processes. In a related study, Stewart (1982) concluded that problem solving in genetics required two types of knowledge; procedural knowledge (skill) and conceptual knowledge derived from the theory of inheritance. Stewart (1983) comments that if problem solving is to be meaningful to the student, procedural skills must be grounded in conceptual knowledge. On the basis of this research, Stewart (1982) has developed a model of meaningful learning in relation to problems involving phenotype/genotype, dominant/recessive and allelic information. This model actively accommodates procedural and conceptual knowledge, and is designed to 'diagnose' student difficulties. The technique used is to compare the actual 'route' taken by a student through the genetics problem with an ideal 'map'
derived from expert knowledge. In situations where students take the 'wrong' path the model is designed to help teachers anticipate and correct the consequences of these 'mistakes' in terms of procedural and conceptual knowledge.

An alternative model of genetics problem solving, based on Piagetian doctrine, has been put forward by Lawson (1979) and Walker et al. (1980). These workers argue that meaningful solutions to genetics problems, based on conceptual knowledge, require the student to have attained the stage of 'formal operations'. Walker et al. (1980) contend that there is a relationship between the student's performance in Piagetian tests and their ability to solve genetics problems. This research would tend to align itself with Shayer's (1974) findings about the cognitive demand of genetics concepts. Formal thinking may indeed be a factor in problem solving. In most genetics problems the student is asked to work with multiple hypotheses regarding the possible outcomes of parental crosses and to relate these to notions of phenotypic and geneotypic probability. These sorts of operations are characteristic of formal thinking, however, the lack of formal operations seems in no way to negate the student's ability to relate to genetics concepts in a meaningful fashion. Non formal thinkers and unsuccessful problem solvers may have an entirely adequate framework of concepts on which to base their understanding of genetics. These idiosyncratic conceptual frameworks may or may not be biologically correct, however for the individual they represent the foundations of understanding.
1.3 Students Prior Knowledge of Genetics.

Deadman and Kelly (1978) carried out research to investigate what students understood about evolution and heredity before they were formally introduced to the topic in school. This research was based on the Ausubelian dictum that if we know more about the quality and character of these understandings, then we can, in some way, increase the effectiveness of teaching and learning strategies. Deadman and Kelly (1978) confirmed in their study that students have a set of definite ideas about inheritance before formal teaching begins, although when viewed from a strictly biological perspective these ideas may seem superficial and underdeveloped.

Kargbo et al. (1980) also investigated children's prior knowledge of inheritance concepts. Their findings suggested that children in the age range 7-13 years have a number of novel ideas about the nature and mechanisms of inheritance. Kargbo et al. (1980) categorised these intuitive ideas into 'environmental', 'somatic', 'naturalistic', and 'genetic' explanations. 'Environmental' explanations given by the children focused on how factors such as water, sunlight, food and parental care might influence the genetic traits of the offspring. 'Somatic' explanations invoked structures such as brain, blood and nerves as systems which would influence inherited traits. 'Naturalistic' explanations centred on motherhood, sex resemblance with parents, nature and life cycles as important determinants of inherited characteristics. Some of the students in the study did use 'genetic' explanations in relation to parental input and dominance characteristics. This study commented on the
age related character of children's ideas of inheritance, indicating that younger students (6-10 years) favoured environmental, somatic and naturalistic explanations whilst genetic explanations were used only by the older children. Despite the Piagetian overtones of this part of the study, there is a clear indication from this work that children have a diverse set of explanations relating to inheritance well before they are formally introduced to the topic in school.

These studies of children's ideas about inheritance prior to formal instruction are an interesting backdrop to research work carried out into children's understandings after teaching. Hackling (1982) investigated a range of concepts related to inheritance and identified what he refers to as "common misconceptions" in student's understandings immediately after units of instruction.

"The notion of dominance as a process which determines which of two alleles is expressed in the phenotype has been confused by the student's preconceptions about dominance refering to power and authority. Many students describe blending in terms of a mixing of genes, a view popular in the nineteenth century prior to Mendel's demonstration that genes are discrete units that are reassorted in each generation."

In a similar study using structured interviews, Hackling and Treagust (1984), working with students who had just completed a genetics course, concluded that many students did understand the relationship between reproduction and inheritance. This research suggested that children know that their features came from their parents and that as offspring they can get a mixture of features from both parents. Hackling and Treagust (1984) comment that this understanding is probably developed in the context of concrete experiences with their own families and that this may explain why
these ideas are more frequently understood than ideas of a more abstract kind, such as dominance. Even after instruction, this study found that most students experienced difficulties in giving an explanation of terms such as dominance, recessiveness and blending inheritance; most student explanations focusing on everyday meanings of dominance and blending.

1.4 Intuitive Knowledge and Learning.

In a case study of adult learning in genetics, Baird and White (1982) found two distinct learning strategies. These researchers describe a learning style which involves the active integration of prior knowledge with scientific knowledge. Understandings based on this style of learning, according to these workers, may have more utility in everyday situations and be more accessible to the learner. An alternative style of learning identified in this research was characterised by learners who used a task orientated approach, which was limited to responding appropriately to received stimuli in order to obtain correct answers. This style was less related to prior knowledge of the topic and potentially at least, was considered to be less useful in everyday situations.

Research into the problems of teaching and learning genetics is associated with a number of epistemological viewpoints, each one informed by a variety of psychologies, theories of learning, and philosophies of science. Depending on the nature of these epistemologies, a number of interpretations can be placed on problems associated with the teaching and learning of inheritance.
For example, if researchers adopt a Realist perspective which emphasises knowledge as being independent of the learner's subjective contributions, the prior knowledge of the student will be measured against the 'correctness' of the received scientific view. If the student's ideas are at odds with the scientific view they may be deemed to be errors or 'misconceptions' which require teaching strategies designed to erase or overwrite the learner's original conceptual framework.

An alternative view of these 'misconceptions' has been proposed by Driver and Easley (1978) and Gilbert et al. (1982). Gilbert et al. describe children's alternative conceptions as

"conceptual structures which provide a sensible and coherent understanding of the world from the child's point of view."

This research suggests that when viewed from a constructivist epistemological position, these alternative conceptions may play a critical and important role in student learning.

It is clear from this review that research into the teaching and learning of genetics draws on various epistemologies, and these in turn encapsulate a number of different ideas about such fundamental notions as, how children learn, the nature of scientific concepts, the status of children's prior knowledge and which teaching strategies bring about conceptual change. The following discussion will review some of the theories of learning, pedagogic practices and cognitive psychologies which have informed the epistemologies of researchers and teachers. This review will illuminate a number of viewpoints adopted by educationists in their efforts to develop an understanding of the activities of the
learner, and will examine how researchers and teachers visualise the student's use of scientific concepts and individual conceptions during the learning/conceptual change process. This discussion will introduce the epistemological and personal commitments which determine my research posture and the nature of my investigations into children's conceptions of inheritance and the process of conceptual change.

1.5 Piagetian Theory and the Structure of Knowledge.

Jean Piaget (1896–1980) has been one of the most influential international figures in cognitive psychology and education. Piagetian theory relating to conceptual change has influenced pedagogic practice, curriculum design and how teachers 'see' the world of the child.

According to Piaget's theory of learning, cognitive development consists of the individual child coming to terms with the physical environment around him in increasingly abstract ways. This transition from reflexive to abstract mental processing is seen to be controlled by four main stages in cognitive development; sensori-motor, pre-operational, concrete and formal stages. Piaget (1964) describes how the child progresses through these stages under the influence of several factors.

"What factors can be called upon to explain the development from one set of structures to another? It seems to me that there are four main factors: First of all maturation in the sense of Gessell, since this development is a continuation of the embryogenesis; second, the role of experience of the effects of the physical environment and the structure of intelligence, third, social transmission in the broad sense
(linguistic transmission, education etc.) and fourth, a factor which is too often neglected but one which seems to me fundamental and even the principal factor. I shall call this the factor of equilibrium or if you prefer it self-regulation."

Piagetian equilibration is central to his proposed mechanism of conceptual change and cognitive development; indeed, the notion of equilibration is unique to Piaget's epistemology. Equilibration represents a process which operates when the child's knowledge of the world grows and when he begins to recognise the problems and errors associated with previous judgements about natural phenomena. These problems and reservations about the nature of the world disturb the child's cognitive structures, and according to Piaget, motivate him to utilise appropriate cognitive operations in order to achieve a new equilibrium. Reaching this new equilibrium state involves the learner in a series of accommodations which adapt his knowledge structures to the assimilations derived from ongoing experiences. Bolton (1977) gives this classic example of equilibration in the context of a 'conservation task'

"...so that eventually the child oscillates between, say, asserting that there is 'more liquid' in the comparison beaker because it is taller and asserting that there is less because it is narrower. The child is thus led to recognise the problem and the error of his previous judgements, he is now motivated to use logical operations of reversibility and compensation to justify a conservation judgement."

Piaget's notion of change through equilibration owes much to the cybernetician's ideas of 'ultrastability' which Jantsch (1976) describes as a system that

"...adapts stepwise via different structural states to an ultimate equilibrium, its evolution foreclosed by the equilibrium telos."
Thus the learner's 'compensations' for new experiences drives the process of equilibration in a spiral of progressive and successive accommodations and assimilations. This view of cognitive development is said to betray Piaget's 'closed' perception of learning in which the learner is seen as being isolated from interpersonal and contextual influences by his cognitive structures.

Wilden (1980) comments

"In Piaget, however, in everything he has to say about 'frontiers', 'boundaries', and 'bounded structures', we find an entirely different and atomistic relation, which is clearly connected with his Cartesian or Husserlian conceptions of the individual. For Piaget, these frontiers are not only conceived of as real they are also obviously conceived as belonging to the structure. (In other words he does, in his theory, what we all do in our daily practice: we separate figure from ground, and then attribute the boundary between them to the figure). Thus, whereas for the ecosystemic perspective, the boundary is the locus of communication and interaction, the paradoxical distinction upon which the whole ecosystemic relation depends - and without which we would all be Kantian rubber balls - for the bioenergetic perspective, and Piaget, it is the barrier to communication. What we see as a Common Market, he sees as a tariff wall, in the terms of a kind of isolationist protectionism. It follows, therefore that what is a barrier to communication will also be a barrier to certain kinds of change, and that it is this epistemological attribution of frontiers to a privileged set of entities, called structures, that makes Piaget's conception of the 'genetic' or diachronic relation of one structure to another in child development so dubious."

In this way the structural logic of stage theory takes precedence over the aims and goals of the learner, and denies the individual freedom of deliberate action on, and in response to, the learning environment that he experiences. The negative feedback activities or 'compensations' of the learner are in fact used to suppress the 'noise' (environmental variations perceived by the learner) from the cognitive environment and reinforce the stability of schemata and
cognitive structures. In a truly evolutionary model of cognitive change (Piagetian theory is more developmental than evolutionary) individual learners do not seek to damp out the effects of experience, but seek to be sensitive to 'noise' and adapt to changes in the cognitive environment by positive feedback strategies which retain an inherent flexibility of response to learning situations. In contrast to Piagetian theory, non-equilibrium theories of change stress the 'openness' and flexibility of the learner's cognitive frameworks and the emergence of learning strategies. Individual learners are thus seen to be involved in a symbiotic interaction with their environment out of which they construct learning experiences and live out the consequences of these constructions in a particular context.

1.6 Piagetian Teaching Strategies and Conceptual Change.

In addition to theoretical reservations, educational researchers have voiced concern as to the utility and fruitfulness of adopting a Piagetian perspective. Hoy (1974) investigating the influence of contextual information on the ability of six year olds to predict the point of view of another person, found that stage development may depend largely on the type and number of characteristics of the subject matter as well as the elicitation procedure used to interview the children. Indeed Piaget (1974) has given support to the notion that stage development may be context linked. This implies that there is a greater reciprocity between the schema of the learner and the quality of the conceptual environment
surrounding her. The researcher or teacher seeking to implement
Piagetian theory whilst recognising conceptual influences, must
consider that at a practical level this requires an increased
awareness of the learner's existing cognitive status, and the
cognitive demand of specific subject areas. Before selecting
'appropriate' learning materials and subject content, teachers must
know the student's level of cognitive development. Much of the
Piagetian 'technology' developed over the years has been aimed at
designing diagnostic tests to facilitate just such an understanding
of the learner's cognitive status (Shayer and Adey 1981).
Underpinning this 'technology' is the assumption that by matching
the cognitive demand of the content to the student's cognitive
status, teachers can better facilitate the accommodations and
assimilations of the learner. Jantsch (1976) comments on this
strategy and refers to a "spirit of Utopian engineering" which he
sees as indicative of this type of normative forecasting which
seems to negate the variety and complexity of learning contexts.
Driver (1983) comments that

"This approach can give some guidance in general planning of
science courses over the years 5-16. However, there are
problems in applying it to particular classes and individual
children. Some problems are organizational and raise questions
of how instruction can be successfully individualised to match
the requirements of all people in the class."

The adequacy of Piagetian analyses designed to assess
cognitive demand within specific areas of the curriculum has been
questioned by teachers and researchers. Depending on the style of
teaching and the learning strategies used to introduce topics, the
level of cognitive demand may be modified in such a way as to
heighten or diminish that level. Topics deemed to be inappropriate for a particular group of children may in fact be meaningfully taught by the imaginative teacher aware of, and sympathetic to, the child's previous experiences and prior knowledge (Driver 1983).

The 'technology' associated with assessing cognitive demand and 'match-mismatch' information is derived from Piaget's notion of cognitive change through successive equilibrations. Translation of this theory into classroom practice has led to an interest in cognitive conflict/dissonance strategies aimed at facilitating conceptual development. Rowell (1983) has articulated a formal model of conceptual change based on the work of Piaget (1977) and Inhelder et al. (1974). Rowell's theory stresses the "cycles of heightening equilibration" associated with cognitive imbalance (situations where the dynamic equilibrium of the learner's cognitive apparatus has been disturbed). These workers suggest that teachers should seek to promote conceptual change by disturbing the learner's equilibrium by inducing cognitive imbalance and then facilitating the student's return to a new, temporary equilibrium state. Case (1978) describes four factors which may influence this strategy:

1. Exposure to situations which could be interpreted as problematic
2. Exposure to situations in which there is a clear indication that the current basis for prediction is inadequate
3. Exposure to situations where the unattended feature is highlighted in some fashion
4. Exposure to models of how to incorporate the additional feature"

This type of conceptual change pedagogy puts great emphasis on teacher influence and expertise, and assumes a perfect
understanding of the learner's cognitive status and prior experiences. This type of 'cognitive profile' is difficult to construct with any sort of accuracy; the task being made more daunting by the incomplete coverage of measures designed to assess cognitive demand in various topic areas and the inevitable generalisations which attempt to fill these gaps.

Case's strategies for inducing cognitive imbalance can be refined, in Piagetian terms, by exposing the learner to a stage of cognitive development one step beyond his present capabilities. The assumption in this procedure being that a '+1 optimal mismatch' will promote cognitive imbalance and drive the developmental processes of the learner to the next equilibrium state. Kuhn (1979) is critical of this strategy in that its mode of action remains "vague" and "incomplete"; indeed, it is as much an act of faith in stage theory as anything relating to good pedagogic practice. At a practical level the effectiveness of these strategies are difficult to assess as they require the 'experimenter' to discriminate between conceptual development resulting from exposure to 'superior' processing and imitation. Rosenthal and Zimmerman (1972) found that children imitated 'correct' procedures and made fewer 'errors' in post tests, after exposure to +1 strategies. Participants in these sorts of studies are often covertly invited by the methodology to change their conceptualisations. In reality there can be no certainty that they have modified their actual
belief systems. In theoretical terms, imitation by the learner can be progressive or regressive. There is no evidence to suggest that the learner, drawn by the upward spiral of equilibration, will selectively choose models of a cognitively superior behaviour to those which are seen to be inferior. Work by Perret-Clermont (1980) using small groups of children selected to optimise cognitive conflict within the group (eg. groups composed of children, some of whom were volume conservers and others who were not) has shown that in a social situation where superior models of cognitive processing are available for inspection, children tend to adopt the cognitive strategies associated with superior models - non conservers tend to become conservers and not vice versa. Kuhn (1972) has tried to induce disequilibrium in the classroom setting by presenting the child with advanced models of cognition. Unfortunately, Kuhn's methods neglect the importance of the interaction between behavioural models and the learner's individual constructions of events.

Rowell and Dawson (1982) acknowledge these various Piagetian strategies in their studies of instructional difficulties associated with such topics as dynamics and volume. They found that children's schemata were difficult to dislodge, even when they were presented with conflicting expectations and concrete examples of the limitations of their present theories. The only change that these workers observed was when the child's existing theory was combined with a new theory to form a hybrid concept. In the light of these findings Rowell and Dawson (1985) developed a strategy to
circumvent this cognitive inertia. Before describing this procedure it is very interesting to note that the hybridisation of ideas is seen as problematic, given that from the learner’s point of view, it may be highly significant for him to retain old and new theories as part of an effective long term learning strategy. If it is not necessary to destroy old ideas before accepting new ones, why should the learner reduce the flexibility of his conceptual frameworks and the adaptive potential of his knowledge base?

The 'Framework Replacement' strategy of Rowell and Dawson (1985) is a sequence of steps designed to promote cognitive change through controlled conflict, whilst getting over the 'problem' of children adding on or retaining current knowledge. Rowell and Dawson (1985) describe the procedure in the following way:

"1. Students were made consciously aware of their existing ideas
2. Different ideas were not discussed in detail or brought into conflict
3. Students were asked to retain their ideas, but were told that one possibility would be taught and that their help would be needed later for its evaluation
4. The idea was taught linking it where possible to existing knowledge
5. Once students could use the new idea, the old ones were recalled for a comparison and both compared with reality."

In this way Rowell and Dawson seek to encourage children to construct an alternative theory based on new experience which conflict with their present schemata. The conflict is not introduced until the children are aware of the new idea. In this way the idea which is subjected to explanation by the teacher is kept separate from old ideas until it is ready for competition. The
methodological rationale for this procedure being derived from Kuhn's (1962) philosophy of science.

"Once it has achieved the status of a paradigm a scientific theory is declared invalid only if an alternative candidate is available to take its place."

Dawson and Rowell (1984) have conducted classroom trials of the Framework Replacement strategy, however, they report inconclusive results from these studies. Perhaps this outcome of their research indicates that we have to consider a more complex or extended type of interaction between new and existing concepts. Rather than conceptual change being a process of awareness raising and exposure to superior models of cognitive processing, we may have to consider the nature of the conceptual ecosystem in which new ideas become established.

The Framework Replacement strategy contrasts with the research of Nussbaum and Novick (1981) which has used a technique based on Festinger's cognitive dissonance theory. In their studies of students' understanding of the particulate nature of matter, they encouraged students to brainstorm ideas in the classroom, thus making a range of conceptions overt and open to inspection. Various responses from the students, from a number of viewpoints, created much discussion. In this climate of critical appraisal, students were expected to restructure their conceptual frameworks in order to accommodate cognitive discrepancies resulting from the 'failure' of their existing ideas to predict events. With this strategy, Nussbaum and Novick (1981) place great emphasis on the teacher as
co-ordinator and facilitator, helping the class to manage their debates and deliberations. This role is defined by these workers in the following terms:

1. The teacher creates a situation which requires students to invoke their frameworks.
2. Teacher encourages verbal and pictorial descriptions of these ideas.
3. Teacher facilitates their expression of ideas.
4. Students debate the pros and cons of different ideas. Creation of cognitive conflict within many of those participating.
5. Teacher supports the search for the best solution (most generalizable) and encourages signs of student accommodation.

The strategy of Nussbaum and Novick involves intense activity on the part of the teacher, and assumes that her understanding of the student's existing knowledge is in a state of heightened sensitivity, ready to capitalise on the conceptual environment created during class discussions. This perception of the teacher's role, although interesting, seems to view the teacher as being one step removed from the activities going on in her classroom; i.e. the teacher is less of a co-participant in the construction of understanding and more of a manager of a learning situation.

Minstrell (1982) has described attempts to have students "reconstruct a better conceptual framework" through the use of learning materials and experiences designed to point out inadequacies in existing concepts. Minstrell claims that there must be a high degree of engagement with the tasks presented, requiring that students organize their observations as well as clarify and justify their conceptions. If children have recourse to the teacher, textbook or any other resource before this process is complete,
Minstrell (1982) contends that this may diminish the student's ability to bring about a change of concept. Stavey and Berkovitz (1980) have also designed materials which encompass a conflict strategy, their idea being to bring children's qualitative-verbal representations into conflict with their quantitative-numerical representation systems. In this way the power of conflict and heightened awareness is embodied in the materials used by the students whilst reducing the work load on the teacher. Champagne, Klopfer and Gunstone (1982) have also utilised an instructional design model in an effort to bring about conceptual change in a classroom context. The first element of their model is a comparative analysis of 'cognitive states' (problem solving strategies are used as a basis for this analysis) of naive students, novices and experts. These cognitive states are then transformed into instructional objectives relating to specific scientific topics. Problem based teaching strategies are subsequently deployed as a way of helping students externalise their ideas. Finally the teacher is encouraged to provide expert analysis of the problems and ask students to assess and to comment on these solutions in the light of alternative explanations. Reports on the success of this modified Socratic method are inconclusive (Rowell and Dawson 1985). As the emphasis moves away from teacher direction towards forms of individualised conflict arousal, teaching materials must have the potential to bring about conflict in individual students. Student engagement with a learning task must not only be measured in terms of motivational factors but also with regard to the effectiveness of
the material in generating anomalies within the conceptual frameworks of novice learners.

1.7 Piaget's Epistemology and its effects on teaching.

Operationalising Piaget's epistemology makes heavy demands on teacher skills. In order to facilitate conceptual change and development, Piagetian pedagogies require the teacher to deploy a range of strategies aimed at teaching 'suitable' concepts at the 'right' time. Trying to apply Piaget in the classroom has often resulted in mixed success, and has exposed the gap between one man's epistemology and another teacher's practice. The work of Gagne (1977) has tried to bridge this gap between learning theory and its classroom implementation. Gagne, like Piaget, was interested in mathematical and physical learning tasks, and his theory of learning is underpinned by a logical framework in which concepts are seen as elemental components of a knowledge hierarchy. Gilbert and Watts (1983) have described this notion of concept and conceptualisation as 'classical'.

"An all or nothing, syllogistic concept bears little resemblance to the rather messy actuality of conceptual activity in either science subject-orientated terms or in everyday life. As Pines and Leith (1981) suggest, it is inappropriate to see concept development in terms of single, bound entities acquired in 'all or none integral steps. It is as Markova (1982) describes, a Cartesian perspective. She characterises it as conceiving of concepts as 'logical atoms', a hierarchical subdivision of knowledge which Kelly (1963) has called an 'accumulative fragmentalist' view. An underlying assumption is that knowledge is stored in the mind in hierarchical layers which can be decomposed into smaller parts and studied independently. Transferred to the area of educational instruction these assumptions imply that the process of acquisition of knowledge is decomposable into

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elementary steps that can be represented by hierarchical
decision trees, so that progress in knowledge is dependent on
whether the previous step is mastered in its entirety: whether
it is right or wrong. Such a model is that used by Ausubel
(Gilbert and Watts 1983)

The 'classical' view of concept described above is more overt
in the work of Gagné than that of Piaget. This may be a
consequence of Gagné's emphasis on the logical structure of the
material to be learned (mathematical/physical), and his commitment
to an 'accumulative fragmentalist' view of concept. Gagné's theory
of learning tends to distill out the constructivist components of
Piagetian theory and leaves a residue of pure logic. An insight
into this process can be gleaned by looking at its effects on
subject content. Typically, a concept will be placed at the apex of
a 'pyramid of understanding'; from this position the concept will
be reduced to its pre-requisite intellectual elements by 'expert'
insights into the nature of the learning process. Running
concurrently with this analysis will be a consideration of the
cognitive abilities needed to move the learner from the base to the
apex of the pyramid; from specific levels of understanding to more
general understanding. On the basis of this type of content
analysis science teachers are encouraged to develop learning
strategies and monitor student performance using the concept
hierarchy as a template for lesson organization, evaluation and
planning. Thus the concept hierarchy created at the analysis stage
can dictate the nature of the learning experiences to which the
student is exposed. Student 'errors' and 'misconceptions' are deemed
to be deviant behaviours which threaten the learner's path toward
understanding, and as such require erasure from his conceptual framework. In complex conceptual domains such as biology, where no single hierarchy of concepts can take account of the multiplicity of interactions between concepts, student 'errors' are not uncommon. These 'bugs' in the system (Brown and Vanlehw 1980) are perhaps less to do with student inadequacies and more a reflection of the emphasis placed on logico-mathematical tasks by Gagne's theory of learning.

Gagne's theories have been used successfully in the organization of curricula such as the Schools Council Integrated Science Project (SCISP). However, at the level of the individual student it fails to capture the complex, idiosyncratic, unpredictable and often illogical nature of conceptual understanding.

1.8 Ausubelian Views of Concept Development.

Compared to Gagne's 'logical' analysis of concept attainment, the work of Ausubel (1968) represents an attempt to bring more fluidity and realism to our understanding of children's conceptual development. Ausubel contends that concept understanding may take a unique and entirely idiosyncratic pathway depending on the individual student's previous and personal experience. His theory of learning describes conceptual development as a continuous series of reorganizations in which existing concepts are modified as they
interact with new perceptions, ideas and beliefs. This viewpoint recognises that young learners can relate complex ideas to 'relevant' background knowledge derived from their existing range of concepts. Thus, in an Ausubelian framework, children can be expected to possess even abstract concepts, and have the ability to handle inter-relationships between concepts. This perspective on learning represents an alternative to the age/stage aspects of Piagetian theory.

In essence, Ausubelian theory holds that new ideas are linked to relevant existing concepts; the term relevant denoting what Ausubel sees as the logical relationship between new and existing concepts. This relationship between old and new ideas can be represented in a concept development context as an hierarchically ordered framework of existing concepts with which new concepts may interact. The nature of this interaction is seen as 'meaningful' when the learner finds the relationship between the old and the new significant for future learning. From this perspective, young children can relate to abstract concepts by finding points of attachment between their existing knowledge and new concepts. Where the learner lacks the 'relevant' prior experiences and correct 'subsumers', Ausubelian theory anticipates that 'misconceptions' will fill the gap in the students conceptual framework. Such 'misconceptions' although often viewed as errors are not wrong when viewed from the learner's standpoint, for they have functional utility and meaning in the context of their personal conceptual framework. The resilience of misconceptions in the face of formal teaching designed to modify or erase them, may reflect the personal
viability of these 'misconceptions'. Ausubelian theory suggests that the teacher seeking to 'correct' the student's 'misconceptions', must provide her with the missing concepts or subsuming experiences which will allow her to integrate the correct ideas and displace improvised misconceptions. This process of reorganization and subsumption can be anchored and facilitated by what Ausubel calls 'advanced organizers'. This notion tends to betray a view of concepts which fails to consider the inherently idiosyncratic character of the learner's rationality and reasoning, and tends to portray an image of learning as a task determined by the logic of the conceptual content. West and Fensham (1974) have reservations about Ausubel's over-reliance on conceptual hierarchies derived from this sort of task analysis.

"...the facts, concepts and principles that the learner uses for subsumption may not be obtained by logical task analysis undertaken by someone who has mastered the learning. They may not be the same for all learners."

The critical question for teachers is what are the subsumers and advanced organizers in a particular knowledge domain, and how do they interact with the learner's existing knowledge: are they the logical elements and precursors of a concept hierarchy, or the intuitive meaning structures of naive learners? Research into these questions has been carried out by a small number of workers. Ring and Novak (1971) examined the effects of subsumers on new learning by testing college chemistry students before the start of their chemistry course and after its completion. They report that
"the presence of subsumers without facts increased achievement, but having facts without subsumers did not."

However, West and Fensham (1974) suggest that the evidence for the beneficial effects of subsumers (Gudrub and Novak 1973) has possible alternative interpretations.

"Research into ways of providing for these potential low achievers, either by remedial teaching to provide relevant subsumers or in providing external organizational aids is clearly dependent on our ability to produce valid measures of the existence of subsumers."

and

"The problem of deciding which prior knowledge 'bits' are needed to act as subsumers is made difficult by the fact that the learner may use concepts and facts as subsumers which bear no relationship to those obtained by logical task analysis by a person who has already mastered the task."

and

"A learner may not have in his cognitive structure the relevant subsumers for a given piece of new learning...the existence of relevant subsumers does not per se guarantee that they will be called into play to produce meaningful learning...there is a chance that the learner will in fact, embark on a process of subsuming new learning but using concepts form his prior knowledge that are not 'relevant'."

Fensham (1972) has shown that students commonly associate a number of concepts, which if used as subsumers, would be quite misleading in the context of learning a new topic.

As well as subsumers, Ausubel's notion of advanced organizers has also been the focus for a number of studies aimed at determining the latter's role in the learning process. Kuhn and Novak (1971) using advanced organizers for two biological concepts (levels of biological organization and homeostasis) claimed that the retention of 'meaningful' material by the students was enhanced by the introduction, prior to learning, of what these workers deemed to be relevant advanced organizers. This type of research
tends to emphasise the quantity of learning rather than its quality; indeed the pre/post test, multiple choice questions used in their research are characteristic of this approach. Lawson (1975) using the theme 'change over time' suggests that, as an advanced organizer, this idea has utility as a superordinate concept in the teaching of evolution. Lawson (1975) claims that by using problem solving learning strategies it is possible to differentiate the idea of 'change' into various subordinate biological concepts.

Research into the effects of advanced organizers has produced some very mixed results. Bauman et al. (1969) and Weisberg (1970) show that advanced organizers are not effective, whilst the studies of Kuhn and Novak (1970, 1971) show that they have a significant effect on learning. These conflicting results may be symptomatic of such studies, for they are largely based on comparisons of learning effectiveness between 'treatment' and 'control' groups of students. The style of this research methodology may impose considerable constraints on the nature of its findings.

At an even more fundamental level of criticism, the problem with research into advanced organizers is that there is nothing to prevent the learner from ignoring the advanced organizers presented to him and, as an alternative, using what he sees as appropriate prior knowledge. This possibility takes us in the direction of accepting that most imaginative learners will possess 'relevant' and 'irrelevant' subsumers either of which will allow them to operate on a given learning task. Researchers have pre-tested students to ascertain their level of prior knowledge in areas which the researcher sees as being related to the learning task.
Unfortunately, they have often failed to examine the range of subsumers that could be used, including those irrelevant prior knowledge subsumers which from the learner's viewpoint are just as effective and equally viable as those provided by the teacher/researcher.

1.9 Ausubelian Pedagogy.

Ausubel's learning theory has been translated into practical teaching strategies for the classroom by Novak and Gowin (1984). These workers have focused on the importance of prior knowledge and its relationship with conceptual hierarchies of subsuming ideas. The emergent outcome of this research in terms of pedagogic strategy has been the development of concept mapping. In its simplest form a concept map can be two concepts joined by a linking word in the form of a proposition. Novak and Gowin (1984) describe the concept map as providing

"a visual road map for a 'journey' we are about to begin and some of the pathways we may take to connect meanings of concepts in propositions."

This description of a concept map using a road map analogy is interesting when one considers the notion of concept which underpins Ausubelian theory and the concept mapping technique. Concepts in the latter context seem to be an uncomfortable mixture of absolutism and relativism based on two other possible Ausubelian interpretations of the road map analogy - a) given the a
priori derivation of logical, relevant hierarchical structures, there
will be a straight line route through the concept hierarchy
representing the 'shortest distance between two levels of
understanding; or alternatively b) given two levels of
understanding there will be a 'correct' route between them even
before the learner begins his journey along the learning path.

Concept mapping is designed to allow teachers and students to
externalise concepts and propositions. It is suggested by Novak
that this is a creative act which allows the student to develop new
concepts

"Undoubtedly we may develop 'new' concept relationships in the
process of drawing concept maps, especially if we seek actively
to construct propositional relationships between concepts that
were not previously recognised as related."

(Novak and Gowin 1984)

This creative aspect of concept mapping is closely aligned with the
Ausubelian notion of 'integrative reconciliation'.

Working with small groups of children, Novak and Gowin invited
the students to negotiate the meaning of a passage from a textbook
and to use their concept maps as a focus for discussion. The
construction of the maps was seen by Novak and Gowin as a way of
mirroring the negotiation of meaning between group members.

"At first blush one may say that the teacher (or textbook) is
supposed to know what is right; how can we suggest there
should be negotiation with the learner. The point is, we are
speaking about cognitive meanings and these cannot be
transfused into a student as blood is pumped into veins.
Learning the meaning of a piece of knowledge requires dialog,
exchange, sharing, sometimes compromise and so on. In a manner
analogous to the professional negotiator who may help bring
labor and management together on a contract, concept maps are
useful tools to help students negotiate with their mentors."

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Thus, it is suggested that in an environment of mutual negotiation, concept maps produced by students can be used to suggest linkages between new ideas and concept propositions which are an existing part of the learner's conceptual framework. This meta-learning aspect of concept mapping strategies is a point of departure from strict Ausubelian notions of concept hierarchies, and moves mapping closer to the notion of concept development.

"the more closely any study approaches an actional view of concept, the more likely it is to contribute to a notion of conceptual development. By this we mean proposals that accept the existence, and value to their users, of alternative frameworks, or seek to modify them towards the consensus view of formal science."

(Gilbert and Watts 1983)

This viewpoint, and the practical outcomes of trying to implement Ausubel's theory in classroom situations, highlights the modifications and compensations that result when practitioners try to apply epistemologies. The closer the teacher/researcher moves toward the notion of 'logical, hierarchical concept maps', 'relevant subsumers', and 'good' maps, the more the learner seems to find these strategies irrelevant and distant from the realities of learning.

Johnstone and Mahmoud (1981) studying student's understanding of water transport and osmosis, used a concept hierarchy approach to monitor the effects of a learning programme devised by their research group. Their comments on the relationship between children's learning strategies and their paths through the 'correct' hierarchy of concepts underline the differences between the expert and the learner's perspective.
"Success with ideas 5 and 6 did not seem to depend on success with ideas 2, 3 and 4. [numbers refer to levels in the hierarchy]......Either our hierarchy was faulty or pupils had found their own self-consistent and sufficient hierarchy in which ideas in the discontinuities were not of any great consequence. In other work in chemistry (Howe 1975, Johnstone 1980) we have come across this phenomenon before. The reasoned adult hierarchy may not coincide with the route taken by an immature learner."

Failure to capture the idiosyncratic and dynamic aspects of conceptual development, through an over reliance on concept hierarchies and expert models of learning, places limitations on the role of the teacher and denigrates the learner's activities as she comes to terms with new concepts.

1.10 Conceptualising and Classifying - A Relational Viewpoint of Concepts.

Whether one accepts or disagrees with Ausubelian learning theory and its related 'technologies', one significant outcome of this work is the way that it has focused attention on the importance of what the learner already knows. One approach to concept development firmly based on this belief, but which has tried to distance itself from the theoretical constraints of "classical" notions of concept, is that associated with the idea of concept formation. From this standpoint, the most important consideration is to help the learner identify the criterial attributes of the concept and to locate these within his existing conceptual framework. Tennyson and Park (1980) have suggested that teaching sequences can facilitate this process by presenting
exemplars of the concept in which the criterial attributes are more prominent than non-criterial attributes. Concept membership is thus understood by way of exemplars, descriptors and inter-concept relationships. Concept formation is thus inherently probabilistic and requires the student to put together through his own activities the membership parameters of a particular concept. Fleshner (1963) stresses the importance of the learner's engagement in concept formation in his description of a teaching strategy which juxtaposes exemplars and non-exemplars of a concept in order to draw the student's attention to the probabilistic nature of concept membership. Gilbert and Watts (1983) suggest that this view of concept and concept formation is best thought of as being "relational" in character.

"That is to say that instances can be judged in terms of their degree of membership to a particular concept (their probability of membership) and the concept judged in terms of its relationship to other concepts. It is the kind of work associated with the semantic networkers...."

Thus learning a concept from a "relational" perspective is more than just using a word label, it is also related to the learner's ability to classify instances and non-instances of a concept. These classifications could be based on criterial attributes, for example, in the case of the concept 'mammal', the learner may discriminate between a goldfish and a cat on the basis that one is a mammal and one is not. This classification may be achieved on the basis that the student knows that a cat is an example of a mammal; alternatively, such criterial attributes as warm blood and the suckling of young could be used. This is not to say that the
learner may in fact use her own idiosyncratic meaning for the concept mammal as the basis for classification and concept membership, for example, everything with four legs and fur is a mammal!

Smith and Medin (1981) have considered this interaction between probabilistic and exemplar components of concepts.

"We cannot ignore the possibility that the representation of a single concept can contain both probabilistic and exemplar components, that is, both a summary representation and exemplars. Earlier we suggested that such mixed representations might be needed for superordinate concepts such as furniture. Now we wish to point out that there is good reason to think that mixed representations may be needed with other kinds of concepts as well. Specifically, recall the developmental hypothesis that as one matures, one is more likely to represent a concept in probabilistic rather than exemplar form. This suggests that children may initially represent concepts in terms of exemplars and then later apply abstraction processes to these exemplars to yield summary representations.... It is even possible that this developmental sequence occurs to some degree whenever adults learn a new concept."

The work of Schaefer (1979) exemplifies the relational view of concept and concept development, both in terms of its theoretical posture and the word association methods used in his research design. Schaefer (1979) describes a 'bur model' concept of a concept in which a 'logic core' of general definitions, representative of a class of things, is defined by a word/concept label. Surrounding this 'logic core' Schaefer (1979) contends that there is an 'associative framework' of personal meanings relating to the concept word. He argues that additions to this associative
framework represent a development of the concept from the learner's viewpoint.

"For example, just the name growth may lead us to remember and to use the concept, as may some phenomenon involving positive feedback (which belong to the logic core of growth) or even the association police (which has been used during a demonstration against atomic power stations which have to do with the energy crisis and this in turn with industrial growth)."

Schaefer's (1979) model allows for the development of concepts by the expansion of the personal realms of meaning which surround the concept core. The conceptual development mechanism suggested by this "relational" perspective is intimately linked with the consequences of the learner's everyday experience which in turn become part of his 'associative framework'. This view of conceptual development assumes that by adding exemplars and changing their degree of membership, the student modifies his existing conceptual framework. Gilbert and Watts (1983) argue that this view is a less than adequate explanation of the process.

"...it is not an adequate description of individual conceptual development simply to describe the process by which the person adds new attributes of a concept, or new semantic members to those that he or she has already acquired. Changing some elements whilst others remain untouched does not account for the often radical or inconsistent changes in knowledge structure."

Smith and Medin (1981) have also considered some of the problems of conceptual change and development within a "relational" perspective.
......consider a child who has both summary and exemplar information about birds, with summary containing the property 'flies'. How should the child update his summary when confronted with one or two species of bird that do not fly? Clearly the new summary should be some combination of the old one and the new experiences, but the child needs some procedure for determining how much weight to attach to the new evidence.

Essentially, the problem with the "relational" view of concept in the context of conceptual change, is the need to consider complex concepts as part of an already defined constituent group of related concepts. Research on conceptual combination highlights the nature of this problem. Zadeh (1965) has used 'fuzzy set' theory to represent concepts with degrees of membership. This development of set theory indicates which entity is a member of a particular class or group of entities. However, as is often the case in considering concepts, the degree of membership of a concept can be counter intuitive to the extent that the conjunct is more representative of the conjunction than either of its constituent concepts.

The "relational" view of concept moves closer to a research and pedagogic posture which recognises and values the complex idiosyncratic interdependencies which link concepts. Even though word association tests may artificially enhance the verbal interrelationships between concepts, it seems likely that the closer we move towards the learner's view of natural phenomena, the more teachers and researchers will have to come to terms with the interconnectedness, complexity and diversity of the everyday and scientific meanings which surround concepts. These constellations of meaning cannot be seen as peripheral to the correct 'scientific' concept, nor immature ideas in search of an existing conceptual
pigeon-hole; from a learner's perspective, his own personal meanings, experiences and conceptual associations along with their apparent inconsistencies and paradoxes are the concept.

1.11 Conceptions - An 'Actional' View of Concept.

Recent research in science education has confirmed that many children come to science lessons with definite ideas about how things happen in the world around them (Driver and Easley 1978). Gilbert et al. (1983) describe these ideas as

"conceptual structures which provide a sensible understanding of the world from the child's point of view."

This view of concepts emphasises the active and continuous process of making sense of the world; the term conception being used to denote the potential individuality of these concepts and their origin in personal theories about natural phenomena. This outlook is supported by the Personal Construct Psychology of George Kelly (1955) which contends that individuals, as an essential, unavoidable and desirable consequence of personal experience, generate their own varied conceptions. In an educational context it is possible to view these personal theories as naive and simplistic artefacts of a particular research methodology (McClelland 1982), or the outcomes of bad teaching and cognitive confusions. However, there is growing evidence that alternative conceptions are fundamental to the learning process and should be recognised and valued by science educators (Pope and Gilbert 1983; Claxton 1984). Indeed Gilbert and Watts (1983) argue that this view of concept
has an effect on the way that we visualise the process of conceptualising.

"Rather than search for invariants (or universals) in either conceptual content or development, it becomes one of mapping the 'topography' of local domains of understanding, or mini-theories (Claxton 1982) and of charting changes in frames of reference so that the durability, stability, coherence and consistency become the point of departure."

Pope and Gilbert (1983) and Claxton (1984) have used a Kellyian perspective to illuminate the activities of the learner when dealing with new experiences. Within Kelly's metaphor of learning, 'man-the-scientist', the alternative conceptions of the students are seen as the productive and desirable outcomes of 'scientist-like' activities.

"...to a large degree - though not entirely - the blueprint of human progress has been given the label 'science'. Let us then, instead of occupying ourselves with man-the-biological organism or man-the-lucky-guy, have a look at man-the-scientist...When we speak of man-the-scientist we are speaking of all mankind and not merely a particular class of men who have publicly attained the stature of 'scientist'. We are speaking of all mankind in its scientist-like aspects, rather than all mankind in its appetitive aspects...might not the individual man, each in his own personal way, assume more of the stature of a scientist, ever seeking to predict and control the course of events with which he is involved? Would he not have his theories, test his hypotheses and weigh his experimental evidence? And, if so, might not the differences between the personal viewpoints of different men correspond to the differences between theoretical points of view of different scientists?"

(Kelly, 1955)

Claxton (1984), using the Kellyian notion of constructs, suggests that the products of the learner's actions, theories and expectations, can be seen as a set of mini-theories.
"Each 'mini-theory' is born out of the need to make sense of, and act effectively within, a new type of situation (the focus of convenience of the theory). Once a successful way of constructing is found, then the same framework or point of view can be applied to other novel but similar events. If the theory copes successfully with such an event, then the specification of its domain of experience is altered to include it."

Thus 'mini-theories' are born out of learning needs, and tend to be context specific. Their translation into other contexts are seen as part of the child's learning processes through which he broadens his theories to take account of novel situations, or discovers the limitations of his existing 'mini-theories'. Claxton contends that each individual may have a wide range of 'mini-theories' for different situations and knowing when to use a particular mini-theory is a significant part of the learning process.

"There is a deep problem here that is important for educators to overcome. Because we talk about "concepts" and "skills" it is easy to think that they exist in the same way as books and tool kits exist - as independent bits of knowledge that one can "acquire" exactly as one acquires a newspaper or a paintbrush. What we forget is that in both cases possession is a necessary but not sufficient condition for effective use. I have also to acquire knowledge about how to wield my new paint brush, and to what sort of job it is suited for. Just so, know-how and know-that are useless without know-when, and it is for this reason that mini-theories always combine both sorts of information."

(Claxton 1984)

1.12 Conceptions and Conceptual Change.

It is perhaps difficult to conceive of learning without considering conceptual change. However, perhaps as a consequence of a 'cultural transmission' approach to teaching, or perhaps because we still have a largely inadequate understanding of the learning process, an
appreciation of the nature of conceptual change in the context of actual teaching and learning remains underdeveloped. The 'cultural transmission' approach to teaching science can be viewed as one where scientific values, rules and 'truths' are independent of the learner's own subjective constructions of natural phenomena. This scientific knowledge represents a true representation of the world as it is, therefore there is little need for the Realist teacher to consider alternative conceptions which may be held by the student. One direct effect of an 'actional' view of concepts is that it poses afresh the question of how students compare and acquire new conceptions. Concommitently, from a pedagogic standpoint there must be a reorientation of objectives toward a conceptual change view of learning.

"If children are encouraged to make their theories more explicit, these can be open for inspection and testing in the classroom. Children's own ideas in fact can provide the necessary raw material to exemplify the plural nature of scientific theory, and act as a starting point for pupils to design critical tests to distinguish between different interpretations."

(Driver 1983)

West (1982) contends that given the centrality of conceptual change in effective learning, two responses are possible when an effort is made to change the learner's existing conceptions. According to West (1982) these outcomes can be either evolutionary or revolutionary. West (1982) uses the term evolutionary to denote the continuity between old and new conceptions; the progressive adaptation by the learner of her existing conceptions to meet the demands of new experiences. This type of adaptation will involve
the teacher and the student in the extension of alternative conceptions in a direction determined by the consensus viewpoint. Alternatively, revolutionary change is associated with large scale and radical modifications of the student's conceptual framework, a well used exemplar of this being the change in a student's understanding as she goes from an Aristotelian to a Newtonian understanding of motion.

Although this dichotomy of change dynamics has been used as a descriptive categorisation of different research postures and philosophical positions, in terms of the general phenomenon of conceptual change, it is quite possible that evolutionary and revolutionary change are part of the same process and not necessarily at opposite poles.

1.13 Theories of Conceptual Change - A Constructivist Perspective.

The work of Donald Schon (1963) provides an interesting exemplar of conceptual change viewed from an evolutionary perspective. Schon (1963) has developed the notion that there is an evolutionary relationship between old and new ideas.

"New concepts grow out of what has gone before and can be seen as changes in the old. But these changes are matters of degree. In some cases the new concept is recognisable as a minor variation of an old one, as in the case of the derivation of 'superjet' from 'jet'.

Schon (1963) also makes the point that this relationship between old and new may be related to their temporal and spatial proximity.
"The concepts that strike us least like the old are by and large those which require greatest change in the old. Our conceptual structure can be seen as a kind of amoeba. In the centre are the concepts most crucial, most intimately tied to others, least willing to let go. Nearer the periphery are concepts less intimately tied to others, less crucial to the whole system, less jealously guarded....The more central the changing concept, the newer in this sense it is."

Schon (1963) recognises that there are difficulties with this evolutionary perspective and that these may originate in the a posteriori nature of our concept classifications.

"My chief difficulty is in our tendency to understand the business of forming new concepts in a vocabulary that is appropriate only to their justification after the fact. We are used to thinking about fully formulated concepts, their relation to one another and their instances. As long as we focus on the concept instance relation, we will be at a loss to understand the formation of new concepts. It is as though we tried to understand the emergence of new species in terms of our concepts of existing species, their relations to one another and to their members."

Schon’s solution to this problem is his theory of concept displacement, in which the learner’s personal experiences continually cause old concepts to evolve through the inclusion of new experiences and exemplars.

"...when a child discovers that ice melts to form water, and that water can be frozen to make ice, not only has he discovered something new (for him) about the world, but his concept of ‘water’ has changed as well. His criteria have changed, and there has been an important change in the kind of instances to which he applies the concept."

The inference here is that all changes in existing concepts involve new ways of conceptualising, and that they are the products of active learning in which the student exposes existing ideas to new situations. New conceptions are derived from the child’s current
'theoretical tools' which in turn form the basis of his conceptions. Schon's root metaphor for his displacement theory is drawn from biological evolution which he describes as being related to concept development in the following way:

"Prior to the development and acceptance of evolutionary theory, the emergence of new biological forms was explained by denying their novelty or tracing them to essentially mysterious spontaneous generation. The function of the notion of the displacement of concepts is to approach an evolutionary theory of new conceptual forms."

Schon's emphasis on the activities of the learner in constructing new concepts, and the primacy of analogy and metaphor as indicators and vehicles of conceptual adaptation, bring his displacement theory within the bounds of personal constructivism and the 'actional' notion of concepts. In this respect much of Schon's (1963) theory can be subsumed by the Kellyian notion of construct permeability and the extension of the 'range of convenience' of a construct. Therefore, it has much bearing on the importance of recognising children's alternative conceptions and their role in the development of scientific concepts.

Continuing this theme of conceptual adaptation and change, Claxton (1984) describes how the 'range of convenience' of children's alternative conceptions or 'mini-theories' can be extended in the light of experience.

"...when the theory fails and failure may be of three sorts, over-extension, under-extension and conflict. Over-extension is often what we are aware of first, we apply a mini-theory to a new situation, it lets us down. We assume that this use of the word 'force' is the same as the previous ones, but find that the everyday connotations are out of place in the physics lab."
Under-extension may follow over-extension or occur on its own: it occurs when we find a gap or a hole in our theories, so that experiences occur which we do not know how to deal with... Finally, conflict occurs when we suffer not from a lack of suggestions but an excess of them. Two or more mini-theories are triggered by the same event, and they give rise to incompatible predictions and interpretations.

Gilbert, Osborne and Fensham (1982) have drawn attention to the various outcomes of traditional teaching in environments rich in children's alternative conceptions. These workers describe a continuum of outcomes from the "undisturbed outcome", where the child's intuitive theories persist in spite of teaching, through a "mixed outcome", to a "unified outcome" in which the child achieves a 'true' scientific perspective. It is possible to speculate that these outcomes may be the outward manifestations of 'successful' and 'unsuccessful' attempts by the child to test the adaptiveness of his mini-theories.

Claxton (1984) has elaborated a model of conceptual change focused on the character and dynamics of children's 'mini-theories'. He identifies 'clusters' of mini-theories which he characterises as 'gut-science', 'lay science' and 'school science'. Gut and lay science are seen as facets of children's mini-theories which relate to the individual's experiences of natural phenomena in a social context.

"Much of gut science is incoherent: that is, it consists of many local theories, each with its own domain, with very little concern for integration and consistency between domains. And much too is inarticulate. It is not available to consciousness, and incapable of being expressed....The descriptions and explanations of gut science are closely tied to a person's direct experience. Authentic gut explanations often boil down to "because I know it" - not intellectually but experientially."

(Claxton, 1984)
Claxton acknowledges that the private world of gut science must often operate within a social context where the form and content of descriptive language is linked to a network of socially constructed meanings.

"Lay science may be evaluated with respect to its utility, but mostly its function is to be entertaining and/or to allow one to converse successfully with family and friends. Much, but not all, lay science will therefore be available to consciousness, and capable of articulation, but it is, like gut science, piecemeal and incoherent. What children can and do spend a lot of time doing is improving the coherence and acceptability of their lay science through discussion and argument with each other."

(Claxton, 1984)

Although the strength of interaction between gut and lay science will vary, Claxton sees them as part of the same conceptual system. He describes the nature of this interaction in terms of the degree of overlap between mini-theories. When the child is able to relate his gut science to his lay science, that is he can map his intuitive expectations derived from experience onto the social world of conceptual consensus, the learner according to Claxton, has integrated his mini-theories. Alternatively, when the learner superimposes lay science onto gut science the degree of overlap may be insufficient to integrate the conceptions. In this situation, where mini-theories are unrelated and unconnected, lay understanding will be accepted but not underpinned by actual experience. Claxton refers to the latter scenario as laminated mini-theories. In some learning situations laminated mini-theories may result in cognitive conflict, particularly when the child tries
to utilise gut science in a conceptual environment which has strong lay science explanations. Reconciliation of such conflicts by the child are not necessarily automatic. Claxton suggests that children can be highly resistant to change particularly when gut science offers a better explanation of scientific phenomena than the abstractions of curricular science. Claxton contends that other factors may influence the learner's reluctance to integrate intuitive theories with scientific ideas.

"Alternatively, if the theories that are in conflict are very basic to my world view, then to change might mean a radical upheaval of everything I believe. Relativity theory is notoriously difficult to get a feel for, for just this reason. Learning may therefore be a threat to my knowledge structure. Finally to give up cherished gut or lay theory may put me in conflict with my society, my family and friends. Learning becomes a threat to my social stability."

(Claxton 1984)

For the science teacher the crux of the problem is when the student is asked to integrate gut and lay science with school science. Claxton suggests that juxtaposing all three perspectives throught the use of 'real life' examples of school science is not enough to turn often laminated theories into integrated wholes. He contends that before this level of integration can be achieved, mini-theories must be laminated and simultaneously active. In this state they must generate anomalies or conflicting explanations which in turn must be perceived by the learner. The child must feel the need to resolve this conflict and actively seek a solution whilst making judgements about the effects that his learning strategies may have on his existing conceptual framework. These preconditions for successful integration present the science
teacher with considerable pedagogic problems. If the teacher seeks
to change the intuitive theories of her students, she must raise
their awareness of these often implicit theories, stimulate the
students to appreciate the limitations of these theories in a
variety of situations, and then help them integrate these ideas
with scientific theories. Throughout this strategy the focus is on
the learner and her activities; conflict, awareness raising, and
conflict resolution cannot be imposed on the learner directly. The
teacher's efforts must be directed toward the creation of a
conceptual environment which has the potential to facilitate these
activities in the mind of the child.

In Claxton's description of mini-theories, the spatial
metaphors of degrees of overlap, lamination and integration
capture the dynamic aspects of mini-theories. Interestingly,
Claxton introduces the idea of conceptions as 'amoeba' which in
turn encapsulates the notion of ever-changing conceptual outlines
within relatively well defined boundaries. This 'organismic'
metaphor in the context of his theory of conceptual change captures
the idea of mini-theories responding in different ways to differing
environments whilst retaining the potential to evolve and move
about in a direction influenced by that environment.

The theoretical underpinnings of Claxton's description of mini-
theories and conceptual change are derived from the personal
construct psychology of George Kelly (1955). From this theoretical
standpoint conceptual change is seen as a process in which
conceptions are adapted by experience. In this way the 'range of
convenience' of the learner's mini-theories can be extended and
tested in terms of their functional utility in a number of contexts. As a result of these activities the learner may develop links between a range of mini-theories enabling her to respond to new experiences; at least to the point where conceptions or mini-theories cease to be appropriate and adequate as a basis for making sense of the world. This process may result in the individual actively resisting attempts to reorganize his construct system, to the extent that he may ignore the need for change. Alternatively, his framework of interlocking mini-theories may undergo a radical or revolutionary change in order to accommodate a new system of construct organization. At a fundamental level this reorganization may require a revision of the individual’s ‘core’ constructs, i.e. those conceptions which provide a foundation of personally adequate hypotheses which provide the individual with an understanding of the world as he sees it. Seen from this perspective, revolutionary changes in the individual’s conceptions are part of the same process of progressive adaptations which refine her construct system. Radical conceptual change for the individual is part of an adaptation process, even if for the observer of the learner’s activities, it may appear that revolutionary events have occurred.

A specific model of conceptual change in a science education context has been elaborated by Posner et al. (1982). This model is largely derived from the philosophy of science, notably the work of Kuhn (1970), Toulmin (1972) and Lakatos (1970). Posner et al. have characterised two phases of conceptual change, likening one to the ‘normal’ science described by Kuhn (1970) where world views define
problems and determine the explanatory adequacy of solutions, and the other to 'revolutionary' science where paradigms are modified and recast. Posner and his co-workers (1982) contend that the first phase is analogous to patterns of conceptual change which occur when students use and integrate new phenomena into existing conceptual structures. Strike and Posner (1982) refer to this phase as 'assimilation' and link it with conceptual change which does not require major conceptual revisions by the learner. In contrast to 'assimilation', these workers associate radical concept changes with 'accommodations' where they suggest core concepts are replaced by new organizing principles. Much of the research of the Cornell Group is concerned with the latter type of change although they readily concede that the differences between 'assimilation' and 'accommodation' may be a matter of degree. This difference of degree is not stressed by the Cornell Group and consequently in their work there is by default an exaggeration of the absolute nature of 'normal' and 'revolutionary' phases of conceptual change. Indeed, little emphasis is given to an appreciation of the non-monolithic character of assimilations and accommodations. This is perhaps a consequence of the historic 'after the fact' origins of the Kuhnian revolutionary/normal dichotomy, where the variation and diversity within these categories is often ignored or at best the continuity between them is de-emphasised.

In this philosophical context, Posner et al. (1982) describe how the learner's current conceptions are modified as a function of the conditions necessary to induce conceptual accommodation. They...
describe four essential conditions before conceptual accommodations will occur.

1. There must be dissatisfaction with existing conceptions.
2. New conceptions must be intelligible
3. A new conception should suggest the possibility of a fruitful research programme.

Underpinning these four tenets, is the belief that core conceptions will only be rejected when they themselves have failed to provide adequate solutions to a range of related problems. Under these circumstances more adequate theories, which have the power to resolve these problems, will replace existing organizing principles. This view of conceptual change draws attention to, and recognises the power of the learner's existing conceptions. Indeed, 'misconceptions' or alternative conceptions will be part of the conceptual framework which may 'judge' the plausibility, fruitfulness, and intelligibility of new ideas as well as the adequacy of old ones.

The Cornell Group describe the relationship between the learner's existing conceptions and new experience in terms of 'conceptual ecologies', a view of conceptual change derived from the scientific philosophy of Stephen Toulmin (1972). Conceptual ecologies are described as environments in which populations of ideas and current theories interact with existing ideas. The nature of these interactions is seen as an important factor in the assimilation and accommodation of new ideas, the direction of change, and the effects of teaching strategies on individuals.
Strike (1982) has described these interactions in the context of a learning situation.

"Conceptual change theories, however, are likely to see misconceptions as emerging from some interaction between experience and other concepts the student has (perhaps themselves misconceptions). They are also likely to see misconceptions as highly problematic and as crucial phenomena for teaching and learning. The reason is that misconceptions will be seen as part of the student's conceptual ecology which will thus function as part of the student's cognitive repertoire for understanding and judging other concepts. Moreover, misconceptions will be seen as fitting into a student's conceptual ecology and thus not easily written over. As part of a conceptual network, misconceptions will be maintained both by their ability to distort and reject incompatible information and by the support that they draw from other concepts in the student's arsenal. Conceptual change theory thus sees misconceptions as crucially important phenomena having both the ability to distort further learning and be themselves highly impervious to instruction."

(Strike, 1982)

Conceptual change in an ecological context will be seen as the resultant of a complex set of interactions between many conceptual features. Posner et al. (1982) have described some of the features of conceptual ecologies; these include anomalies, metaphors, the learner's metaphysical beliefs and epistemological commitments as well as knowledge obtained through personal and social experiences. These features may be identified as being related to a specific learning context or subject domain, however, they may equally be derived from 'irrelevant' experiences distant from the knowledge boundaries of the subject. Thus understanding the process of conceptual change through an understanding of the learner's conceptual ecology requires that teachers and researchers develop an holistic view of the learner's conceptual system, from the
idiosyncratic world of alternative conceptions to the communal beliefs of his socio-cultural environment. Hewson and Hamlyn (1984) have used an ecological model of conceptual change to examine African children's conceptions of heat. Hewson and Hamlyn (1984) considered that African children may hold a different set of 'misconceptions' from their Western counterparts as a result of their different cultural and linguistic background. These workers concluded that African children were in fact less likely to have a caloric conception of heat when compared with Western children's conceptions because of the differences in their everyday experiences and the prevailing social metaphors of their culture. Joan Solomon (1984) has also drawn attention to the importance of everyday experiences and socially constructed knowledge as determinants of the child's view of the world. Indeed West and Pines (1983) have argued that another dimension, the 'non-rational', must also be considered part of conceptual ecologies.

"The process of conceptualization, be it intelligibility, plausibility etc. taken separately or together, involves the learner's feelings. Does the student feel good? or proud? or satisfied? or alternatively, bad? demeaned? We are claiming that these are integral parts of what learning is, and not simply motivational, attitudinal, or affective antecedents upon which learning depends. Learning is feeling good, proud, satisfied, etc., as much as it is Posner et al.'s four conditions; and feelings are never rational."

Strike and Posner (1983) accept that these factors will play a part in conceptual change; they see the need for some measure of selectivity when we investigate conceptual ecologies.
While we recognize that there are other variables and intellectual tools relevant to conceptual change in science students, we choose to follow what appears to be a fruitful line of inquiry before embarking on other possible ones.

Our decision about our research has been to look at these relations between the evidence students have and the conclusions that they draw. The decision is motivated by several considerations; that evidence does make a difference, that understanding the role of reasoning in learning is important and that one should wade through one quagmire at a time.

The power of an ecological perspective seems to be its potential to develop comprehensive, multidimensional understandings of the factors influencing conceptual change. However, when the researcher moves from an observational mode towards an investigative posture, the sheer complexity of conceptual ecologies mitigates against understanding. For this reason it seems inevitable that the researcher will be concerned with constructing a comprehensive picture of conceptual systems based on features which he believes significant in the context of his enquiries. In this way research into children's changing conceptions of natural phenomena moves from an ecological to an ecosystemic perspective.

1.14 Conceptions in an Ecosystem.

An ecosystemic approach to children's changing conceptions will be selective in its account of conceptual features. However, it will always recognise that the individual's conceptions can never be isolated from their conceptual environment. Stephen Toulmin's notion of concepts (1972) encapsulated a view of this relationship.

"Each of us thinks his own thoughts; our concepts we share with our fellow men. For what we believe we are answerable as
individuals; but the language in which our beliefs are articulated is public property. To understand what concepts are, and how they play a part in our lives, we must come to terms with the central relationship between our thoughts and beliefs, which are personal or individual, and our linguistic and conceptual inheritance, which is communal."

The personal dimension of Toulmin's notion of concept is closely aligned with an 'actional' viewpoint, capturing as it does, the idiosyncratic nature of concepts whilst reconciling them with the socio-cultural dimension.

"Concepts play their parts in the lives of individuals, and scarcely have any actuality apart from these roles. At the same time, individual concept users acquire the concepts they do within a social context, and the sets of concepts which they employ play identifiable parts also in the lives of human communities - whether societies, congregations or professions."

(Toulmin, 1972)

To some extent this ongoing dialogue between the personal and the public has been dichotomised by 'schools' of thought which have traditionally seen these conceptual dimensions as distinct and unrelated. In this respect Science itself has been instrumental in this demarcation.

"Individualism endowed man with an absolute rationality in which the knowing subject is detached from his social context.....This individualistic epistemology, which has dominated psychology, and has had wide currency in sociology, produced in the social sciences an empirical concern for the objective, manifested in cross-sectional studies, with semantically rigid categories and quantifiable symbolic representations. It has become the scientific epistemology."

(Eslan, 1981)

This schism is also apparent in the perception of children's views of the natural world.
"Do the empirical ground rules really support such an individual constructivist position? If informal knowledge has been personally assembled in such a rational way why is it then inconsistently applied? When the history of science itself has thrown up so many theories of mechanics, light, heat, and respiration to explain the simple happenings of our world, how is it that our young children hold so many ideas in common? If our pupils have such a valuable grasp of the hypothetico-deductive method, why do they then have such difficulty understanding the method of school science? It would seem simpler to abandon the whole idea of each child being his own scientist laboriously building up general structures out of a limited personal experience of events, in favour of a more social construction of knowledge."

(Solomon, 1984)

This degree of polarization is unnecessary and indeed difficult to justify. If one adopts a personally constructed or a socially constructed view of knowledge it is difficult to divorce one from the other. Berger and Luckman’s theory of socially constructed knowledge (1979) visualises a continuum of knowledge construction from the personal world to the realities of everyday life. Berger and Luckman’s vision of the individual is of a communal organism, acting in concert with others to construct and objectify concepts destined to become part of the individual’s perception of reality. Thus the culture is created and absorbed by individuals and emerges from the subjective meaning that they use to make sense of the world. As Procter and Parry (1978) contend, socio-cultural values are not passively received, but can be personally validated and authenticated by the individual. There is an ongoing dialectic between individual conceptions and socially constructed meanings producing an interactive environment in which the individual becomes aware of her personal constructions of social realities.
An ecosystemic view of children's conceptions represents a synthesis of personal and socially constructed knowledge. From this perspective, an 'actional' notion of concepts is intimately associated with an entailment of cultural experience, representing what Toulmin (1972) calls 'an ecosystemic self-portrait'. This description is drawn from two viewpoints, one individual and the other communal; conceptions can be visualised in these separate dimensions but must be put together if we are concerned with gaining a proper perspective on conceptual change and development.

This chapter has developed a perspective on children's conceptions and the processes of conceptual change. It has been suggested that the problems experienced by students and teachers when they set out to learn and teach about inheritance phenomena, are bound up with the child's intuitive theories and the conceptual change strategies deployed by teachers. Many of these provide an inappropriate base on which to develop an understanding of children's beliefs and the process of conceptual change. The basis of this weakness is that theories of learning have often failed to operate at the level of the individual learner and his learning environment. It is concluded that research into the child's conceptual processes benefits from an 'actional' view of concept and a conceptual change perspective on learning. This chapter also identifies the need to develop a research framework which describes the personal and social aspects of children's beliefs and combines this with a model of conceptual change which resonates with the complexity of the child's everyday conceptual activities.
Chapter 2

Models of Change
2.1 Modelling Conceptual Systems.

Increasing awareness of the importance of alternative conceptions of natural phenomena in our understanding of how children learn has presented cognitive research with a new set of challenges. The core of this challenge is located in the results of research programmes which reveal how children use their conceptions in learning situations. Children's conceptions are active at the frontiers of their experience and, for the learner, represent a way of 'experimenting' with conceptual organization whilst keeping it open to change and modification. Children's intuitive theories are involved in the exploration of understanding. At the interface between their existing knowledge and new experience children explore the interrelations of differing viewpoints. Conceptions are the active and constructive elements which form the basis of 'experimental' transactions between the learner and his or her environment. The problem for the teacher/researcher is how to visualise the dynamic organization of children's conceptions and the processes of conceptual change.

Cognitive research guided by an ecosystemic view of children's conceptions must consider that conceptual change may take place within a multidimensional environment of continuously evolving personal and communal knowledge. The dynamic created by this diverse, metastable environment will be inseparable from the reality of children's conceptions of natural phenomena. Conceptions must be capable of evolving in order to have worth and utility in
the everchanging world of experience. They must therefore be 
'open' to the influences of that world if they are to have any 
relevance to the learner. This 'openness' can only be achieved if 
conceptions are part of a dynamic conceptual ecosystem. In 
cognitive research the 'parts' of an ecosystem cannot be viewed as 
isolated and self-contained components of a conceptual 'mechanism'. 
Research into children's conceptions has consistently shown the 
interaction and interdependency between conceptions (Gilbert and 
Pope, 1982), and between conceptions and 'other knowledge' (Posner et 
al., 1982). This mutualism between conceptions and their ecosystems 
requires the researcher/teacher to develop an understanding of 
conceptions in environments whose complexity, heterogeneity and 
metastability are an integral part of those conceptions, and where 
the relationship between ideas may have a significant effect on 
learning. Gilbert and Pope (1982) described the existence of 
'multiple frameworks' in children's conceptions of energy, and 
comment on situations where a child requires a number of 
simultaneously active conceptions to formulate a satisfactory 
explanation of a given situation. Conceptions are contextualised by 
an ecosystem of interactive ideas and they are not pigeon-holed 
or immutably locked into specific experiences. Rather they are 
interwoven in a matrix of experience which provides a coherent 
pattern of understanding for the learner. Research which ignores 
the nature of this relationship and seeks to isolate the 
idiosyncracies of children's conceptions from ecosystemic 'noise', 
moves towards a reality different from the child's everyday use of 
conceptions.
When an ecosystemic view of conceptions is adopted the 'machine' metaphors of closed systems are discarded in favour of a research paradigm which retains its sensitivity to the 'fluctuations' and the openness of conceptual systems. However this has its problems for, given the 'chaotic' character of conceptual ecosystems, it is quite possible for the researcher to become lost in an ever-changing conceptual landscape of bewildering complexity.

Educational research has always been on the horns of this methodological dilemma. The researcher wants to capture a global picture of the learner's activities but is frustrated by the limited resolution of this perspective and his inability to see what is actually going on amongst the complexity of interactions taking place before him. The researcher is forced to adopt a more restricted field of view in order to recognise at least some of the routes and signposts used by the learner. To enhance the resolution of this latter viewpoint, researchers have often imported and adapted theories from psychology, sociology and biology in order to provide model systems on which to base research design and educational theory. This has been an effective strategy but has had its problems. When models and theories derived from base disciplines have been applied in educational contexts, some have tended to metamorphose from illuminative heuristics which guide research, into theoretical edifices which isolate and exaggerate elements of the learning process and distort the way that we think about children's conceptions.
"If there is any truth in the idea that modelling and theorizing is essentially an analogic, metaphoric activity, then this fact will significantly affect any kind of reflection about the foundations of thinking, including that in this paper, in particular making such ideas ultimately unformalizable. So it seems to me that we should in fact avoid looking for too strictly coherently formalized theories, which it would be very reasonable to expect to show up rapidly as seriously inconsistent with the facts, or to lead us astray in various crazy ways. I think, instead, that in this kind of research we are pretty much—for the time being—up against a need for cognitive generalization of a large set of 'language games' aiming in the first instance at no more than 'verifying' such theoretical ideas." (Viennot 1985)

For the researcher interested in children's conceptions there has to be considerable concern regarding the appropriateness of some of the theories imported into educational research from 'base disciplines' and their relationship with the 'open' character of conceptual systems. If conceptual systems are open systems, then they can be thought of as reciprocating, symbiotic universes of experience, sensitive to environmental change through the exchanges and actions of the learner. This notion leads to a description of conceptualisation as an active, constructive and creative process which constantly adapts the existing conceptions of the learner's experiential base in the light of 'new' phenomena and novel situations. If such open systems are modelled on static theories of conceptual 'stability' and the metaphors of closed systems, then they will fail to resonate i.e. be in harmony with, the fundamental character of these systems, thus enfeebling rather than enriching the researcher's understanding of conceptual systems. If Man only goes where his models direct him, then with respect to conceptions and conceptual ecosystems, the research models that we adopt must be compatible with open systems. In this way their ability to
interact with, and amplify the characteristics of these systems (resonant models) will be enhanced, thus illuminating rather than obscuring the complex dynamics of conceptual environments. Impetus theory tried to explain why and how things move, but it was only when Galileo replaced this static model with a dynamic one that we began to understand and predict the behaviour of moving bodies. So it is with conceptual ecosystems.

2.2 The Metaphorical Transference of Ecological Models and their Compatability with Cognitive Research.

Black (1966), in the context of what he calls 'theoretical models' (eg. describing conceptual systems as if they were biological ecosystems), describes a successful model as one which is 'isomorphic with its domain of application'. The rational basis for using an ecological model in a cognitive domain is, in the context of this thesis, the existence of open systems in both these fields. Wilden (1980) describes this unifying aspect of both domains

"Open information systems are defined to include all systems capable of using or incorporating new information (learning) and/or in which any kind of 'purpose' or 'program' - a kind of 'open', as yet unstructured, feedback relation to an environment - can be conceived of as systematically ANTERIOR to any later construction of closed-loop relationships to certain kinds of information."

On the basis of this commonality between biological and conceptual systems, a good research model will also seek to promote the analogical development of ideas from one field into another.
Stephen Toulmin's (1953) use of the term 'conceptual ecology' was an attempt to describe the complexity of interacting factors which determine the evolution of scientific theories, but is underpinned by a commitment to the power of models,

"It is in fact a great virtue of a good model that it does suggest further questions, taking us beyond the phenomena from which we began, and tempts us to formulate hypotheses which turn out to be experimentally fertile."

(Toulmin 1953)

Black (1966) in his description of 'archetypal models' comments on the nature of analogical extension in models where parent domains supply ideas to other fields of inquiry to which they do not immediately and literally apply. Black (1966) suggests that in these instances, a detailed account of key words and expressions is needed, along with their paradigmatic meanings in the field from which they are originally drawn. In the following section I will describe a variety of ecological terms and concepts in a biological context, the desire being to describe how these original meanings become extended in an ecosystemic model of conceptualisation. I will argue that, at a 'theoretical' and 'archetypal' level, ecological models derived from the life sciences have much to contribute to an understanding of conceptual systems. I suggest that this support is born out of their common concern with the dynamics of open systems and that ecological metaphors developed in biological contexts can be transferred to and extrapolated within the realms of conceptual systems with a view to testing their appropriateness in cognitive research. If the use of ecological models in cognitive research can be justified at a comparative level it should be possible to move towards a research posture which releases the
creative potential of these models as new ways of thinking about conceptual systems. In the context of my research into children's alternative conceptions of inheritance the use of biological models may also have the added advantage of facilitating the transference of research findings into practice; given that the target audience for the findings of the research will be students and teachers with some understanding of biological models.

2.3 Connectedness in Open Systems - a Comparison of Biological and Conceptual Ecosystems.

In the life sciences, ecological research emerged from a research tradition dominated by reductionist/mechanistic models. Ecological research certainly benefited and continues to benefit from the latter perspective. However, the emphasis has progressively moved to a study of organisms in the environment, acting on and being shaped by, the multidimensional features of the ecosystem. This ecological holism has focused on the complex webs of biological interaction within specific ecosystems and has begun to question the meaningfulness and utility of research findings based on simple, linear chains of cause and effect.

Ecological research has illuminated the nature of reciprocity and interaction within ecosystems, indeed many of our present concerns about the effects of pollution on the environment stem from research which has uncovered the biological ramifications and consequences of human activity. In such systems, organisms and their habitats are the products of adaptations, selection pressures
and mutual interactions which are in a continuous state of evolution. Ecosystems are thus maintained not through isolation from interaction, but by remaining 'open' to the influences brought to bear on the ecosystem and by adapting accordingly.

Ecosystems are unique environments and, although limited generalizations can be made about the nature of interactions within them, these have to be moderated by the certain knowledge that no two ecosystems are identical. Consequently, ecological theories have to be flexible and cognizant of limits of generalizability. In this respect ecological research places great value on studies conducted in 'natural environments' where experimentation and theorising are open to the fluctuations and idiosyncrasies of real life situations. The failure of many laboratory based theories to explain the activities of organisms in the wild underlines the value of ecological field studies carried out in natural environments; pest eradication by natural 'enemies' has always proved less effective in the wild than in controlled experimental situations. There is undoubtedly a balance to be struck between the realism and meaningfulness of field-based research and the constraints placed upon the researcher by the practical problems with which it is associated.

If we now turn to cognitive research and conceptual ecosystems, it is possible to find a research paradigm in education which resonates with ecological research methods in the life sciences. By 'resonate' I mean the ability of the two research contexts to overlap and interact in such a way as to amplify the nature of the system under investigation. In describing the
naturalistic approach to cognitive research Gilbert and Pope (1982) make the following points

"The aim of the naturalistic approach is to describe a natural setting as fully as possible (holistically) so that a better understanding of such persons/events can be achieved. This is in contrast to the usual aim of experimental research which seeks to prescribe what future interrelations are likely to be between certain variables which have been the focus of the study."

Rist (1977) supports these values and assumptions and stresses the interconnectedness of learning systems

"...it is precisely because reality cannot be broken down into component parts without severe risk of distortion that an holistic analysis is necessary. Focussing on a narrow set of variables necessarily sets up a filtering screen between the researcher and the phenomena he is attempting to comprehend. Such barriers, from the vantage point of those employing an holistic analysis, inhibit and thwart the observer from a necessary closeness to the data and from an understanding of what is unique and what is generalisable from the data, and from perceiving the process involved in contrast to simple outcomes."

Gilbert and Watts (1983) compare naturalistic research methods in education with the axioms of more traditional methods.

"...these two traditions have become reflected in two paradigms for research in education, and hence in science education. These we call paradigm 1 and 2. Paradigm 1 following the erklaren approach is: 'traditional', in that it is of longer standing; 'scientific', in that it relates to the empirical-inductivist view of science; 'experimental', in that the notion of controlled situations is employed; 'reductionist', in that phenomena are subdivided and the divisions selectively paid attention to; 'prescriptive', in that the outcomes of enquiry are intended to determine future actions; 'quantitative', in that suitable sections of a general population are enquired into; 'nomothetic', in that general laws are sought. Paradigm 2 on the other hand, following the verstehen approach is: 'non-traditional', in that it is of fairly recent standing; 'artistic', in that its view of science is closer to the relativist schools; 'naturalistic', in that the notion of natural occurring situations is employed; 'holistic', in that phenomena are studied in their entirety; 'descriptive', in that there is no..."
The naturalistic paradigm in educational research described above, has emerged in response to the growing awareness of the need for a research paradigm which is capable of dealing with open systems in a meaningful and relevant way. In the previous chapter an 'actional' view of concept was discussed and this perspective led to a view of concepts and conceptual systems which stressed their creative construction in response to environmental influences, their uniqueness, their individual and communal construction, their adaptiveness and their ability to shape and be shaped by the learner's experiences. In this sort of conceptual ecosystem, ecological/naturalistic research paradigms would seem to offer the best guidelines for meaningful research. At a paradigmatic level there is considerable overlap between the concerns of ecological research in a biological context, and the nature of conceptual systems in education. This observation is not surprising given that both are 'open systems'. I would suggest that this degree of convergence indicates that at a methodological and theoretical level, ecological models which have been developed in the life sciences, may have considerable utility as a way of looking at conceptual systems. Such a strategy would be aimed at verifying the appropriateness of these models and testing their ability to suggest new foci of research interest.

2.4 Extending the Ecological Model - New Ways of Looking at Conceptual Ecosystems.
The notion that there are sets of common values and assumptions associated with an ecological research perspective of biological and conceptual processes, leads inevitably to a discussion of ecological theory and its relationship with conceptual systems. This will show to what extent different perspectives on their respective behaviours might yield different insights useful for both cognitive theory and pedagogic practice.

Research interest in conceptual ecosystems represents a transfer of interest from the static world to the changing, apparently 'chaotic' world of fluctuating systems. The complexity of ecosystemic interrelations can often obscure the processes going on within ecosystems. For this reason they are often best perceived, and conceived of, when they are in the process of gradually coming into being. This perspective is encapsulated in the developmental and evolutionary theories of the life sciences. In ecological contexts, it is associated with the study of colonization and the pioneering activities of organisms in 'new' habitats. The utility of the latter perspective is best illustrated by reference to a particular colonization scenario.

Consider a virgin habitat such as a new volcanic island; the island becomes a focus for the pioneering activities of plants and animals as they 'test' the limits of their geographical and physiological range. In the course of time, the island may experience several waves of colonization before a relatively stable population becomes established. In the period between initial colonization and the establishment of 'mature' ecosystems, the ecologist is afforded a unique insight into the interactions
between organisms and between organisms and their physical and biological environments. During this phase, the dynamics of developing ecosystems are highlighted, and as a result it has been possible to study some of the processes controlling colonization. The following control factors have emerged as being significant in the development of models of colonization and ecosystem dynamics; selectivity, adaptation, interaction, competition, heterogeneity, stability and resilience (Jantsch and Waddington, 1976). These factors play distinctive roles in theories of colonization.

Habitats exert selection pressures on potential colonizers. Physical factors such as light, temperature and rainfall as well as biological factors, predispose habitats to colonization by specific types and groups of organisms. Animals and plants with physiological 'plasticity' and high levels of environmental tolerance may successfully colonize a variety of differing habitats, whilst those with a more limited repertoire may be confined to a very narrow range of potential habitats. The selectivity of environments can also affect individual organisms and populations in such a way that descendants are more closely adapted to the habitat through differential mortality and by affecting rates of reproduction. In this respect some populations may be directly adapted to the prevailing conditions, or they may have been preadapted, whereby features have been selected by a habitat in the past or at another place which now prove to be of advantage in completely different circumstances. A combination of pre-adaptation and physiological/behavioural plasticity may give some organisms an advantage over other potential colonizers. Where evolutionary
adaptations (as opposed to plasticity) have had this effect on patterns of colonization, it is important to take account of the heterogeneity of populations of colonizers, as this confers on the group the ability to respond to changing selection pressures. In this respect many groups of organisms remain dormant within the ecosystem and it is only when selection pressures change or new habitats are created that the researcher gains an insight into the diversity and heterogeneity of the population.

This interaction between organisms and their environment is characteristic of open systems. It is important from a research perspective to realize that this is an ongoing interrelationship and not simply confined to phases of initial colonization. Organisms which become established in a new habitat, change that habitat as a direct consequence of their physiological, metabolic and behavioural activities. In this way colonizers create new habitats, and although this may lead to the consolidation of their position in the habitat, it can result in a situation where pioneering organisms create an environment where they are at a selective disadvantage. In the latter circumstances initial colonizers may have to compete with other organisms better adapted to the 'new' environment. Pioneering organisms poorly adapted to their environment may persist in the habitat if competition is weak or if there is an abundance of resources within the environment. It is important to stress at this point that these interrelationships within habitats and ecosystems are far from being deterministic. In fact they are profoundly affected by random events. Chance through the agency of fire, flood etc. can play a
dramatic role in the dynamics of colonization and the creation of ecosystems.

Random events such as natural disasters are perhaps the most obvious change agents acting upon ecosystems. However, ecosystems are in a continuous state of flux induced by the covert but no less effective influences of selectivity, adaption and competition which combine to produce a continuously evolving system. The fluctuations of these open systems are fundamental to the colonization and evolutionary processes. If populations or individuals are to persist in the ecosystem they must be capable of adapting to change and responsive to transient periods during which favourable conditions exist. This persistence is assured by the unstable and fluctuating character of open system and their sub-systems. This paradox of stability through fluctuation is one of the most intriguing aspects of open systems as it challenges the uniformity/equilibrium centred models of change in complex systems.

Holling (1976) has suggested that the dynamic aspects of ecosystems with respect to change and stability can be defined by two distinct properties; resilience and stability

"Resilience determines the persistence of relationships within a system and is a measure of the ability of a system to absorb changes of state variables, driving variables, and parameters and still persist. In this definition, resilience is the property of the system and persistence or probability of extinction is the result. Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is. In this definition, stability is the property of the system and the degree of fluctuation around specific states...."
Using Holling's (1976) definitions, ecosystems with high resilience will be characterised by having a high degree of flexibility, heterogeneity and fluctuation. Holling describes the corollary of such a system by referring to a specific biological situation

"It is not surprising, therefore, that the commercial fishery systems of the Great Lakes have provided a vivid example of the sensitivity of ecological systems to disruption by man, for they represent climatically buffered, fairly homogeneous and self-contained systems with relatively low variability and hence high stability and low resilience. Nor is it surprising that, however readily fish stocks in lakes can be driven to extinction, it has been extremely difficult to do the same to insect pests of man's crops. Pest systems are highly variable in space and time; as open systems they are much affected by dispersal and therefore have a high resilience."

The notion of stability and resilience in the example above indicates, that if the extinction of an ecosystem or part of its population is the desired aim, then one course of action is to reduce the level of fluctuations in the system. In this condition the system may be 'pushed' in a specific direction by external influences. However, if heterogeneity, flexibility and fluctuations are maintained in the system, the effects of unilateral actions imposed on the system will be unpredictable and generally damped out by the resilience of the system. If resilient systems have this power to absorb changes and damp out the effects of external influence, we must ask: how do they retain their openness and the potential for change and adaptation?
2.5 Modelling Conceptual Change in Open Systems.

The dissipative structures theory of Prigogine (1980) is a well-articulated model of qualitative change. It provides a model of change in open system which gives an interesting metacommentary on the notions of stability and resilience in ecosystems. Prigogine identifies three types of open system,

1) those at equilibrium with respect to the environment,
2) those near equilibrium and
3) those far from equilibrium with respect to the environment.

Open systems far from equilibrium are characterised by their degree of diversity and heterogeneity. In this condition Prigogine's model suggests that they are capable of reorganizing their internal relationships without the imposition of external change agents. Dissipative structure theory contends that fluctuations, variability and diversity in open systems far from equilibrium confer on the system the latent ability to self reorganize in a spontaneous way. These spontaneous changes emerge from the system as an indirect consequence of an external environmental change. Far from equilibrium systems can be pushed toward equilibrium conditions by increasing their stability, insulating them from the external environment or by reducing the diversity and the amplitude of fluctuations within the system. Dissipative structure theory suggests that systems moving in this direction ie. towards greater stability, will also change their sensitivity to change agents.
"Imagine a primitive tribe. If its birthrate and death rate are equal, the size of the population remains stable. Assuming adequate food and other resources, the tribe forms part of a local system in ecological equilibrium. A few additional births (without the equivalent number of deaths) might have little effect. The system may move to a near-equilibrium state. Nothing much happens. It takes a big jolt to produce big near-equilibrium states. But if the birthrate should suddenly soar, the system is pushed into a 'far-from-equilibrium' condition, and here non-linear relationships prevail. In this state, systems do strange things. They become inordinately sensitive to external influences. Small inputs yield huge, startling effects. The entire system may reorganize itself in ways that strike us as being bizarre."

(Prigogine and Stengers, 1984)

Ecosystems which are 'far from equilibrium' thus have the apparently paradoxical ability to resist change whilst being sensitive to change. 'Plus ça change, plus c'est la même chose' or perhaps plus c'est la même chose, plus ça change. How then do systems change and at what point is the system's persistence relinquished in favour of change and adaptation. Jantsch's (1976) notion of 'going with the fluctuations', whereby fluctuations within the system are amplified by internal and external factors, suggests that 'far from equilibrium' systems reorganize in response to positive feedback influences. This positive feedback effect can also be seen in the contention of Sawada and Caley (1985) that

"As a system approaches far-from-equilibrium states it does not necessarily have to undergo a spontaneous re-ordering although the number and extent of internally generated fluctuations increases dramatically. At some indeterminable point, however, the possibility for spontaneous re-ordering of the system, as the result of internal fluctuations, occurs. This point is known as a bifurcation point because there will exist two or more possible re-ordered states. It is impossible to predict with certainty when or where a bifurcation will occur or what the re-ordered state will be...."
In natural ecosystems, for example, an increase in the density of a particular species may lead to an increase in the number of pathogens associated with this organism. Before the population density increased, host-pathogen interactions would result in fluctuations within their respective populations. However, if as a result of host numbers increasing the pathogen increases from endemic to epidemic proportions, the effects on the ecosystem can be catastrophic. In these situations host and pathogen may require to dramatically reorganize their ecosystemic relations. Host organisms may mutate and give rise to more resistant forms whilst pathogens may require to enter a dormant phase of their life cycle. During this period of reorganization the entire ecosystem may also be undergoing fundamental changes in its patterns of interaction and interdependence. Thus when the resilience threshold of the ecosystem is exceeded, positive feedback leads to its reorganization and the emergence of a new order.

In the biological sciences, the evolution of an ecological research paradigm has led to the emergence of ecological principles which guide applied research. Elements of this praxis, discussed above, focus on the resilience of ecosystems; the heterogeneity and adaptability of their populations; the selectivity of habitats; the dynamics of colonization; fluctuations within ecosystems and the effects of these changes on the system. In accordance with the contention that these biological perspectives may yield useful insights into conceptual systems, the next section will describe a putative model of how these insights might be obtained.
2.6 Modelling Conceptual Systems on Ecological Theory.

Ecological theory has emerged as one way of understanding an evolving, unpredictable, plural and diverse world of interacting organisms. Ecological models are a representation of open systems and they allow biologists to communicate their observations of ecological systems. When children share their learning experiences with each other, and in the process use their conceptions in solving communal and personal problems, they become open systems. Sawada (1984) comments that

"By participating openly and freely in the process of communication with themselves and with others, students and teachers as individuals and as a group become open systems...."

When children conceptualise they leave a residue of ambiguity and indeterminacy which many cognitive theories find hard to 'explain'. The problem here is that the 'organization' of children's conceptions does not fit into models which are based on fixed hierarchies of concepts and 'logical' interactions. What makes it worthwhile to extend ecological models from organic to conceptual systems is the extensive parallel between accounts of children's conceptual 'organization' and ecological systems. The questions raised by conceptual and biological interaction are intrinsically ecological and to do with the nature of open systems; how do things interact, what determines the ways in which they interact, what conditions are necessary for interaction. An 'actional' view of concept puts to one side the notion that 'scientific' concepts are the only components of the child's conceptual system. If we
consider the problem solving world of the learner and the conceptions used in particular contexts and situations then we move closer to an ecological world. This perspective invites the transference of ecological ideas from organic to conceptual domains because of the common concern to describe events in a particular context and not on the basis of generalizations and 'absolutes'. This metaphorical extension thus represents more than a likeness between two domains of knowledge. What is being suggested is that there is a connectedness between ecological and conceptual systems and that by extending the ecological metaphor it is possible to evoke and describe a level of intra-connectedness between 'open' systems which goes beyond simple comparison.

Ecological theory suggests that by observing the coming into being of an ecosystem through the dynamics of colonization, insights can be obtained into the nature of ecological interactions. Posner et al (1983) in their description of conceptual ecologies, describe a complex system of metaphors, metaphysical beliefs, previous knowledge etc. Understanding the complexity of interactions within an individual's conceptual ecology is an enormous research undertaking, representing as it does the unravelling of a lifetimes experience of the world. Conceptual ecologies represent a population of beliefs and ideas about the world, and a pool of experience on which the learner draws when constructing and updating his understanding of natural phenomena. Conceptual ecologies are a source of tried and tested ideas, conceptions and beliefs available whenever the learner is confronted by novel experiences or 'problem' situations. If we consider the latter as
conceptual niches then it is possible that the student's existing conceptual ecology provides a ready source of colonizing conceptions. Theoretically, some of these existing ideas may provide an adequate explanation of new experiences and consequently conceptual niches may be rapidly colonized. New learning experiences beyond the student's present understanding may also exert a selective influence on the sorts of ideas he imports from his conceptual ecology. In some situations the conceptions derived from intuitive ideas and previous experience may be adapted, extending their range of convenience and their explanatory adequacy within the problem niche. Whatever the mode of colonization, the conceptual ecology of the individual creates an ecosystem of conceptions as existing theories colonize and interact with new areas of experience. By studying the way that elements of conceptual ecologies are selected for by the conceptual niche and the adaptation of conceptions by the student during the creation of a specific conceptual ecosystem it may be possible to illuminate the processes of interaction within conceptual systems and the dynamics of conceptual ecologies. Conceptual colonization of problem niches or novel situations by naive learners creates a research environment in which the observer/researcher may be able to describe some of the factors influencing conceptual change. Indeed, when conceptions are adapted or selected by the learner to become part of a created ecosystem this process involves conceptual experimentation which tests their personal worth and their social acceptability/plausibility in terms of providing a coherent understanding of the world.
Conceptual ecosystems constructed from the learner's existing ecology of conceptions, are open systems which may be in varying states of stability. Dissipative structures theory suggests that the equilibrium state of the system will determine the effects of change on the ecosystem. Conceptual ecosystems 'far-from-equilibrium', for example, would be extremely sensitive to small perturbations which in turn would bring about disproportionately large effects on the system. Ecosystems at or near equilibrium would be less sensitive to small scale fluctuations which the system would tend to damp-out. Assessing the state of conceptual ecosystems may be of critical importance in determining the timing and the type of learning experiences which will have the greatest effect on student understanding. In this respect research interest would focus on indicators of ecosystem states, in particular the effect of personal inputs (teachers, other students) and contextual changes on conceptual ecosystems which may reveal how discussion and argument between individuals, or learning strategies designed to bring about conceptual change interact with ecosystems. This research perspective in turn may illuminate factors influencing the stability of the system.

Dissipative structures theory suggests that if conceptual ecosystems are made up of heterogeneous and diverse populations of conceptions, they will approach a far-from-equilibrium state. Research into the diversity of the conceptual ecosystems created by students may illuminate the importance of this factor in determining conceptual change.
2.7 A Research Model.

Diagram 1 is a synthesis of the ideas discussed in the previous section. A, B and C represent the conceptual ecologies of three individual students, an outline of which has been made indeterminate in an effort to convey the notion that our understanding of these ecologies will always be hypothetical and incomplete. Indeed, the students themselves may have little awareness of the complexity, variety and interrelatedness of their experience within these systems until a particular event or set of circumstances raises their awareness. A₁, B₂ and C₃ represent conceptual ecosystems created by each student in response to new experiences or problem niches. In the diagram the degree of overlap between ecologies and ecosystems denotes the mutualism and interdependence of these systems, and the fundamental continuity that exists between them. Ecosystems are not isolates of conceptual ecologies. The creation of ecosystems A₁ etc. would encapsulate the notion that constellations of ideas, conceptions and beliefs are actively colonizing 'problem' niches. This process may or may not result in the adaptation of existing conceptions, but if it does this would be of particular interest in research into conceptual change. The heterogeneity and diversity of ecosystems created in this way would also be of interest as this may be indicative of the potential of the ecosystem to bring about conceptual change. The central triangle in the diagram represents the interactions between individual ecosystems. These may be verbal or non verbal transactions between students as they agree and disagree about the
merits of particular conceptions. Equally it may represent the ongoing dialogue between individuals as they develop an understanding of one another's ideas in relation to a specific conceptual niche. This social discourse will link individual ecosystems, influencing and being influenced by, the conceptions which emerge from each ecology. Interactions between individuals and their respective ecosystems will also be a source of fluctuation(s), which, depending on the level of resilience within the ecosystem and its state of equilibrium, may or may not bring about change within that system. The nature of group discourse may in this respect provide an insight into, and an overview of, the quality of interactions between individuals thus providing a measure of the system's potential to generate fluctuations.

The use of an ecological model in conceptual change theories by Posner et al. (1982) and Toulmin (1972) is the product of a metaphorical transference between biological and cognitive systems, mediated by the 'universal' characteristics of open systems. This extension of ecological terminology from organic to cognitive systems is also facilitated by the parallelism between ecological accounts of interactive systems and cognitive development. The ecological model as applied to conceptual systems has, to date, focused on the consideration of sociological, political and personal issues within disciplines and their effects on the development of concepts. Toulmin has achieved this, in an historical context, by making philosophers of science more aware of the sociological and scientific factors which have surrounded the history of science. The work of Posner et al. has suggested that in personal
conceptualising, researchers must countenance a situation where a wide range of personal, cognitive, metaphysical and epistemological considerations have to be considered. The research model proposed above takes the ecological model one step further in the investigation of conceptual systems. In research terms this requires that the model be operationalised so that it can find application in a set of specific contexts. Through analogical extension it is proposed that this research model can provide new insights into conceptual systems. The model provides a non-falsifiable framework on which to structure my observations of children’s conceptualising. This framework provides a way of articulating my research findings whilst providing an opportunity to test its applicability in research design and data analysis. In this way the limitations of the model can be explored, although it is recognised that from the outset the model focuses on the development of existing conceptions rather than on the generation and the origin of children’s beliefs about inheritance.

Research findings which emerge from this study will not test the model directly at the level of empirical evidence, but will evaluate the framework provided by the model in terms of its explanatory utility. To this extent the model operates at a 'metaphysical level' insulated from empirical disproof, although this in no way negates its role at a comparative, descriptive and creative level.
Chapter 3

Fieldwork - Research Practice and Design
3.1 Theoretical Influences on Research Design.

Over the last decade, research into children's conceptions of natural phenomena has left few educationists believing that students come to lessons with minds that are scientific "tabulae rasae". In order to illuminate the world of children's science, researchers have developed and deployed a range of research methods; some novel and innovative, others, adaptations of existing instruments derived from base disciplines such as anthropology and psychology. Alternative conceptions research has utilized a range of research methods, a feature which has tended to obscure the theoretical and epistemological underpinnings of these methodologies. This is a critical issue in any review of research methods, for it is the theoretical stance of the research worker that influences his choice of instrument and the conduct of research. At a phenotypic level research instruments which appear identical may have important differences in terms of the researcher's perceptions of the problem and its possible solutions. In the following section I will selectively review a number of research methods in association with the theoretical influences that have shaped the nature of these approaches.

The choice of intuitive theories as a focus for investigation acknowledges the importance of children's conceptions in the context of the individual's own cognitive development and their relationship with the norms of school science. Research focused on the latter aspect has been investigated by a large group of research workers. A characteristic of these workers is their
assessment of children's intuitive theories by reference to the accepted norms of teacher and curricular science (Gilbert et al., 1982). When student conceptions are seen to run counter to these norms they are described at best as misconceptions or at worst mistakes, misunderstandings or 'simply' wrong. From this perspective, the orthodoxy of school science is a major influence on research methodologies, in that it defines the nature of the problem (students getting it wrong) and the character of possible solution (better teaching strategies). Consequently, the design of research instruments has reflected patterns of school assessment, student activity, course content and teaching strategies associated with learning in science.

In order to investigate student difficulties with content areas of biological syllabuses, Johnstone and Mahmoud (1980, 1981) and Johnstone and Mughol (1976) have used a number of methodological approaches in order to illuminate student misconceptions. Structured individual interviews as well as group interviews were used by these workers to identify student misconceptions. Findings obtained as a result of these procedures were authenticated by written tests involving a large 'sample' of students. In some instances special classroom materials were prepared by the researchers in order to test improved teaching strategies designed to alleviate conceptual difficulties. Hackling (1982) using written responses and word association techniques constructed frequency measures of particular misconceptions in genetics. In subsequent studies (Hackling and Treagust 1984) 'probing' interviews were used in conjunction with a list of key propositional statements deemed
by the researchers and 'experts' to be fundamental and relevant to a complete understanding of the topic. In these studies 'cross validation and construct validity' were emphasised in relation to the school biology syllabuses followed by the 'subjects'. Searching interviews closely linked to known courses of instruction have also been used by Posner et al. (1982) and Pines et al. (1978).

Whatever the instrument, whatever the method, the prevailing influence on this type of research is the yardstick of school science and the 'barrier' of student's intuitive theories. Methodologies are directed and orchestrated by the perception that misconceptions can be put right by better teaching strategies which are more effective at getting school science over to the student.

In contrast to the latter group of 'conceptual pedagogues' a number of research workers investigating children's science can be thought of as 'conceptual ecologists'. Again specific research interests go hand in hand with methodological options. Interview techniques, laboratory observations and written tests are also commonly used by these workers. However, in their attempts to capture student's conceptions there is a concern not to influence those conceptions (although various aids may be used to capture the child's imagination and stimulate discussion) a consideration which acknowledges the power of misology and affirms the perceived importance of student conceptions in their own right rather than describing them as the products of inattention or misunderstanding. Driver (1983) using classroom observation and audio recordings of student discussion has developed a research methodology which is
closely related to school learning situations. By analysing transcripts of student dialogue she focuses on the explanatory adequacy of children's intuitive theories and their ability to explain natural phenomena as perceived by the student. Gilbert et al (1981) and Watts (1982) using an Interview about Instance (IAI) approach conducted interviews with students. Using pictorial representations of instances and non-instances of concepts to elicit student conceptions these workers were able to describe a range of intuitive theories held by individual students. Researchers using this technique pay great attention to the student's own language and are reluctant to paraphrase the child's descriptions of natural phenomena. IAI methods can be likened to 'case studies' of student understanding where interviewer and interviewee negotiate meanings for words and critical comment and evaluation are avoided; the emphasis being on open discussion and the importance of the student's own viewpoint. Concern that this method might be sensitive to interviewer bias, Gilbert and Pope (1982) explored the nature of the interviewer's influence on the conceptions produced by groups of children. Video tapes were made of small groups of ten to twelve year olds discussing IAI style cards concerning energy. These workers noted that in the presence of an interviewer certain types of questions seemed to evoke particular 'frameworks'. When left alone in their groups Gilbert and Pope describe how the children produced a rich set of conceptions and maintained a debate about the adequacy of their ideas based on their own experiences. These workers commented that this adaptation of IAI methods seemed to produce a more realistic and
spontaneous environment in which children could discuss their intuitive theories, and that without the prompting of an adult the children were free to talk at their own level, at their own pace and in a direction determined by their own interests and experiences.

Osborne (1981) describes a single lesson procedure in which students are encouraged to think through a practical investigation from initial planning to prediction of results. Using their own conceptions students were then encouraged to discuss their ideas and then implement them in experimental procedures. Working in groups students record and discuss their results and suggest further experiments. Much of this activity is carried out in open class discussion where individuals can relate and interchange their ideas with those of other learners. Solomon (1983) has used recordings of classroom discussion to investigate the flow of ideas between students and the effects of consensus on student learning.

Conceptual ecologists place great emphasis on conversational methods and the individual beliefs of students. Criticism that this method merely generates information of an anthropological nature, unrelated to school learning and nebulous in terms of informing teaching, fails to recognise the constructivist underpinnings of this research (the Personal Construct Theory of George Kelly in particular). Research methods used by conceptual ecologists reflect a viewpoint which allows students to play an active part in the construction of their personal theories, to make judgements as to their validity, to listen to the opinion of others, and to change or not to change their ideas to those held by other students or by
their science teacher. Interviews, transcripts of group discussion and video recordings of student activities are not instantly identifiable as being relevant to the classroom. However, if learning has anything to do with communication, sharing ideas, and subjecting those ideas to trial, discussion, and modification then these research methods are highly relevant to all teaching and learning environments.

In summarising this section on research methods the phrase "it's not what you do, it's the way that you do it" seems particularly relevant. In judging the utility of research methods or selecting particular designs of instrument the researcher must carefully consider where his interests lie, his perceptions of the problem and those of his audience, as well as the practicality of using particular methods. The ultimate choice or design of a method cannot be taken as a reliable indicator of relevance or utility until it is matched with a resonant set of epistemological and theoretical commitments.

3.2 Research into Children's Conceptions of Inheritance: The Design of an Appropriate Methodology.

On the basis of a personal commitment to the constructivist theories of learning described above, and the naturalistic methods of research adopted by conceptual ecologists, my initial investigations into children's conceptions of inheritance were much influenced by the research methods of workers who shared this
commitment. In this respect the Interview about Instance approach (Gilbert, Osborne and Fensham 1981) was the starting point for my research design. IAI has been used extensively to study children's intuitive theories. Using audio and/or video recordings of dyadic discussions with students, focused by a series of picture cards, researchers have elicited student conceptions in a range of content areas such as light, energy, characteristics of living things, gravity, and force. Much of the research using this technique (particularly the group based at the University of Surrey) has been carried out within a naturalistic paradigm of research and has been guided by a constructivist epistemology. The IAI approach extends the format of Piagetian clinical interview by giving students greater freedom of response within a wider contextual frame; a frame constrained only by the limits of their experience and their imagination.

IAI approaches using picture cards (Watts 1981) or observable phenomena (Erickson 1979) offer relevant and interesting content to the student and encapsulate it within a task situation. This provides an interface between interviewer and interviewee which diffuses suggestibility and provides a reference base on which to ground shared meanings. In this respect the most critical element of all interview strategies is the interviewer himself. Interviewers require to have a good knowledge of the content area of the investigation as well as an empathetic feeling for the meaning structures of the student. The skilled interviewer's use of dialogue and questions and answers is the background on which student conceptions acquire their tone and perspective. In essence the
interviewer using IAI methods seeks to understand conceptions which are not his own, in so doing he is required to walk a narrow path between convergent questions which keep the interview on track, areas of suggestibility where he may influence the nature of student responses, and divergent questions which may reveal the diversity of the student’s conceptual system. Planned or structured interviews may enable interviewers to determine the route taken by interviewees, however one of the strengths of the IAI approach is that its loose structure often leads to interesting ‘excursions’ into realms of meaning which can never be anticipated.

In order to develop a personal perspective on these research methods, a pilot study was undertaken. The aims of my pilot study were

a) to learn interviewing skills whilst developing an understanding of how children perceived the notion of family traits and inheritance,

b) to develop an effective elicitation procedure based on IAI technique which would give me access to children’s conceptions of inheritance,

c) to develop a research method which would be sensitive to those features of conceptual ecologies which affect conceptual change in students,

d) to identify a group of students who were capable of becoming co-participants in my main study, i.e. who would enjoy the research activities, would have good levels of engagement with the activities, and would be able to communicate their ideas in a natural and unhindered way, and
e) to provide an environment for the ongoing development and refinement of methodologies.

3.3 Design of IAI 'Inheritance' Cards.

The design of IAI card decks is traditionally focused on situations which may or may not represent an example of the concept. Underpinning the drawings/pictures on the cards is a concern to depict in some elemental form the essence and application of the concept in a particular set of contexts. The concept of inheritance is a complex one, but basically it involves the relation between parents and offspring and the transmission of inherited traits. Using the mouse as a model organism a set of cards were designed which focused on the phenotypic traits of parents and their offspring. At a theoretical level (not explicitly referred to in the cards) the card design was based on the dominance and recessiveness of characteristics in simple monohybrid crosses involving black and white mice. A large number of genes affect coat colour in mice, C being the fundamental colour gene necessary for the production of any pigment at all. In a recessive form c, this leads to an albino condition no matter what other characters are present. Black colour is determined by the dominant gene B.

It was elected to use the mouse as a exemplar of inherited characteristics in that it is a familiar pet, a well known character in books and cartoons, as well as being one of the classic organisms of genetics. In this respect human or plant
genetics were also candidates for inclusion, however the mouse seemed in the former instance less controversial in terms of race and sex issues, and in the case of the latter less arcane and more relevant to everyday experience. (not everyone is aware of the differences between smooth and wrinkled peas — they are all Birds Eye anyway). The triadic method of elicitation used in conjunction with repotory grid techniques (Pope and Keen 1982) appeared to offer an interesting format for unstructured interviews and it was decided that a combination of pictorial and triadic methods of elicitation might have considerable utility in the design of IAI cards.

After some pre-testing with the children of colleagues the following format emerged. A set of 12 cards were designed each one depicting a set of mouse parents. Below each parental set appeared drawings of three 'baby' mice. The colouring of all the mice was initially kept to black or white or spotted (black and white) the aim being to keep the drawings as simple as possible. The task associated with the cards was for the student to decide on the basis of being told that each 'family' had two 'babies', which two offspring belonged to the parents or which one didn't. On the basis of the students choice, questions could be asked about why they had made a particular selection. At a superficial level the cards depicted a variety of 'crosses' but fundamentally they centred on the differences between offspring produced by parents of the same colour and those in which the parents were of two different colours. In order to study student reaction to situations where parents of the same colour give rise to babies of different colour, some of
the cards depicted situations where the child had to choose a baby mouse which was a different colour from its parents. eg. two black parents were associated with two white and one black baby. Although this triadic method of elicitation tended to restrict student choice to the coloured offspring presented on the card, it was an effective focus for discussion and debate between the interviewer and interviewee.

3.4 Interviews.

After negotiations with head teachers and their staff interviews using these cards were arranged in primary, middle and secondary schools with students in the age range of 7-16. Interviews were conducted on a one to one basis and in private. The children were told that the research was aimed at helping teachers and students understand how pupils went about solving problems. The interviews were anonymous and the students were assured that although it was a problem situation it was not a test nor would their teacher be in any way involved. The interviewer also stressed that the task problems were "not like maths problems" because there were no right or wrong answers, only different ways of seeing the problem. The permission of the students was sought to record the interview on audio tape and they were given details of what would be done with the tape. A small lapel type microphone placed on the table and a dictaphone style recorder were used to minimise the effect of equipment on the informal atmosphere created by the researcher. Children coming along to interviews were
selected by their teachers from those whose parents had given agreement for their involvement in the study. In selecting the students, teachers were asked to choose a range of 'personalities and 'abilities'. Although there must have been a tendency to send 'good' students to interview, I felt happy that a good cross-section of the class were turning up at the sessions. In most cases the whole class came to interview and teacher selection was based not on who should come, but on when was the most opportune time for individuals to leave their class work. The conversations with students lasted from 20 to 30 minutes. This included some general chat at the beginning and end of the session. The aim of the interview was to conduct a non-evaluative, reflexive, and open discussion; emphasis was given to establishing a good rapport with the student. Interviews were focused by the card deck and this provided a basis on which to extend the conversation in ways which reflected the interests of the researcher. As student and researcher made their way through the cards replicates of previous instances were encountered. These were phenotypic 'negatives' of earlier cards and allowed the interviewer to challenge and revisit previous aspects of the student explanations.

During the course of this pilot study 65 students drawn from four schools were interviewed and as the research progressed the order of presentation and the content of the interview was reviewed. In addition to the cards depicting mouse 'families', a picture of cows and their offspring and dogs and puppies was included in the task format; the question being once again to identify the 'babies' /offspring. At a later stage a pictorial
representation of a mouse family tree was used to describe generations of mice and their offspring. This picture was used at the end of the interview and the children were asked to describe what they thought the drawing was meant to represent.

3.5 Outcomes of the Pilot Study

Initially interviews were transcribed in full, providing a basis for analysis as well as developing transcribing skills and an awareness of its associated difficulties. After ten interviews had been analysed in this way, transcription gave way to a less formal method of analysis as the amount of data increased. This approach involved a research notebook containing summaries of each interview annotated directly from tapes. During the pilot study analysis was much influenced by the received biological viewpoint and centred on 'framework spotting'. In hindsight, this was a rather restricted outlook but as with the research methods which were to develop from this preliminary study, this outlook on data analysis did much to shape the character of the main study. I will not discuss the details of children's conceptions of inheritance at this point as I intend to give a more detailed description of these ideas in the context of my main study. Suffice to say that the process of interviewing and listening did much to enhance my own awareness of the child's point of view and to acquaint me with the descriptive vocabulary and the meanings used by a range of children when talking about inheritance. Interviews allow the researcher to follow up 'interesting' responses, and in this respect
over a period of time with a large number of children a feeling for meaning can be developed; not that you can ever be certain that you share a child's frame of reference.

The dyadic interview in itself is a powerful research methodology, coupled with an IAI type elicitation procedure it was very successful in creating for the researcher stimulating, enjoyable, and revealing conversations with students. However, as the pilot study developed and my own expertise improved, the convergent, selective probing of my questions, albeit against a background of open and divergent discussion, had a considerable impact on the nature of interview. Gilbert and Pope (1982) in describing "the interviewer effect" draw attention to how types of question can cue specific types of response in terms of student frameworks. Although the transcripts of my interviews have no specific instance of this type of question - response relationship, as the pilot study proceeded and my own interviewing skills were refined, there was a growing awareness of how my inputs, challenges, reflections, clarification, reiterations and summations modified the quality and quantity of the child's responses. This developmental perspective highlighted the process whereby the 'target' conceptions of the researcher are progressively exposed to the interviewee and how this leads to increasing congruity between the researcher's viewpoint and that of the student, ie. the researcher's viewpoint 'becomes' that of the student. This meeting of minds seemed to me to be based on points of contact rather than areas of overlap, where ideas were being bounced off the researcher
by the student in order to determine the direction of the conversation and the nature of the hidden agenda.

The influence of the interviewer is an inevitable consequence of moving research away from a purely observational mode toward a more interactive posture. In naturalistic-ecological research the ideal is always to have a minimal effect on the system being studied, nevertheless this cost-benefit aspect of interview-based research has to be balanced against the aims of the research. Given that my interviews were designed to reveal intuitive theories about inheritance, that my hidden agenda was to focus on those phenomena, and that this illumination of the child's conception had to be done in a short interview session, then it is inevitable that the interviewer will influence the student. This effect would seem to be entirely acceptable in the context of studies aimed at describing student competence and their ability to use a range of conceptions of inheritance. However, if the focus of research is the natural conceptual ecologies used by children in everyday thinking and discussion, then this approach may be inappropriate. If research is concerned with interactions between a child's existing intuitive theories, then the influence of the interviewer's own specific interest in aspects of inheritance may obscure more children's conceptions than it reveals. Cognitively, children in discussion with an adult are fragile entities, and if we seek to investigate the fine structure of their understanding in natural learning environments, then we may have to use a research instrument whose interaction with their conceptual ecologies is of
an order of magnitude which stimulates rather than conditions student responses.

The design of the IAI type cards and the triadic elicitation procedure were successful in terms of stimulating discussion, focusing activities and diluting the "strangeness" of the interview setting. However, the restricted choice imposed on the student by the 'rules' of selecting two baby mice, and the fact that the mice were either black, white or spotted seemed to frustrate a number of the children. Having to make a choice in this way was a major constraint on their imagination and tended to reduce the openness of the conversation. The interviewer's request " which two baby mice do you think belong to these parents" followed by "why do you think it was those two" seemed to short circuit the discussion at a level where the student was having to justify a choice which to a certain extent he was 'forced' into making. This aspect of the task situation seemed to be suboptimal and in need of revision.

The mouse as a model system proved to be sufficiently abstract and unfamiliar to allow speculative and hypothetical thinking by the student to occur, yet familiar enough to encourage the use of the student's everyday experiences of inheritance.

The pilot study involved a wide age range of students in primary, middle and secondary schools. The younger students aged 7-10 were keen co-participants in the project and they provided an interesting range of ideas and theories in relation to the problem task; indeed they were no less capable than the older students in their ability to engage with the problem and to theorise about possible solutions. However, with the younger children the choice
of the baby mice was the central focus of their activities, and once selected there seemed less of a need from their point of view to explain that choice. If pressed they would come up with a rationale behind a selection but this often seemed to me to be 'superfluous' in terms of their reading of what the interview was about. This behaviour was much less common with the older children although it was observed with some of them. Through the ages of 11 - 16 the students were more inclined to present a concerted approach whereby they linked their choices to consistent theories of action. However, with many of the older children particularly those following exam syllabuses with a genetics, health education, inheritance component, there was a great deal of concern to choose the 'correct' mice, in spite of being told there was no right or wrong answer. In more than one case, at the end of the session I found myself and the student engaged in an ad hoc revision session based on the "Laws of Inheritance". The feeling that there was a definite solution to the problem haunted many of these older students, particularly the specialist biologists. This concern did not prevent the older students discussing a range of intuitive theories with the researcher, but it tended to change the character of the interview from a free and open discussion toward a 'set piece' evaluative test of understanding, ie. they had accepted the idea of a 'scientific truth' and/or the utility of a 'correct' answer in the context of a 'test'.

Early on in the pilot study children from middle schools in the age range 11-13 seemed to me to be a group of students whose engagement with the task and the interview was often optimal. They
were often "naive biologists" in that they had had no formal introduction to concepts of inheritance and they were generally a confident group of children able to settle quickly into a productive rapport with the interviewer. Lastly, many seemed to enjoy the interview experience and appeared to relate meaningfully to the situation. One other facet of middle schools as a research environment was the ease of access to students; when compared with secondary schools the flexibility of their timetables and the absence of external exam pressures made the process of negotiating access to students much easier and less time consuming. Middle schools still demanded letters to parents and formal approaches to education authorities etc., however once access had been negotiated a productive period of research was almost guaranteed.

On the basis of my pilot studies I concluded that various explanations were used by children to account for the transmission of inherited characteristics and that this was indeed a fertile area for my main study into children's intuitive theories of inheritance. The IAI type of approach used in the pilot study seemed suboptimal in terms of investigating the normal range of conceptions used by children. What seems to be called for is an elicitation procedure which causes a level of perturbation in student conceptual ecologies consistent with the intensity of normal learning situations. This consideration would be reflected in a desire on the part of the researcher to minimise the influence of methodological factors which could have a potentially radical effect on the quality and quantity of interactions within conceptual ecologies. Eleven to thirteen year olds in middle
schools were identified as a group of children whose accessibility and engagement with the inheritance tasks made them excellent co-participants. These findings and considerations, coupled with an improved awareness of children's personal theorising, were to become the central determinants of the elicitation procedures, tasks and methods used in my main study.

3.6 Main Study - The School Setting

The school setting has always been the desired context for my research. However, this necessitates that the researcher make a number of decisions affecting the form of that research. The investigation of children's conceptions in a school setting can take a number of forms. One method is to gather information about conceptions within the working classroom, with the research instrument as part of the everyday work of the class. Using individual microphones the researcher can 'eavesdrop' on student discussions during practical, group work or normal class activity. Technically this is a difficult procedure made even more complex if video taping is also part of the research technique. The classroom milieu, the sounds generated by class activity and the extraneous noises which surround every classroom, is capable of defeating the most comprehensive recording equipment and makes the analysis of classroom recordings extremely difficult if not impossible. In an effort to overcome these technical problems many researchers have sought to isolate groups of children in 'laboratory' type
classrooms where recording and observation can be optimised. This extraction technique can be very successful (Gilbert and Pope 1982), but requires preplanning and experience on the part of the researcher. The artificiality of these 'studio' environments and the fact that the children have been transported from their normal classrooms, makes it imperative that time and effort is invested in giving the students time to acclimatize to the situation. This may involve the researcher, the students and the school in a considerable investment of time, energy and resources.

A compromise arrangement, between the classroom setting and the studio, and the preferred methodology of my main study, is the extraction of groups of students to 'quiet' areas close to their classroom (usually an adjacent classroom which was not being used) where audio and video equipment had been set up previously. Technically this arrangement gave excellent results, although in keeping with other extraction techniques, qualifications have to be made about the transferability of findings to actual classroom situations. The primacy of the spoken word in this type of research and the need to have good recordings of student talk limits the number of degrees of methodological freedom; research in this field will by necessity be a trade-off between artificiality and realism in terms of the selection and creation of a research environment.

3.7 The Selection of Children

No specific 'type' of child was involved in my research. VRQ, performance grades etc., were not used to select individuals.
Children participating in the study were selected by their class teachers with the proviso that they were not to be *ad hoc* 'super groups' put together especially for the purpose of the research. Teachers were told that there was no evaluative sub-plot or 'hidden' aspect to the work and that the prime consideration was to listen to what children had to say about inheritance problems. Teacher selection was most often motivated by the social and behavioural attributes of the groups. Friendship/working groups were the most common basis for selection, but on several occasions teachers put together groups of children on an experimental basis uncertain of "how they would get on". The methodology used in my main study required groups of three children to work together on a task, this number representing the minimum group size and such technical considerations as being able to discriminate individual voices in audio recordings where group members often spoke simultaneously. The groups of middle school children chosen were always from the same class or year group and they tended to come to the sessions in natural working groups or friendship groups. In all of the middle school participating in my study, group work was a natural classroom activity and many of the children involved in the study were experienced in this method of working. Arranging to sit in on lessons was not difficult to negotiate once the nature of the researchers presence was made clear. Indeed, the researcher in these circumstances becomes more often than not another teaching resource within the classroom. Groups were sometimes single sex and sometimes mixed. The children involved in the main study represented a range of personal, interpersonal and cognitive styles.
Given that there is no such thing as an average child or group of children, the students in this study were on the basis of my own teaching experiences mostly able, well adjusted, healthy children of European origin drawn from caring educational and social backgrounds. This ethnography was a product of social geography and opportunity rather than deliberate research policy. By taking whole class groups from mixed ability sets a reasonable level of group diversity was achieved within the limits described above.

3.8 The Task.

The nature of this methodology and instrumentation was based on the findings of previous pilot studies. The instrument was presented to the children in the form of a problem task consisting of three elements. The problems related to the prediction of the phenotypes (observable characteristics) of first generation offspring in situations where they were given or chose the parental phenotypes. Each group member was given a set of twelve large cards (Appendix I), each one featuring a coloured 'cut-out' of two mice (the parents) showing their phenotype in some detail. The selection and production of these cards and the colour of mouse families were based on actual strains of mice and real life crosses. The strains of mice appearing in the cards were Agouti (wild type), Albino, Black, Black and Tan, Brown and Grey. Coat colour in the mouse pictures also depicted variations of coat colour within these strains showing the action of dilution genes. This referent introduced a much wider variety of mouse coat colours.
and this was consistent with the outcomes of the pilot study. In this way greater choice and variety of phenotype gave students more flexibility and realism in their predictions. Some of the cards displayed an additional feature consisting of an 'extra' cut-out depicting one of the offspring derived from the parental cross shown on the card. Each student received an identical set of cards arranged in an identical order. Each set of cards used a different coloured background to aid identification on video and to enhance the appearance of the cards. The task was introduced to the group in the form of a problem which required them to "find the missing children". The group were told that the mice on the card represented "a family which had lost some of its children", (the approximate number of lost children was decided upon in negotiation with group, somewhere between four and six.) The problem for the children was to visually identify the offspring or as it was described to the group, "find the missing baby mice" in a box of missing babies containing over 200 cut-outs of various mice with different coat colours. Each cut-out in the box represented a possible missing offspring and the children were encouraged to empty them out and find the estranged babies. Each of these cut-outs was backed by a velcro pad which allowed the students to stick or unstick their selections to the card. The search for missing mice and the sticking and unsticking of choices encouraged a great deal of collaborative activity and debate amongst the group. Motivation and engagement with this task was immediate in the majority of cases and this activity was both a successful
elicitation procedure and an effective way of raising the student's awareness of inheritance.

As each member of the group made their way through the cards (most groups started off working in unison, some maintained this throughout, others worked in a more individual way), the order of presentation of the first few cards was designed to coincide with the most common conceptions of inheritance illuminated by the pilot studies. This possible 'garden path' was interrupted by the subsequent presentation of potentially, counterintuitive, anomalous offspring eg. two brown parents were shown with one of their albino offspring. This type of card was not designed to produce some form of cognitive dissonance but to provide a potential focus for student discussion and debate in which one student's existing theories might be challenged by another. I saw this as a significant development of the challenges and debates stimulated by the interview method of the pilot study, in that these discussions were at the level of the students and phrased in their terms, in their vocabulary and in their own particular style. Throughout this activity, 'replicate' cards with the same basic crosses as previous cards were encountered. In these cases the phenotypes were always different and the greater variety of coat colours used in this activity made them less obvious and more effective at eliciting more discussion rather than "we've done this one before it's just the same as that last one".

On completion of this task the children were invited to read a "solution" to the previous activity. This second phase of the research instrument represented a form of comprehension task. The
text given to the children to read was a reasonably complex factual description of Mendel's Law of Dominance (although not explicitly mentioned in the text) as it relates to the phenotypes of mice in the initial task (Appendix II). The information contained in the text gave the children, at least in theory, the ability to predict the phenotypes of offspring given the parental phenotypes. (no frequency data was included in the text). This element of the research instrument was in no way intended to teach the students the principles of genetics, but was designed to

a) keep the format of the activities interesting by interposing a different activity between two similar ones,

b) to change the nature of the activity to maintain motivation,

c) to illuminate the ways that they tried to make sense of the text and its relationship with the ideas that that had expressed in the first activity and,

d) to observe how a potentially interactive notion such as dominance might align itself with existing conceptual ecosystems. This facet of the design is derived from the Vygotskian (1978) "functional method of double stimulation" in which the way an object or an idea is drawn into a problem solving situation is observed. It was hoped that in this way the researcher might gain an insight into the existing conceptual ecosystem of the student and develop an understanding of how it interacts with student comprehension of related problems.
The third and final element of the task was carried out by the children in the group after they had finished their reading. This phase involved a similar problem to the first task but was based on the construction of a mouse family tree. This open-ended task has identical characteristics to the first activity where students predict the phenotype of offspring, but it has, potentially at least, an added dimension of family lineages. The group were invited to use the cut-outs from the previous task and to work together on the creation of the family tree. One large board with a family tree skeleton was given to the group, and this provided a central focus for group activity, collaboration and interaction (Appendix III). Once again the velcro pads enabled the group to change their selections as they constructed the family tree. A record of the group's effort was made at the end of the session to aid subsequent analysis (Appendix IV).

The design of these tasks reflects a change of emphasis between my pilot study and the main study. In an effort to minimise the influence of interviewer effects on children's conceptions the tasks are orientated toward the creation and maintenance of autonomous group discussion in an interviewerless situation. The major concern is to provide an opportunity for children to ask one another about their conceptions and to give each member of the group the chance to try out their ideas and predictions. The aim of the researcher is to gain access to individual conceptual ecosystems through the dialogue and the interactions of the children. On a continuum of research styles from observational to interventionist, this design seeks to enhance
the quality of observation through increased interaction at the level of the participants.

3.9 The Task Situation and Procedures.

Children taking part in the study were selected by their class teacher and withdrawn from the classroom. Usually they were given advance notice of their participation but little detail about the nature of the activity. Consequently the children arrived in the "quiet area" with many preconceptions about what they were going to be doing (many of these were based on vague ideas derived from what had been said by classmates who had already participated in the study, "something to do with mice"). In the main, the students arrived 'cold' with little real idea of what the activity was about. After formal introductions by the class teacher I was left alone with the students. Ideally I would have liked to have introduced the tasks and then left the children completely alone during the task activity, but in all four schools this was seen to be less than desirable and it was preferred that I should be close by and in earshot, and that the children should be aware of this. In the light of this constraint I decided it better to be in the room with the students rather than to be seen 'lurking' about nearby.

The students were seated at a desk or table with chairs arranged in a horseshoe pattern the intention being to enhance eye to eye contact; the children more often than not migrated from this position to one where they worked side by side facing the camera.
The nature of the research project was explained to the children in the following way:

Rchr. "Did Ms Smith say why I wanted you to come along today"

Stds. "No....... eh something to do with mice"

Rchr. "Thats right....what I want you to do is to try and solve some problems which concern mice "

Stds. (worried glances)

Rchr. "Don't worry these aren't difficult problems. The problems I want you to solve today have no right or wrong answers, only different ways of seeing the problem. I am interested in how you go about doing the problem. Why I want to know is because if we know how you went about it, then we can tell other boys and girls and their teachers how best to go about doing these problems."

The group were told that I wanted to video record the session and that this record of their activities would not be seen by their teacher or their classmates unless they wanted them to see it. They were told that the video record would help me understand how they had gone about solving the problem.

The group were introduced to the first task; every opportunity was taken to settle the children and to familiarise them with scene around them. Often we would discuss technical matters about the video and they enjoyed seeing themselves on the monitor. Depending on the group I would draw their discussion together after completion of the first two cards asking open ended non suggestive questions to make sure that they had understood the nature of the task. This chat continued the process of acclimatization before letting them go on by themselves. While working on the first two
cards there was much debate about how they looked on TV and this awareness of the camera/audience produced many performance behaviours. During this period the monitor was left in view and they were able to make faces etc. On completion of cards one and two a playback session was used to continue the process of coming to terms with the technical features of the method. The children enjoyed this and used it as an insult session joking with each other about hair and noses etc. This period of acclimatization took up to 15 minutes but it was time well spent in terms of overcoming the group's embarrassment and anxiety at being the focus of attention. It was noticeable in many of the groups that during this period voice levels increased and a more confident persona emerged as they became familiar with the situation.

The TV camera (a small portable unit of modern design) (Appendix V) was positioned as far away from the group as possible but in plain sight of all three students. Once the camera was focused on the group it was left alone, a fixed position being used throughout the session. The tightness of the frame on the group was a compromise between getting a good view of what they doing and keeping lively children in shot. Sound recording was achieved using an extension microphone of the lapel type feeding the video recorder, and a separate audio tape recorder as backup. The two small microphones were positioned in front of the group. No attempt was made to conceal the equipment only to reduce its impact on the local environment.

The students were left to complete the first task at their own pace. Inevitably there were interruptions and distractions as with

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normal class activities however a high level of task engagement
was achieved. The duration of this phase was of the order of 20-30
mins. On completion there was a very short 'debriefing' the intent
being not to elicit more information but to draw the activity to a
close, to thank and praise the group and give them a breather. The
next activity, that of reading the prepared text was usually
introduced in the following manner

"that was well done........can I tell you what I want you to do
next. When this problem was given to some boys and girls in the
secondary school they used a set of rules to help them decide
which mouse belonged to which family. Before we do the last
problem today which is a bit like the first one, I would like you
to read some of the rules that they used to see what you think of
them and whether they might be useful in solving these kinds of
problems."

The text was contained in a flip card booklet (Appendix II)
which made it easy for each student to move readily through the
contents. Reading styles varied; some read out loud to each other,
some in silence and some in unison. Some groups discussed their
reading in the context of the previous problem while others moved
quickly from page to page scanning the contents. The text
information was presented in the style of 'key facts' and reading
took between 5 and 10 minutes.

The family tree problem was presented on completion of the
reading task. Many of the children recognised the format of the
problem having experienced historical manifestations of family
trees relating to kings and queens (usually Henry VIII or the
present Royal Family). With the help of the group I would go over one or two branches of the tree in a random fashion to refamiliarise them with the conventions of laying out the tree and how my skeleton tree gave the information about offspring numbers etc. The basic familiarity of the children with this format made these sessions more confirmatory rather than instructive. With all three students working together on this task, this activity was a lively forum for debate and collaboration. Engagement with the task was excellent in spite of the fact that they had been working together for nearly 45 minutes. On completion of this final activity a debriefing session took place although this was often terminated by the school bell. The debriefing was not a mini-interview but an opportunity to give the children a brief summary of their achievement and leave them with a positive attitude towards their efforts. Any outstanding concerns or problems were dealt with before a playback session was organized (usually at the end of the school day). To my knowledge no child found their participation in the study to be any less than an interesting and enjoyable experience. The study involved 30 groups of three children drawn from four middle schools. The schools were in predominately urban settings with a catchment area populated by mainly white middle class families. Nevertheless, most teachers felt that students in this study were closer to a 'comprehensive' population rather than a 'selective' one, and as such, were a fair cross section of 11 to 12 year old boys and girls.

3.10 Transcription of Tapes.
The transcription of tapes is a very difficult and time consuming process; this fact was amply illustrated during my pilot studies and it was a major concern when the decision to use interviewerless group discussions was taken. When compared with the 'simplicity' of the one-to-one interview and the luxury of transcribing one voice at a time, group sessions had children talking simultaneously, children who sounded alike, noise from a variety of sources, children speaking softly, all elements which made the transcription process less than straightforward. However, against this background the use of video recordings did much to minimise the problems of trying to decide who was saying what and what it was they were saying. Audio tapes were used as a back up in my study and when listened to in isolation it was difficult to make out what a child was saying or who was actually speaking. However, when the audio sequence was matched with the video recording and the visual channel was open to the transcriber difficulties were substantially reduced.

The basic transcription procedure was to go through the audio tape record first and make a rough draft of the group session. This process left many gaps, question marks and uncertainties in the transcript but it allowed the researcher to concentrate on what was being said. With the video tape record one often felt caught between watching and listening, especially in the early stages of transcription. After the preparation of a rough draft the video tape was used to refine its accuracy and to annotate the session. It is difficult to measure this level of refinement in quantitative terms, certainly it dramatically reduced the number of doubts about
what was said and who was saying it, but at another level it made a qualitative difference to the transcripts in that the transcriber was now not just listening to children talking but was reliving the session. The qualitative approach to research places much stress on the meaningfulness, credibility and utility of the information gathered; the contribution of the video recording is that it expands the researcher’s interpretative base by creating an information channel which is considerably richer than that offered by audio recordings alone. A component of this richness must be the researchers access to non-verbal information but there is undoubtedly much more to this in terms of developing a feeling for the data. (In this latter respect I feel that as a result of the nature of my research it was important that all aspects of the transcription process should be carried out by the researcher). In refining the transcript a great deal of searching, replaying, and ‘freezing’ is carried out. A facility used in this research which made this process much easier, was to have an elapsed time display appear on the monitor screen. Used as a tape counter and in conjunction with a remote control unit this technical refinement made the review process much easier.

Transcribing tapes can be a major effort in the context of this type of research, however, it represents a means to an end in terms of providing a basis for data analysis. Transcripts are interpretations of situations seen through the eye of the researcher/transcriber, and as such they form part of the relationship with the subsequent methods of analysis used to ‘make sense’ of group discussions. In the following chapter I will
selectively review some methods of discourse analysis as a way of developing a rationale for the analysis of my transcripts of group discussion.
Chapter 4

Dialogue, Interpersonal Communication and Conceptual Change
4.1 Accessing Conceptions through Dialogue Transformation.

Many of the strategies used to gain an understanding of children's science have evolved from research instruments designed to access conceptions from interview data. The style of analysis in this research has often had as its focus the description and illumination of 'cognitive structures' embedded in discourse. Consequently, less attention has been given to those features of children's talk which play a part in the communication, adaptation and evolution of conceptions. In the following sections I will selectively review strategies used to 'uncover' conceptual systems in children's talk, and compare these methods with alternative strategies of analysis which seek to understand the 'life histories' of conceptions through discourse. In subsequent sections I will argue that we may have to unite these methods of discourse analysis if we are to understand how children use their conceptions and adapt them in the light of experience.

4.2 Categories and Frameworks.

A method used by a number of research workers (Watts 1983, Ault 1984b) is to reduce the unique and variable conceptions of individual students obtained through interview, to a finite number of alternative conceptions; the contention being that there is a strong derivative relationship between the scientific viewpoint and the alternative conceptions of children. Gilbert and Watts (1983) have made a case for varying levels of response
transformation, from short summary descriptions which capture explicit and personalised meanings of individual conceptions, to 'categories' constructed on the basis of multiple data, and 'frameworks' which represent generalised transcontextual characterizations derived from multiple sources of student response. A problem associated with this method of analysis discussed by Gilbert and Pope, (1982) and Engel, (1982) is the practical difficulty of containing 'mixed' student responses (written and verbal) within specific conceptual frameworks. This gives an insight into the complexity of interactions within conceptual systems and the problems of trying to isolate specific conceptions from a constellation of interrelated and idiosyncratic ideas. The reduction of unique and variable conceptions to a finite number of frameworks has much utility in terms of data management and as a way of making teachers aware of the common 'misconceptions' held by their students. However, if research is concerned with change, and how children's conceptions live out their lives within a conceptual ecosystem, then systems of analysis which depersonalise and decontextualise meaning are less than desirable. The creation of highly transformed 'categories' or 'frameworks' during discourse analysis may have its merits where research is focused on relations between orthodox science concepts and children's conceptions, or where the adaptation of the latter can be seen in terms of the reasoned and rational steps that transform children's intuitive ideas into 'scientific' ones. However, if research is concerned with the fate of particular conceptions within a particular student's conceptual system, then the emphasis
of analysis is directed toward following the 'life' of that conception and the influences which affect its development. Consequently, this type of research will value analysis which focuses on the personalised conceptions of individuals and the actions of the person, made evident through the use of language and discourse. Analysis at the general level of the framework and the category may give a representation of statements used by children, but they cannot capture the nature of discourse involving conceptions and therefore give little information about interactions between conceptions or between different conceptual ecosystems.

4.3 Concept Mapping and Conceptual Ecologies.

Concept mapping has already been discussed in the opening chapter of this thesis as a method used to gain access to children's conceptions. However, it has also been deployed by a number of workers as a method of discourse analysis designed to give information about conceptual change and development. Characteristically, transcripts derived from interview studies have been transposed into a concept map which compares the students' understanding with that of an idealized scientific 'template'. This analysis focuses on how the student's concept map (and its assumed underlying cognitive structure) changes as the child learns specific concepts (children are asked to do a concept map once a term for example). These maps are 'freeze frames' of conceptual development which may reveal a great deal about the content of
conceptual systems as children go through school, but very little about the interactions between these conceptions as they change. Concept mapping as a method of analysing conceptual change strategies tends to be dominated by the notion that if enough 'time slices' are taken through the process of concept development, researchers using a hierarchical 'template' will be able to infer what has been happening to conceptions between successive maps.

In conjunction with these activities members of the Cornell Group (Ault, 1984b) have tried to codify natural language (as opposed to children's concept maps or knowledge vees) and its semantic structure as a way of searching for and verifying the relationship between proposed hierarchical patterns of conceptual understanding and the organization of the learner's conceptual system. The Novice Science Semantics (NSS) of Ault (1984b) in this respect contends that changing contextual features observable in the semantic patterns used by students result in changing concepts and that concepts derive meaning from their role within a network of concepts. Unfortunately, this notion is diluted by Ault's system of analysis (NSS) which over-formalises the connectedness of concepts and meanings used by children; the impression being that these dimensions can be interrelated in a 'logical' network of hierarchical concepts. The effect of this epistemological commitment to concept hierarchies on discourse analysis can be likened to giving an amoeba a rigid skeleton and then trying to describe its activities as amoebic.

Paralleling these efforts to analyse the use of concepts by students and their relationship with conceptual organization,
Posner, Strike, Hewson and Gertzog (1982) have articulated a method of analysis which emphasises how concepts change. Their categorization scheme of conceptual change conditions (dissatisfaction, intelligibility, plausibility, fruitfulness) and mechanisms of change (anomaly, metaphor, metaphysical belief) considers concepts as part of a conceptual ecology which influences the nature and direction of conceptual change. This analytical perspective is based on a theoretical and epistemological foundation derived from contemporary philosophy of science and the nature of change within scientific disciplines. Using complete descriptions, or examples of their categories drawn from transcript excerpts, these workers have tried to stress the interconnectedness between conceptions and the effects of knowledge and experience on these ideas. The category system used by Posner et al. (1982) reflects this group's commitment to an interactive model of change. However, the effectiveness of their data analysis is reduced by allowing these categories to take on a taxonomic role when applied to discourse analysis rather than to be used as a basis for studying interaction between categories and within the conceptual system itself. It would seem that the next step to take in terms of analysing children's conceptual organization and verifying the features influencing conceptual systems is the use of models which give a more dynamic picture of the activities of conceptual populations and tell us more about how they operate in specific learning situations. Children using conceptions to solve a problem or conduct a discussion reveal much about how conceptions function and how they connect with other viewpoints. Therefore we need to
consider theoretical models which, when used in the analysis of conceptual systems, take into consideration the activities of the student (verbal/non-verbal) as well as placing those activities within a relevant model of conceptual change. In developing analytical models of the latter kind, the role of student discourse and its influence on conceptual systems would seem to be of great relevance and importance given that many of the learner's activities will be mediated by communication and discourse.


Changing and adapting one's conceptions is catalysed by the ability to communicate and receive ideas. In this respect a student's ability to collaborate with others when solving problems, to see another's point of view, to elicit and facilitate an exposition of differing viewpoints, and to use and appreciate 'hypothetical' speech modes, will influence the process of conceptual change.

Conceptual ecosystems are 'open' systems thus they are involved in and influenced by exchanges of information with the learning environment. This exchange of information will be based on the learner's existing conceptualisations of natural phenomena which will be understood through the ongoing dialogue that he has with other learners as he relates these experiences and responds to the comments, observations and criticisms of others. Conceptual change does not occur simply because someone tells you 'how it really is', for in the first place you may not choose to say what you think
and secondly you don't have to listen. Conceptual change has much more to do with the quality of interpersonal communication which not only gives the student access to alternative viewpoints but also provides an insight into his own belief system. Conceptual change strategies will embody activities in which there is an internal dialogue between the learner's conceptions and direct experience, but there also has to be an external articulation of these beliefs if the student is to evaluate the worth of these ideas to himself and to others. Conceptual change will thus have a great deal to do with the way the learner explains his conceptions to others, and how this discourse determines the range and the number of opportunities for conceptual change. In theory at least it is possible to visualise a situation where student discourse dominated by exploratory speech characteristics such as questioning, tentativeness, reflexivity, and self awareness. As well as the interpersonal linguistic skills of making qualifying statements, recapping, acknowledging the viewpoint of others and interrelating different ideas, might enhance the opportunities for conceptual change.

Methods of discourse analysis designed to illuminate this verbal and social interplay must try to capture both of these elements of children's talk as well as the content on which the student's activity is focused. Speech characteristics and the content of discourse are of course not isolates but interdependent components of interpersonal communication, and this is where the difficulties of analysis begin. Halliday (1978) has developed a system of discourse analysis with an orientation towards the form
of language and its semantic character in social situations. Halliday's (1978) analysis assumes a direct and parallel relationship between semantic systems and linguistic form, i.e. it is theoretically possible to proceed from a sociological analysis of 'situation' types to an analysis of 'meaning potential' in a given situation, to an analysis of 'functional components' of this meaning potential, to an analysis of grammatical structures.

"Now it is very important to say that each of these systems, semantics, grammar, and phonology, is a system of potential, a range of alternatives. If we take the grammatical system, this is the system of what the speaker can say. This relates back to the previous point we were discussing - it seems to me unnecessary to talk about what the speaker knows; we don't need to be concerned with what is going on in his head, we simply talk about an abstract potential. What the speaker can say, i.e., the lexicogrammatical system as a whole, operates as the realization of the semantic system, which is what the speaker can mean - what I refer to as the meaning potential. I see language essentially as a system of meaning potential. Now, once we go outside the language, then we see that this semantic system is itself the realization of something beyond, which is what the speaker can do - I have referred to that as 'behavioural potential'. I want to insist here that there are many different ways of going outside language; this is only one of them. Perhaps it would be better at this point to talk in terms of a general semiotic level: the semantic system, which is the meaning potential embodied in language, is itself the realization of a higher level semiotic which we may define as a behavioural system or more generally as a social semiotic. So when I say can do, I am specifically referring to the behavioural potential as a semiotic which can be encoded in language, or of course in other things too."

Halliday's (1978) 'potentials' and his system of discourse analysis generally ignore the diversity of meanings available to individuals and groups. This diversity is highlighted by research into children's conceptions of natural phenomena where children are seen to continuously negotiate their conceptions and interpersonal beliefs, their social relationships and what they deem to be
relevant knowledge in a given context. Halliday's approach may have some utility in formal linguistics but it lacks a dimension of analysis which would allow it to cope with the flexibility and imagination of children's talk; a feature characteristic of the cognitive and interpersonal dynamics of children's conceptual systems.

Researchers interested in how children understand different viewpoints and how they reflect on their existing organizing principles in social situations have considerable problems in coping with the diversity of these personal and interpersonal domains of language. Consequently, the analysis of children's discourse has focused on either situations where language is structured by situations such as the classroom (Eggleston et al. 1976), or the analysis has imposed a set of *a priori* 'rules' by which to judge the nature of discourse. In the latter style, Toulmin et al. (1979) have developed a system of discourse analysis which focuses specifically on

"the critical procedures through which ideas are examined in competition with each other and judged by relevant criteria so as to make it possible for us to arrive at reasonable choices."

Toulmin et al. (1979) identify two uses of language with the labels instrumental and argumentative. Instrumental language achieves its purpose directly without the need for supporting argument, i.e., it may take the form of an order, a direct request, or a complaint. By way of comparison, argumentative uses of language involves utterances that succeed or fail only to the extent that they can be
supported by argument, evidence and reasoning. The claims and assertions of argumentative language give rise to what Toulmin et al. (1979) describe as "trains of reasoning" which if successful result in a person changing his view. Toulmin et al. (1979) locate these trains of reasoning in public, interpersonal and social situations.

"Whenever an idea or a thought may come from, it can be examined and criticised 'rationally' - by the standards of 'reason' - only if it is put into a position where it is open to public, collective criticism. Reasoning is thus not a way of arriving at ideas but rather a way of testing ideas critically. It is concerned less with how people think than with how they share their ideas and thoughts in situations that raise the question of whether those ideas are worth sharing. It is a collective and continuing human transaction, in which we present ideas or claims to particular sets of people within particular situations or contexts and offer appropriate kinds of 'reasons' in their support."

Toulmin et al. (1979) acknowledging the transactive character of 'arguments' and 'trains of reasoning' and their role in conceptual change, have constructed a structural framework with which to analyse discourse. In this system six different elements of language likely to bring about conceptual change are considered; claims, grounds, warrants, backing, modal qualifications and possible rebuttals. Toulmin et al. (1979) summarise the role of these components as

"The claims involved in real-life arguments are, accordingly, well founded only if sufficient grounds of an appropriate and relevant kind can be offered in their support. These grounds must be connected to the claims by reliable, applicable warrants, which are capable in turn of being justified by appeals to sufficient backing of the relevant kind. And the entire structure of argument put together out of these elements must be capable of being recognised as having this or that kind and degree of certainty or probability and as being
dependent for its reliability on the absence of certain particular extraordinary, exceptional, or otherwise rebutting circumstances."

It is difficult to imagine this system of analysis being useful to the researcher interested in children's changing conceptions. It is based on highly formal situations where arguments are heavily structured by specific situations in which participants have defined roles and specific clear-cut bodies of knowledge to draw on. Indeed, the various contexts used by Toulmin et al. (1979) which they refer to as 'typical' forums of argumentation such as university seminars, law courts, board meetings, medical consultations etc. are highly atypical when compared to the informal discourse of children talking about natural phenomena. Nevertheless, this type of 'logical' analysis based on highly structured situations is evident in interactional analyses of children talking, particularly in classroom settings where there is a measure of socio-linguistic structure imposed on the setting.

4.5 Interactional Analysis.

Bales (1950) analysis of group processes, which has been used extensively in educational research, has its origins in the analysis of discourse at management meetings in commerce. The category system of Bales provides an observational device which seeks to record the nature of interactions between individuals in a group. Using this system the researcher can arrive at a profile of the group which he hopes reflects the character of interpersonal
activities within the group setting. The behaviour categories selected by Bales are designed to record task orientated and socio-emotional behaviours, and in this sense his system tries to direct the researcher's outlook away from the strictly logical interplay suggested by Toulmin et al. (1979). However, in spite of giving researchers greater awareness of the role of language in the socio-personal dimension, operationally defined protocols of this type, impose on discourse a set of observational foci which distort the observer's perception of the linguistic and social milieu within the group. The a priori nature of category systems artificially rigidifies the observer's perceptions of group dynamics by underpinning observation with notions such as group efficiency, democratic structure, and task orientation. In this way the actual content of group discussion and the orientation of individual students towards that content is neglected.

If we are to gain a better understanding of conceptual change processes, a cognitive dimension must be present in the analysis of group discourse. Previous research, particularly category systems have not always emphasised the intellectual content of student contributions to discourse, and this has impoverished our understanding of the relationship between cognition, communication and conceptual change. The purely linguistic approach to group discourse fails to consider how individuals organize information, ideas and conceptions. Any system of interactional analysis which fails to take into account individual meanings may misinterpret reality and provide only assumptions about broad patterns of interaction which lack the resolution needed to observe students'
conceptions in action. Barnes and Todd (1977) comment on these limitations.

"It often seems that the features which are most visible, most readily isolable, are those which are the least important; whilst those features which the observer focusses on as being the most significant are precisely those which are the hardest to categorise in a reliable way. It is clear to us that in these conversations much more was happening than as observers we could hope to be aware of, much less describe. Moreover, our concentration on the language at the expense of the paralinguistic channels of communication again narrowed our range of reference. Our approach has been to separate out from the very complex meanings negotiated in the discussions some of the more visible phenomena in order to make sense of these. This has necessitated the assumption that the meanings we have assigned to these more visible phenomena are in some way representative of other meanings out of reach, this assumption, though clearly open to dispute, seems to be forced on anyone investigating this kind of data. Under these circumstances any attempt to create rigorous and exclusive category system would have been out of place and misleading."

4.6 A Cognitive Dimension to Discourse Analysis.

If a better understanding of conceptual change processes is to be gained, a cognitive dimension must be present in an analysis of student discourse. Michell and Peel (1977), in their analysis of classroom discourse, developed a system designed to monitor both the levels of thinking of individual students and their interpersonal interactions during informal (teacherless) classroom situations. The aim of their analysis was to reveal patterns of interaction between students working in small groups, and to illuminate the cognitive operations used during student discourse. The system of Michell and Peel (1977) divides student discourse into two categories; student talk deemed directly relevant to the
content material presented to the group is allocated to a 'target' category which is subdivided into Describer and Explainer utterances. Other discourse is categorised as being 'interactional'. Although not directly concerned with conceptual change this work concluded that students analysed their experiences more effectively in discussions which were dominated by the open, tenative and hypothetical speech acts associated with their Explainer category.

From a methodological point of view it is interesting to reflect on the basis of this sort of conclusion. Michell and Peel (1977) describe Explainer and Describer categories as

"Describer - Material quoted or repeated direct from source. Description of events without explicit evaluation or explanation. Anecdotal talk where there is no attempt to state generalizations or implications.

Explainer - Full interpretations, explanations, judgements, opinions substantiated with example and argument. Utterances which include the consideration of alternative viewpoints and possibilities. Anecdotes linked to the problems being discussed."

In the above category descriptions it is not difficult to see how the 'ideals' of 'effective' group discourse are in fact imposed on student talk. These descriptions do not emerge from an understanding of what student discourse is but of what it should be. When we try to give the analysis of discourse a cognitive dimension it has to be from the student's perspective and that means getting much closer to the conceptions used by individual students. If we are to gain a better understanding of the way students interpret their experiences then we may have to be less concerned with systems of analysis which define 'target' material.
and 'relevant' content from a teacher/researchers standpoint and consider the intellectual contributions of students to group discourse in the context of the conceptual ecosystems of learners within a specific group. Category systems by definition reduce the variability and diversity of children's talk and give structure to an apparently structureless situation, however the cost of this approach is that we negate these features of discourse by this form of analysis. A cognitive dimension to discourse analysis must conserve rather than eliminate the content orientated and idiosyncratic elements of individual cognition which form the basis of understanding and contextualise interpersonal communication; it is on this foundation that I can begin to construct a description of the cognitive activities of the student.

The analysis of Michell and Peel (1977) also tries to bring the cognitive and social aspects of discourse together in order to highlight the relationship between learning activities and interpersonal interaction. However, the degree of interdependence between these 'interactional' and 'target' categories is obscured by a system of analysis which isolates them into 'distinct categories' and leads to a de-emphasis of their mutual reciprocity.

Barnes and Todd (1977) have explored the utility of social and cognitive aspects of discourse in their description of group learning situations. Although this work is based on a category system which describes social skill, cognitive strategies, discourse moves and logical processes within group discourse, these categories emerge from their data in an a posteriori fashion. This
methodological posture is supported by their interpretation of conversational meanings as being problematic. "Our gravest doubt about our categories is whether they do, in fact, conserve those features of the children's talk which we see as theoretically important. We are interested in learning, in cognition, in the construction by the children of some of their own knowledge. We recorded children talking together in the hope that we could distinguish knowledge in the process of being made during their co-operative effort. The difficulty is to decide how crucial is the presence of any particular linguistic and interactional features. Those we find striking may merely represent the habitual style of these particular children. Perhaps other children would create equally valid and complex solutions to the same problems without using any of the same verbal strategies. This is a doubt we have to live with: our analysis is based upon what these children did."

This modest approach to the limitations of discourse description, their hypothetical character and the uncertainty of analysis methods is much more in keeping with research which is aware of the nature of children's conceptual ecosystems and the ways that children communicate their experiences to others. Barnes and Todd (1977) conducted a number of studies of small group learning situations on the basis of their category system. During these activities they became aware of individuals in the group constructing a cumulative and idiosyncratic account of what had been going on. The construction of this account was often out of phase with 'observable' events within the group as each member reflected on previous utterances and events. This observation displays the 'leads and lags' of natural discourse and highlights how the researcher is confronted by a situation where meaning may not adhere to particular utterances, but may be based on previous
utterances which remain tacit during much of the subsequent discourse.

The researcher/observer of natural dialogues between children is thus directed away from exclusive category systems towards 'strings of cumulative reinterpretations' which characterise the ebb and flow of ideas, the ongoing interpretation of experience, the continuous conceptual adjustments and interpersonal interactions that comprise group discourse. The cumulative and dynamic aspects of these activities require a method of analysis which takes the linear and temporal aspects of group discourse into account as well as accommodating the episodic nature of events and experiences which may punctuate the evolution of understanding and conceptualisation within group discourse. When the research focus is on the ways that conceptions adapt over time and the factors influencing these modifications it is important that the method of analysis retains a temporal component and does not artificially fragment the nature of group discourse. To use a photographic analogy I am concerned with an analysis of discourse based on moving pictures rather than on a sequence of freeze frames.

In addition to these considerations, groups of children talking by themselves represents a situation which does not lend itself to structural methods of analysis. In an environment where no individual lays claim to the direction dialogue should take, and where perceptions of subject matter, order of speaking, and how content is to be handled, are negotiated rather than predetermined by specific roles, (student, teacher, classmate etc.) methods of
analysis must match this level of fluidity if they are to capture
the interplay between dialogue, conceptions and conceptual systems.

In an effort to deal with the multisemic and fluid nature of
group discourse Barnes and Todd (1977) have proposed a theoretical
construct which they call a 'Frame'.

"The use of the concept Frame frees us from any need to assign
a determinate and unchanging meaning either to the content of
an utterance, or to its significance as a move in the
interaction. It aids the observer to deal with (a) the
different interpretations held by different participants, (b)
the ebb and flow during a conversation between more sharply
defined Frames and those moments when Frames are blurred,
because in flux or mutually contradictory, (c) the dual aspect
of the necessary tacit knowledge, which refers in one direction
towards supplying a context for the subject matter and in the
other towards a set of expectations about the social meaning
of actions. To sum up, Frames refer to participants' implicit
expectations about (a) what they are talking about, and (b)
their relationship and communicative behaviour. Frames are
offered by those who speak and interpreted by those who
listen, thus changing in the course of the conversation."

Barnes and Todd (1977) identify two Frames used simultaneously
by participants in dialogue; a Content Frame which refers to
subject matter and an Interaction Frame which relates to the
interactive relationship between individuals. These workers suggest
that

"the meaning of utterances lies not in the utterance itself but
in the implicit hypotheses about it which shape the future
history of the conversation. Meanings are characteristics of
people not of utterances, or - to be more precise - are
attributed by people to utterances in context. Participants in
communication understand an utterance in terms of the Content
and Interaction Frames which they ascribe to it, that is in
terms of 'knowledge of how things are' which they bring to it.
(Barnes and Todd, 1977)

The notion of the Frame as a unit of analysis can be seen as
the outcome of a desire to move away from category systems toward
a more intuitive type of discourse analysis. It also possible that
the Frame may represent a coming to terms with the limitations of discourse analysis and in particular the problems of the observer who tries to construct a 'picture' of the world as seen by participants in group discourse. From a structuralist perspective, the Frames of Barnes and Todd (1977) could be interpreted as a symbol of defeat, in that they represent a method of analysis which acknowledges the ambiguity, indeterminacy and the flux of children talking in groups but fails to reduce this 'chaos' to some form of ordered perspective. Researchers/observers of group discourse impose an interpretative structure on events through their own experiences and beliefs (without this there could be no analysis); but what Frame analysis suggests is that this intuition should be used to help the observer construct a concurrent understanding of group discourse in much the same way as the participants. Thus as the individuals in the group piece together their understanding of events the researcher moves with the discourse, incorporating its ever changing character and indeterminate nature as part of his on going analysis: in some ways this activity can be likened to the construction of a historical narrative compiled by an historian in the same time stream as the events he describes, (as opposed to the picture described by an historian looking back on important events from another time period).

4.7 The Analysis of Group Discourse in this Study.
Two main themes emerge from the review above. Firstly, that in trying to describe children's conceptions and the way that they use, adapt and communicate these conceptions in a group setting, the researcher has to come to terms with the 'chaotic' nature of discourse between children. In addition he must be aware of the limitations of methods of analysis which seek to give determinate meanings to children's utterances. In my research I was interested in children's conceptions of inheritance and the ways that these conceptions change, and therefore was required to develop and construct an interpretation of events relating to these interests as seen through the eyes of the participants in my research. The intuitive Frame analysis of Barnes and Todd (1977) allows the researcher to follow the development of group discourse and the participation of individuals in the communication of their ideas. This type of analysis resonates with a study of individual conceptions and the factors influencing their adaptation. However, if this is to be applied to children's conceptions of inheritance and an understanding of how these specific ideas change, then what this type of analysis requires is a model of change and conceptual activity in the context of group discourse. Secondly, if the findings of this research and this analysis are to have some impact on our understanding of how children learn then there must be a theoretical foundation on which to base the analysis. The nature of this theoretical base, as in Posner et al. (1982), can take the form of a model of conceptual change derived from the philosophy of science. At an even more general level, a theory of learning such as Piaget's or Wittrock's (1977) might be used.
What I now wish to suggest is that the model described in Chapter 2 is capable of providing this theoretical base on which to analyse and describe the dynamics of children's conceptual ecosystems as they relate to inheritance. In addition, the same model is also relevant to the analysis of group discourse and can relate the character of children talking about inheritance problems to a theory of learning based on conceptual change. Thus the model used in the analysis of my data represents a symbiosis of theory and practice which emerges from a consideration of children's conceptions of inheritance, the features of their conceptual ecosystem, and an appreciation of the learning context.

4.8 A System of Observation and Analysis.

The research data derived from this study consisted of audio and videotapes of group discussions. This data was analysed in the following manner.

An initial draft transcript of the group's activities was drawn up, the main aim of this being to prepare an accurate and detailed record of the discussion. No overt analysis was attempted at this stage; the emphasis being on increasing the transcriber's/researcher's familiarity with the group's activities, whilst recording as much of the detail of the session as possible. Ideally transcripts would be prepared immediately after the video sessions, however, in practice it was difficult to keep pace with the rate of data acquisition. Every attempt was made to transcribe tapes while the video session was 'fresh' in the researcher's
memory. This initial transcript, as with subsequent drafts, was not divided into sentences nor was it punctuated. The main aim of the transcriber was to capture the character of the spoken word. A standard transcript format was adopted, with speech filling the central part of the page with wide margins for tape counter units and elapsed time as well as additional comments. Where it was difficult to make out what was said asterisks in brackets were used to denote the number of 'missing' words as far as possible. Pauses were shown by full stops, the number of dots indicating the length of the pause. Longer pauses were timed in seconds. Where appropriate the text was indented to show overlapping speech where the students talked simultaneously.

From this 'rough' transcript a more detailed one was prepared and it was during this transposition that conscious efforts were made to analyse the data. This is a long and tedious task which is often 'sub-contracted' to someone other than the researcher. However, there are definite benefits to be gained from the process of transcribing. Given that the researcher has been through the transcript at least once during the initial phase of transcription, the rewriting of the transcript and the concurrent analysis of the data, brings with it a definite feel for the evolution and development of the group's activities. This, coupled with the frequent replaying of the videotape, heightens the observational skill of the researcher whilst sensitising him to specific interpersonal interactions and conceptions.

4.9 The Analysis.
The purpose of analysis is to develop a qualitative description of the transcript data. Through this description will be obtained an understanding of children's conceptions of inheritance and their interactions with features of their conceptual ecosystems.

It is possible to adopt a procedure in which an individual's conceptions are identified and their characteristics examined in the context of the learning situation. An alternative approach is to analyse the group's social and cognitive activities as a whole, and then break this down into individual components. Bearing in mind the complexity of conceptual ecosystems a holistic approach followed by gradual analysis has much to recommend it. However, no matter what the approach, describing and understanding a conceptual system needs a starting point and the decision was made to look in the data as a whole for the emergence of 'units' of interpersonal interaction and individual conceptions. These 'units' of interaction and cognition are defined ecosystemically in that they are identifiable in a variety of student groups and represent patterns of conceptual understanding and interpersonal interaction in a number of similar group problem solving situations.

Meaning in a group discussion does not adhere to isolated 'units' of conception or specific utterances, but are part of the conceptual and interpersonal ecosystem created by the participants. Each student creates their own conceptual ecosystem and this in turn is the basis on which they understand what other students in the group are saying.

As a conceptual ecologist/researcher I have adopted the role of the enlightened observer, making full use of the opportunity to
listen and watch group activities again and again. No matter how many times one reviews the videotape, meanings attributed by the observer to student actions and words will always be hypothetical and from one particular viewpoint.

My personal model of this analysis was drawn from an ecological metaphor, where one imagines oneself in a variety of conceptual habitats observing and trying to understand what is going on in the ecosystem. One is aware of different settings, varying backgrounds, new backcloths to the actions and behaviours of the participants in the ecosystem. Simultaneously the observer is focusing in on identifiable conceptions and 'units' of behaviour that can be recognised as interacting within the ecosystem.

4.10 The Analysis Procedure.

The initial ('rough') transcript was analysed as it was rewritten onto prepared pages laid out with a large central section for the dialogue, a narrow left hand margin for tape counter and elapsed time information, and a wide right hand margin divided into two columns. As each piece of dialogue was transcribed/transposed, it was categorised in terms of social interaction and conceptual content. These conceptions and 'units' of interaction were recorded in the right hand columns of the transcript along with any comments or observation. During this process video and audio tapes were used along with the initial transcript to 'revisit' the groups activities and to make decisions about what was happening.
The scheme of analytical categories which evolved from the data are given below. The formulation of this system being derived from the work of Gilbert and Pope (1982). It is important to stress that these are not absolutes but part of a descriptive vocabulary used by the observer to develop his own personal understanding of conceptual ecosystems.

Social Interactions

(a) Progress through the task

   i. Suspension of discussion - often as a result of being unable to reconcile problems or obtain mutual agreement in the group; often associated with the group moving on to an alternative task.

   ii. Moving on - changing the focus of attention to a new card or page or part of a family tree.

   iii. Task management - looking for or being asked to look for offspring or find relevant pieces of text.

(b) Competition and Disagreement

   i. Competition for the floor - usually two or sometimes all three students trying to tell each other at the same time which offspring they should choose. Often associated with 'thinking out loud' and giving a public airing to personal opinions.

   ii. Disagreement - often the unqualified rejection of another student's choice of offspring; or,
the denial of a group member's choices on the grounds that they do not concur with the group's or an individual's present thinking.

   iii. Challenge - A situation where one student, or two students in collaboration, would challenge another's explanation of their offspring choice. This may take the form of asking for elaboration of the student's conceptions or the consideration of the consequences of his/her conception. Often the opposing students would make their own challenging conception explicit during these sort of exchanges.

   iv. Gatekeeping - Where one student seems to act as arbiter of what is logical, or acceptable, or a sensible suggestion for offspring selection.

(c) Supportive Activities

   i. Acceptance - Often passive agreement by one student of another point of view or his particular offspring selections.

   ii. Echo - Where one student repeats the words of another by way of support and making explicit their 'alignment' with the previously expressed viewpoint.

   iii. Referring forward/back - Here one student refers to a previous or future card or page of text by way of supporting or describing the group's present activities.

   iv. Chairing - Usually where one of the students takes on the role of chairperson, summarising the group's actions and providing an overview of any consensus of opinion.
The following list of conceptions of inheritance have emerged from the pilot and case studies. They are not a set of a priori categories, but the product of many hours spent listening to the ideas used by children in their efforts to solve inheritance problems. As such, they constitute a set of 'results' and in this respect they share many of the features of children's conceptions of inheritance identified by other workers (Kargbo et al, 1980) and described in Chapter 1. However, I have chosen to place these descriptive categories or conceptual frameworks (Gilbert and Watts, 1983) within this chapter (as opposed to concluding chapters) because I view them as an analytical device rather than an 'end-product' of research. This may be a personal reaction to alternative conceptions research in which the aim seems to be one of 'framework spotting'. My feeling is that although these categories help structure our understanding of children's conceptual systems, they are a means to an end; they provide an overall picture of children's conceptions and a framework for descriptive analysis, they do not constitute in themselves an understanding of the processes of change going on within conceptual ecosystems.

In this research project, the utility of the conceptual framework is acknowledged but the aim is to use these generalisations to illuminate and describe the specific and unique processes which make up conceptual systems. Having travelled from the specific to the general and back again it is hoped that one is better placed to make sense of individual conceptual ecosystems.
Conceptions

Conceptions are unique, idiosyncratic, personal theories about the way things are. The categories of conceptions below are not definitive nor representative of individual conceptions. They provide a descriptive frame of reference through which an understanding of conceptual ecosystems can be constructed.

(a) 'Like begets like' - a conception which is based on the familial similarities between parents and their offspring. Students make their choice of offspring on the basis that 'children' look like (take after) their parents.

(b) Offspring variability - students contend that there is a degree of colour variation or variability in the offspring of a given family. They expect the offspring of a given family to look slightly different.

(c) 'Blending' - a conception which predicts offspring choices on the basis of a blend or 'mixture' of parental colours. A black mouse mated with a white mouse will have grey offspring.

(d) Sibling similarity - students contend that 'brothers and sisters' will look similar. If a family of mice have one brown offspring they are likely to have another offspring of the same colour.
(e) **Grandparental influence** - a conception linked to the idea that offspring can take after members of previous generations. Traits not obviously inherited from the parent are seen to come from the grandparents.

(f) **Albino frequency** - students contend that albinos are relatively rare occurrences in families. They occur 'by chance' and can happen in any family at any time.

(g) **'Dominance'** - a conception often linked to the student's notion of colour strength and the effects of 'strong' colours on parent/offspring coat colour relationships.

These analytical categories provided a descriptive baseline of the conceptual and social activities of individuals within the group. However, these categories are interrelated and part of an everchanging conceptual and social group dynamic. Within this dynamic are to be found the features of conceptual ecosystems which affect the process of conceptual change. Therefore, a more holistic analysis of group activity was carried out by interpreting and constructing the frames of reference being used by group members. By describing the content and interaction 'frames' of students, (Barnes and Todd 1977) in the form of a metacommentary, conceptual and social interaction categories were interrelated with each other and with other features of the students' conceptual ecosystems. The resulting 'narrative'/case study of the group's activities was able to place conceptual and social interaction
categories into a set of changing contexts. This interpretation allowed the researcher to follow conceptions as they 'lived out their lives' within the group and to comment on those features of the students' ecosystems which had a significant effect on their conceptions. At this level of interpretation and analysis it was also possible to describe features of conceptual ecosystems such as analogies, metaphors, and personal anecdotes.

Using this narrative approach to analysis, which involves an holistic and reductionist perspective, it was difficult to keep track of everything that was going on within the group. Faced with a complex and changing system of interactions, the researcher is forced to move back and forward in time trying to capture an understanding of events. Equally difficult is the task of focusing at one moment on a conception and the next on its interaction with the conceptual and social environment which surrounds it. The written word in the form of a metacommentary is an excellent way of presenting data; but it is a difficult medium to work with when actually carrying out an analysis which requires one to glean a continuous overview of events past and present. Consequently, in addition to the evolving metacommentary of the groups activities, a symbolic/shorthand representation was made concurrently with the written description. This provided an alternative 'picture' of events in a form that, although linear and two dimensional, gave an easily assimilated overview of conceptual and social patterns (Appendix VI). This 'symbolic' form of representation made it possible to gain an impression of events over time as well as providing a 'reference map' of the analysis.
The final stage of analysis is to take the case studies obtained by these methods and to test the putative ecosystemic model suggested in Chapter 2. By 'colliding' the analysed data with the model it is hoped that insights will be gained into whether characteristics of open systems such as resilience, heterogeneity, stability and adaptation have utility in the development of our understanding of conceptual change processes. This in turn may inform subsequent analysis and interpretation of the data by focusing attention on specific aspects of conceptual ecosystems.

In the following chapter the products of this method of analysis are presented in the form of five case studies. These studies were selected from twenty eight group sessions as being representative of the children involved in the study, the groups' composition in terms of age and gender, and the problem solving activities of the students.
Chapter 5
Case Studies
5.1 Case Study 1.

This group consisted of three girls aged 12+. All three were classmates. The session took place in the students' classroom, in the presence of the 'interviewer', while the rest of the class attended lessons in adjacent rooms. The girls sat side by side, facing the camera which was positioned about twelve feet away. The researcher sat in view of the group monitoring the video equipment. Cards 1 and 2 were used to introduce the first task and to give the children a chance to acclimatize to the situation.

Card 3 (albino x albino) began the girls' discussion.

1 Su Grey.....do you think it could be like that one
2 T Yeah.. a possibility
3 Su Have them all the same colour really..that colour cos thats nearly white
4 T Yeah
5 Su and the white ones they'd be darker than that
6 T Mmmm
7 Su Mmm
8 Sa They might be white ones
9 Su Do you think they will have an other one
10 T Yeah..what
11 Su like that
12 T They may have the odd one
13 Su Yeah
14 Su ...have you got any more white ones
15 T I did but I've just dropped it (laughs)
16 Sa I've got one white
17 Su one like that
18 Sa Yeah
T Yeah

Sarah moves on to the next card, the others follow.
Sue takes the lead during the discussion of this card. She invites the others to participate but seems eager to have her ideas accepted. Sue presents a reasonably strong interaction frame as she attempts to control the group's activity. The content frame at this point seems weak. Sue has a vague conception that parents and offspring should be similar (3) and that grey coloured offspring are a plausible variation in the offspring's phenotype (1,3,5). Tracey and Sue are rather passive in their exchanges with Sarah, accepting her ideas but not really committing themselves. Audience awareness may at this stage be encouraging Sue but inhibiting Sarah and Tracey. The latters' conceptions are not articulated and Sue's are indeterminate.

Card 4 (Black x Light Brown)

19 Su         thats got to be ****
20 T         spotty one...something like that
21 Su         What about that one
22 T         with a spotted..with different colours on it
23 Sa         What about one like that
24 T         You'd get one like that
25 Su         Yeah definitely
26 T         Black ones
27 Su         What about that one
28 T         Maybe it depends
29 Su         something like that or that
30 Sa         No (very quietly)
31 Su         Might get .spotted..two like that ***..two mixtures
32 T         This one ......that one put that one on
33 Su         Yeah I've got that one
34 Sa         Have you got that one
35 T         Thanks.....it on its
36 Su         ..it might have got brown .. from there and then its black
37 T         Yeah
38 Su         yeah thats about it
39 T         Yeah
40 Sa         Yeah....only it might have one of those as well on it
41 Su         Might do (moves to next card)
During discussion of this card Sue and Tracey 'compete for the floor' over the choice of offspring. (19-23, 27-32). This 'competitive collaboration' between Sue and Tracey strengthens the interaction frame between the two girls. At (22) Tracey's implicit notion of 'mixing' seems to be cued by the black and brown parent mice. Sue, after trying to get her choice of offspring accepted, picks up on Tracey's lead of "spotted" (31). Sue qualifies this choice with reference to "mixtures" (31). The implicit conception seems to be that each parent mouse contributes its phenotype to the offspring and these are, as a consequence, a mixture of both parents (36). The agouti mice provided may act as a cue given that they are brown with black spots. On the basis of the "spotted" and "mixture" choices Sue and Tracey seem to have established a consensus view; an apparent resonance of ideas based on a still very weak content frame. Sarah is not very involved in the discussion, her contributions are largely ignored inspite of, or perhaps because of her reflections on Tracey's and Sue's actions (30,40).

Card 5 (Black x Black + Dark Brown Offspring)

42 T That ones
43 Su it might have.....that again
44 T Yeah. because because they've got the other one
45 Su If they've got
46 Su a brown one they might get another one
47 T Do you reckon they would have a lighter one ...what about
48 Sa that colour
49 T with that one they might have one of those
50 Su its a bit lighter
51 T if they've got one brown
52 Su so they might get a mixture
53 T If they've got a brown one they could easily have a black
54 Su Yeah yeah like that
55 T a special one yeah

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Sue and Tracey continue their 'competition for the floor'; a strong interaction frame is presented by both girls as they competitively collaborate. At (43 and 45) Sue seems to be implying that her choice of offspring is influenced by the 'sameness' of siblings. At (50) she interrupts Tracey with her idea about "mixture" in the offspring and she uses it again at (59) to sum up the girls' selections. What she means by mixture remains vague. Tracey at (51, 55 and 60) picks up on the word mixture and is allowed to develop her ideas as there seems to be some consensus as to the conception of mixture. However at (60) Tracey's idea of mixture becomes more explicit (strengthening content frame) and this is challenged by Sarah (61). Tracey's conception of mixture seems to be, given parents of different colours or an offspring which is a different colour to its parents, that this represents such phenotypic variability that a variety of offspring coat colours are possible. Sarah's challenge at (61), and her disagreement with Tracey's idea, brings her into the discussion. Her challenge to Tracey's conception of mixture is elicited by the extension of the potential anomaly presented by card 5 (two black
parents and a brown offspring) when Tracey suggests that they could even have an albino. This may be outside the limits of plausibility for Sarah and may interact with her own conceptions which might be that offspring should look a little like their parents.

It is interesting that Tracey's mixture conception may allow her to 'explain' the potential anomaly of card 5 (Black parents, brown offspring), whilst Sue's conceptions of sibling similarity on the one hand and phenotypic variation in the offspring on the other, may interact in such a way as to reinforce the explanatory adequacy of both conceptions. The possibility of discussion and interaction between the girls' different conceptions is not taken up and from (62-65) there is a rapid suspension of the discussion.

Card 6 (Black x Agouti + Agouti Offspring)

66 Sa Oh no
67 Su Oh..thats funny..oh no get that one
68 Sa Yeah
69 Su I think you'll get one like that as well dont you
70 Sa You'll get one like that

71 Sa Similar to that
72 T You might get some black..one
73 Sa Black ones
74 Su Black ones ..yeah
75 Su You might get ..black....with some yellow at the bottom
76 Sa They're orange..orange
77 T Yeah
78 Su Have you got ..have you got a black one..a plain black one
79 T Yes ..there
80 Sa (inaudible)
81 Su If they've got the..that one with spots..they might have one without spots
82 T The grey
83 Su Yeah
84 Sa Oh yeah..they might
85 T Might have said grey
86 Sa Mmm I don't know
87 T ..and dark grey like that
During the discussion of card 6 the content frame remains weak throughout. No conception is made explicit. All three girls are competitive in their collaboration. Tracey, who seems to take the lead in the choice of offspring, has her ideas generally supported and accepted (82-99). At (81) Sue seems to be returning to her conception that there may be variation in the offspring, but this is not taken up by the others. There is a reluctance to make explicit their ideas and an apparent emphasis on the development of consensus and mutual agreement. This social interaction coupled with the ambiguity of the weak content frames being used by the girls may keep the ecosystem heterogeneous and maintain/re-establish its resilience after the events of card 5.

Card 7 (Brown x Brown + Albino Offspring)
Competition for the floor between Tracey and Sue with Sarah following her own line of thought marks the beginning of the discussion. The conceptions being used are vague and implicit; the pause at (113-114) may be the result of an awareness by the girls of a lack of cohesion and the fact that their choices of offspring lack consensus. At (114) Sue questions Tracey's choices and revisits the 'mixture' conception at (60-62). This interaction between Tracey's 'mixture' conception and Sue's conception is evident in (114,115) as Tracey tries to justify her choices on the basis of the amount of variability in their offspring choices. Sue's ideas at (102 and 110) are vague but at (114) she seems to be indicating once again that the limits of the mixture will be determined by the colour contributions of the parents and the 'given' offspring. Sarah's contribution at (116) defuses the potential for debate between Tracey and Sue over their respective conceptions. Her suggestion of albinos may indicate her awareness that this represents a coat colour which cannot be disputed as it is one of the 'givens' associated with this card. Alternatively this may represent her own ideas about sibling similarity. Tracey agrees at (117) and (119) to
this 'compromise' and seems to accept Sarah's reservations about her idea of 'mixture'. It is interesting that as with card 5, card 7 also presents a potential anomaly in the context of parents producing like offspring. This situation again brings Tracey's mixture conception to bear and results in a degree of interaction between Sarah's ideas and to an even greater extent Sue's conceptions.

Card 8 (Agouti x Agouti + Black Offspring)

120 Su  looks like they'll get a mixture with that one
121 T    Yeah
122 Su  They've got a black one
123 Sa  (inaudible)
124 Su  Reckon they'll get another black one
125 Su  ......might get another brown one a mixture...a mixture with grey at the bottom
126 T    thinking, a black one with orange at the bottom
127 Sa  there might be ......they might have a little plain brown one
128 T    Plain brown one
129 Sa    dark brown
130 Su  like that
131 Sa  No darker
132 T    the dark brown
133 Sa  yeah the dark

At (120) Sue immediately returns to the idea of mixture as the basis of offspring appearance. The fact that in this card the parents are Agouti, an obvious mixture of colours, and have black offspring, may resonate with Sue's conception of mixture as this combination gives a great deal of potential in terms of colour mixing/blending. Tracey's agreement at (121) is tinged with a smile and she may be reflecting on the previous exchange at the end of card 7 and Sue's apparent lack of consistency. Sue and Tracey's differing conceptions of 'mixture' seem to be simultaneously active and mutually tolerant in this
situation; they do not re-examine their underlying assumptions (125-126) allowing an apparent consensus to be established by Sue whilst Tracey, perhaps understandably in the light of previous challenges, does not push her mixture conception. At (124 and 125) Sue seems to be using sibling similarity as the basis for her choice of offspring. During the rest of the discussion it is Sarah’s ideas that are a focus for the group activities. These are accepted by Tracey and Sue although they remain implicit; from (127-133) there is task collaboration between all three girls.

Card 9 (Light Grey x Black)

134 Sa These’ll be like the last one
135 Su They’ll gonna get a grey one or some mixtures of grey
136 Sa probably get some dark greys as well
137 T Dark greys with different coloured greys
138 Sa dark and light ones
139 Su Have you any black ones left
140 Sa no. I don’t think so
141 T black ones with orange bits
142 T ...make it one of those browny sort of colours
143 Su Yeah I’ve got one of those
144 Sa that one
145 Su maybe because thats a bit lighter
146 Sa Yeah
147 T make it a white one
148 Sa ...but it couldn’t
149 Su ..brown one cause you had a white one with other different
       colours didn’t you....mmm that one
150 T You might be able to get a white one
151 Su a white one
152 T there’s a white one ....there’s a white one

Sue at (135) seems to be indicating that her notion of mixtures is once again related to the blending of parental colours. Sarah seems to be echoing this notion making the blending notion more explicit in her reference to dark greys ie. the contribution of the black parent is
significant when blended with the light grey (136). Tracey at (137) picks up on Sarah's qualification and seems to share her conception. At (141, 142 and 147) Tracey also develops her conception of mixture (147) and her suggestion that an albino is again part of this notion of variability in coat colour. As before this leads to disagreement by Sarah at (148). Sarah does not qualify her disagreement but it may be that her blending notions used at (136) make Tracey's choice of an albino seem implausible. Sue and Tracey at (149-152) seem to develop agreement on the possibility of a white offspring. Sue seems to be influenced at (149) by the evidence of a previous card (card 7) which had an albino as the product of two brown parents. The girls develop a strong interaction frame in this discussion perhaps associated with their increasing confidence in their predictions. Sue and Tracey seem to have adapted their respective conceptions of 'mixture' and have achieved a consensus view.

Card 10 (Black and Tan x Brown and Tan + Black and Tan Offspring)

153 T You might get a multicoloured one
154 Sa You might get a spotty one ..you might get a dark brown ones as well
155 Su Yeah...what like that
156 Sa Yeah
157 T put one more on ..plain ....black one
158 Sa Yeah
159 Su I've got that one ...no I haven't
160 T They've got a mixture

This card gives rise to a brief discussion. Tracey seems to be using her mixture conception at (160) as a qualification of her offspring choices. The range of coat colours involved in this card seem to
resonate with her ideas and may cue her description at (153). Tracey's description of the offspring at (160) may serve to re-establish the plausibility of her mixture notion. Sarah seems to retain her notion of blending at (154). Sue seems to be taking a back seat in the discussion at this point.

Card 11 (Dark Brown x Dark Brown + Light Brown Offspring)

161 Su They'll get a brown one in that won't they
162 T Yeah
163 Sa a bit obvious
164 Su a brown one (**)
165 T have you got another brown one
166 Sa I couldn't find it. I haven't got a dark brown one
167 Su have you got a dark brown one.....change it
168 T can't find a dark one
169 Sa (inaudible)
170 T make it a black one
171 Su or white one...yeah
172 Sa you might get a sort of
173 T grey sort of colour
174 Sa yeah that black really
175 T you might get...mmm darker sort of colour
176 Su that sort of colour...that one there
177 T get me one like that
178 Sa Might do
179 Su yeah I don't know...they did have (****)

(Suspension as Tracey moves on to 12)

Sue's strong lead at (161) and its acceptance by the others may indicate the plausibility of the conceptions being used. In this instance the 'like begets like', sibling similarity and blending/mixture conceptions are all plausible. Sarah's comment at (163) may reflect on the plausibility of Sue's choice of offspring and her own conceptions (shared content frames). The content frame being used by the girls remains implicit. At (170) Tracey's suggestion seems to cue
Sue's qualification at (171); Sue seems to be using Tracey's mixture conception; indeed her choice of a 'white one' is a strong echo of Tracey's previous 'mixture' conception. A strong interaction frame is presented by all three girls as they collaborate on the task in a competitive spirit, each trying to influence the other without actually making their ideas explicit. It may be that this style of interaction keeps their personal ecosystems open and heterogeneous, insulates them from being 'wrong' whilst keeping open the possibility of conceptual and social resonance.

Card 12 (Agouti x Albino)

180  T       white ones white ones white ones
181  Sa      here's another one..I've got it
182  Su      I've got a spotted one
183  Sa      brown ones
184  Su      They might be like that
185  Sa      they might be
186  Su      cos its lighter
187  T       You might get one with an orange stomach
188  Sa      might
189  T       as they've got a sort of mixture
190  Su      You might get a grey sort of like that
191  Sa      Yeah
192  T       Yeah
193  Su      Yeah

At (180, 187 and 189) Tracey seems to deploy her mixture conception with the tacit agreement of the others. This conception combined with her notion of variability in the offspring and non-familial resemblance have a great deal of explanatory power in the context of the task; almost 'anything goes' in terms of offspring choices. Sue at (184 and 186) seems to be using her blending notion in which the offspring is lightened by the albino parent. Sue and Tracey present
strong interaction frames but there is little actual interaction between their respective conceptions of mixture. This perhaps indicates the mutual adaptation and tolerance which has been developed between the two conceptions. Sarah is eager to help in the task activity and seems happy to follow the other girls’ ideas.

The girls were introduced to the second task (reading/comprehension). They read the materials mainly in silence but with the occasional quiet aside to one another. This behaviour may be associated with a set of expectations about the nature of reading in class and the need to do it quietly and in private. The girls read for four to five minutes in what seemed to be a ‘browsing style’.

The girls were now introduced to the third and final activity of ‘making’ a mouse family tree. They were familiar with the idea of family trees and after a brief resume of the skeleton tree and what it meant they started the task.

194 Su Shall we start with two coloured ones
195 Sa Yeah
196 T two different colours
197 Sa one there......a grey
198 T and make one a black one
199 Sa Yeah
200 Su and how can you ..uhm
201 Su ..and a grey
202 T have a grey one and a white one or something like that
203 Su or a speckled one
204 Sa white one ..have a darker grey
205 T Have a white and a sort of speckled one
206 Su yeah a speckled one
207 T white and speckled
208 Su that way you might get...you might get one like that cos you'd get one
209 T yeah
210 Su and you'd get one with speckled as well
211 Sa you might get one thats just plain black

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Strong interaction frames are presented by all three girls as they choose the components of the first level of the tree [1] and [2]. The content frame is weak with choices being 'thrown' into the discussion with no justification. The exchange between Sue and Tracey at (205 - 209) highlights how even when Sue makes an attempt to qualify their agreement over a set of parents for [1], her reasons for the choice are vague. All three are concerned with getting their choices on the board whilst trying to work together.

212 T Mmm
213 Sa just plain black yeah

At (214 and 216) Tracey introduces the words 'inherited' and 'dominant' which she has probably gleaned from her reading of the
text. This may bring some authority to her choice of offspring for (2) at (214), and for (1) at (216), where she refers to the dominance of darker coat colours. At (217) Sue's suggestion of a grey coat colour for one of the offspring in (2) is immediately modified by Tracey at (218) to dark grey; she seems to be using dominance not as an absolute phenotypic effect, but as an additive factor (colour strength) in colour determination/modification. Tracey's use of this conception is interesting in terms of its contrast with her previous ideas about mixture and variability. Sarah echoes Tracey's choice at (219) apparently accepting her reasoning. Sue at (222) has an alternative view of what the offspring in (1) should be in which she makes explicit a blending conception of coat colour determination. Almost in unison Tracey and Sarah at (225-226) challenge this conception. Sue does not respond in defence of her offspring choice. At (230) Sue seems to accept the dominance notion through her alternative offspring choice; Tracey and Sarah accept this reconciliation to their viewpoint at (231-232). Sarah at (226) seems to be also operating the conception that 'like begets like' in relation to the statement that the parents in (1) will "probably get another one like the white one". Indeed, despite her support for Tracey's dominance conception Sarah questions the implicit use of this conception by Tracey (233-236). Tracey seems uncertain at (237) about how dark the offspring will be and this perhaps indicates that Tracey and Sue are using dominance as an adaptation of a blending conception which might equate dominance with strength of colour and the notion that dark colours will tend to make lighter colours darker as opposed to the corollary of this effect.
In this discussion the girls are trying to select the offspring of C4L. A strong interaction frame is presented by all three girls. At (242 and 244) Tracey weighs up some alternative offspring colours without making her reasoning explicit. At (247) she is suggesting that one of the offspring will be like one of the parents (dark brown). Sue at (248) and Sarah at (254) disagree with this sameness between parents and offspring. Equally Tracey and Sue (249, 250) suggest a lighter coloured offspring to which Sarah objects (251). It seems that there is a highly contradictory environment of conceptions being used; dominance/blending is proposed and questioned; 'like begets like' is used and questioned by individuals. At (255) Sue's strong lead and task direction suspends the discussion of C4L.

256 Sa Start over here..have a white
257 T No no
258 Sa have a grey
259 T a black a black
260 Sa a black. yeah
261 T black black black...that one's a plain black
In their discussion of [3] the girls seem to be again competitively collaborating as they deploy a number of conceptions. After an initial interchange between Sarah and Tracey about a mate for one of the offspring of [1] (256-261) they decide on a black mouse. Sarah at (262) proposes that another black mouse like the parent is a possible offspring. This seems to contradict her previous position where she disagreed with the sameness of parents and offspring. At (264-269) a consensus develops between Tracey and Sue. The choice of speckled (Agouti) and dark brown offspring may also represent a compromise of conceptions with speckled being a 'blend'/mixture of the parents and dark brown derived from a conception of blend/dominance. By 'chairing' at (269) Sue again moves the focus of discussion to a new part of the tree.

270 Sa Get black because they (*** without colours
271 Su You might get a speckled because that brown and black
272 T Yes
273 Su a speckled one with orange at the bottom
274 T do we have a speckled one with orange at the bottom.... don't think we do...get those with orange at the bottom
275 Su can you get a speckled one without
276 T can you get a speckled one (**) right at the bottom
277 Su got one here
278 T and you might get one of those
279 Su Yeah definitely
280 Sa You wouldn't get a light one because look
281 T they are the same dark colours
281 T you might you might if you get a speckled one
282  Su    I think you might

In their discussion of section (5) a number of conceptions are deployed. At (271) Sue seems to be using a blending conception in which the brown and the black of the parents give rise to a speckled (Agouti) mouse. The "orange at the bottom"(273) is used to describe the tan belly of some of the mice, its significance in this context being that one of the parent mice is a black and tan. At (280) Sarah suggests that light coloured offspring are unlikely as both parents are dark coloured. The use of "dark" in this context may indicate that the dominance/blending conception is operating here. Tracey's disagreement at (281) and Sue's support for her (282) indicate the fluctuating social and conceptual environment in which ideas are expressed.

283  Su  (****) over here (**)  
284  Sa  We've got to get something to go with that  
285  T   have a grey one  
286  Su  have a grey one . a grey one  
287  T   You need two to go there....don't you  
288  Sa  that one .that one  
289  Su  let me have that one and that one there  
290  Sa  I think you would get one of these because they're sort of a mixture  
291  Su  Yeah...you might get speckled ...you might get that lighter brown sort of thing  
292  Sa  Yeah  

In discussing (6) Sarah describes and justifies her choice using the mixture/blending conception (Agouti)(290). Sue picks up on this at (291) echoing Sarah, and describing the 'speckled' agouti, adding that a "lighter brown" is also a possibility. She is apparently using a blending conception.
T now we've got these two
Su now we've got these two
T Oh you probably get a grey in there
Su oh yeah...yeah
T and a grey with a white
Su yeah
Su and you'd get
T maybe a darker brown
Su a darker grey maybe like that
T maybe darker
Sa maybe you'd get brown because you've got two different colours
Su yeah
T yeah...yes you've got two brown
Sa a dark brown
Su a darker grey maybe like that
T maybe darker
Sa maybe you'd get brown because you've got two different colours
Su yeah
T yeah...yes you've got two brown
Sa a dark brown
Su you might get a white one
T yeah.. you probably get a white one
Su you might get a white one
T we get grey with white again..grey with white
Su pop it in
T no,that's about it really,you might get a sort of darker grey dark grey
Sa probably take the light colours
T maybe and have a white
Sa maybe that
Su Yeah
T a sort of odd one
Sa Mmm
T have another white
Su have another white

All three girls compete for the floor as they discuss [7]. The content frame is weak; the blending conception is used by Sarah at (303) and this is accepted by the others as plausible. The use of "dark"/"darker" by Tracey, Sarah and Sue may indicate that the 'dominance' of darker colours is actively being considered. A less critical consensus seems to be developing during this exchange; they are still keen to have their ideas accepted but also be supportive of one another.
In their discussion of [8] Sue and Tracey agree that an albino might be introduced as a mate for one of the offspring of [7] (310-312). The girls seem very tentative about their ideas. The conception underlying their choice of light grey offspring seems to arise almost by passive acceptance. Tracey suggests a white offspring at (317) and is supported by the others. She qualifies this choice at (320) as "an odd one". It seems that she may be referring to the frequency of albinos when at (322 and 324) she contemplates the possibility of another "white one".

Discussion of [9] (327-332) very passive and uninvolved. The offspring are chosen by all three girls with little debate. At (333) Sarah suggests that the cross [10] will have "light browns". Sue seems to
agree tentatively with this choice (335) which seems to be underpinned by a blending conception. Sarah's response to Tracey's suggestion of "dark brown" offspring is interesting; she seems to be in two minds as she perhaps reconciles blending on the one hand (light browns) and 'dominance' (darker/stronger) (338) on the other. Sue at (342) seems to be in the same predicament. Tracey at (337) again refers to the frequency of white mice in response to Sarah's 'invitation' at (336). Task orientation and consensus are again much in evidence. It is interesting that the four offspring chosen at [10] are albino, light brown, brown and dark brown, representing the spectrum of shades 'between' the two parent coat colours.

5.1.1 Summary

Presented with the first task, it is Sue who takes the lead in the discussion, chairing the activities of the others. Her initial conceptions are, in common with most of the conceptions used by the girls, implicit rather than explicit. During this early period Sue uses her strong leads to 'float' conceptions and seems to be choosing offspring on the basis of a) that they look like their parents (like begets like), b) that there is a degree of phenotypic variation in the offspring, c) that siblings tend to look alike, and d) that offspring are a "mixture" of their parents. This ecosystem of conceptions is an interesting response to the 'cues' set up by cards which show phenotypically homozygous parents, heterozygous parents and parents with one offspring. The mixture conception is being used in the heterozygous situations and 'like begets like' in homozygous cases.
With respect to Sue's use of her mixture conception and in particular the term "mixture", the strong interaction frame presented by Tracey and Sue allows them to develop their own idiosynchratic understanding of this conception. Their mutual support and acceptance of each others offspring choices gives the impression that the mixture conception is the basis of common understanding. However, Tracey's mixture conception seems to be based on the idea that there is scope in the choice of offspring for a wide range of phenotypic variability; offspring are less of a colour mixture determined by the parents colour and more 'mixed up' in the sense that their colour will be unpredictable. Sue's conception of offspring variability seems to be confined to limits set by the parental phenotypes, but the competitive collaboration between the girls never exposes this difference in their conceptions as they go along with one another's suggestion without ever questioning the basis of the choice. The lack of conceptual explicitness and the nature of their interactions allows both girls to develop their own conceptions.

The differences between Sue and Tracey's mixture conceptions are exposed when Tracey presents Sue and Sarah with the apparent anomaly of two black parents having a white offspring. This is in fact an extension/amplification of the potential anomaly presented by the card itself where two black mice have a brown offspring. It is Sarah's disagreement with Tracey's albino choice that exposes and makes more explicit the difference between Sue and Tracey's notions of mixture and may indicate that Sarah shares Sue's conception of mixture and that this is the basis of her disagreement. Although Sarah seems very aware of the 'audience' around her and appears passive, this exchange
with Tracey indicates she is involved in the activity. It is worth noting that the girls do not follow up this episode with further discussion of their viewpoints, indeed the discussion is suspended by Sue who moves on to the next card. This action may act in such a way to damp out the focus of disagreement and thus maintain the cooperative relationship within the group.

Before leaving this episode it is interesting to speculate that the anomaly recognised by Sarah only became effective when Tracey exceeded the limits of plausibility of Sarah's conceptual ecosystems i.e. offspring "mixtures" determined by the parents coat colour, and some degree of variation in the offspring coat colour.

In their discussion of the card following Sarah's disagreement with Tracey, Sue seems to be supporting Tracey by using her conception of variation in the offspring phenotype. This meets with the agreement of the others and their consensus is re-established. Whether Tracey takes this as an acceptance of her mixture conception or not, she re-introduces her related notion of offspring variability. Again Sarah disagrees with her and this is supported by Sue. Interestingly Sarah seems to arbitrate with the others to re-establish a consensus in which Tracey sticks to her conception of mixture/variability and Sue operates her sibling similarity conception along with her notion of mixture/blending.

During the discussion of the next few cards Tracey and Sue seem to adapt their conceptions of "mixture" and accommodate each others ideas. Thus, neither Tracey's nor Sue's conception is refuted and both remain viable and active in their ecosystems. Sarah again disagrees with the selections made by Tracey and Sue on the basis of their "new"
conception of offspring variability/mixture/blending, she seems to be advocating the use of a mixture conception similar to Sue's original notion. She maintains this position whilst Tracey and Sue 'cement' their tolerance of each others mixture conception; Sarah seems to eventually accept this position and her disagreement seems to have little effect on subsequent offspring choices. The variability/mixture/blending conception shared by Tracey and Sue seems to have developed a high degree of explanatory adequacy.

After the comprehension task the girls competitively collaborate over the selection of parents and offspring in the final 'problem' task. Tracey introduces the 'dominance' conception with some authority almost immediately; dominance is interpreted as strength of colour, and the 'dominance' of dark colours. Tracey's choice of offspring on the basis of her 'dominance' conception cause Sue to challenge her selections. It is at this point that she makes explicit her mixture conception and the notion of blending parental colours contained within it. It is interesting that this blending conception interacts with the notion of offspring variation in that various shades of colour are possible on the basis of the parental mix. This in turn may be the basis of Sue's understanding of Tracey's variability/mixture ideas, but she seems reluctant to adapt the conception to the idea of dominance as a type of blending in which strong (dark) colours dominate lighter coat colours. Indeed it is left to Sarah to make this connection between the blending of colours and the dominance of darker colours. This adaptation of the blending conception to accommodate the notion of dominance is an interesting reflection on
how the range of convenience of a conception can be extended, and how
an existing conception is used to 'make sense' of a 'new' idea.

This episode with its contradictions and uncertainty seems to
reduce the level of interaction between the girls. Perhaps conscious of
the need to monitor the harmony of their relationships, this may again
damp out the opportunity for more detailed discussion of their
conceptions and their respective points of view.

As the discussion picks up again Sue seems to reconcile her
conflict between blending and dominance conceptions accepting Tracey
and Sarah's synthesis of the dominance and blending. Equally, Tracey's
choices of mice reflect the use of the blending conception without its
dominance component. Sarah also perseveres with her conception of
'like begets like' whilst this is going on.

During the rest of the activity all three girls seem mutually
supportive as they deploy dominance and blending conceptions. They
seem to establish a consensus on the use of blending parental colours
and dominance of darker colours; the two conceptions eventually seem
to merge with Sue and Sarah appearing to extend the range of
convenience of blending to include the 'dominance' of darker colours.
Blending/dominance becomes the main conception used by the girls in
the latter stages of the task.

Interestingly at this time Tracey introduces another conception
about the frequency of albino offspring within families. This
conception is not made very explicit but it is possible to speculate
that not only does it increase the heterogeneity of Tracey's ecosystem,
but it may also have some bearing on the tendency of the dominance
conception to produce darker colours i.e. not white. Thus Tracey's
conception of the possibility of mouse parents producing the "odd white" (albino) may not only be based on an everyday awareness of the rarity of albinos but that this conception can explain the appearance of white mice alongside those chosen on the basis of the dominance conception. Thus Tracey in this way may add to the flexibility and heterogeneity of her conceptual ecosystem as it evolves to meet the needs of the problem context.

As the girls work through the tasks, consensus and the maintenance of good working relationships seems to act in such a way as to reduce the heterogeneity of their conceptual ecosystems whether by adaptation (range of convenience of conceptions extended) or by social interactions which damp out debate and disagreement centred on the utility of conceptions. This consensus may bring temporary stability and reduced heterogeneity to their ecosystems as some conceptions are used more than others perhaps depending on their explanatory adequacy in a number of problem contexts. Acting against this trend are several other features of the ecosystem. The lack of explicitness surrounding conceptions coupled with the style of interaction in which offspring choices are 'thrown out' by the girls (competitive collaboration/strong interaction frames) perhaps as a way of experimenting with their conceptions in a social context. This strategy maintains the heterogeneity of their ecosystem by insulating its conceptions from the selection pressures associated with 'getting it wrong' in the eyes of the other girls or exposing the weakness of an idea in relation to someone else's conception(s). Even when disagreement causes a conception to be made explicit or anomaly brings it into competition with other conceptions, conceptions do not seem to be overtly
discredited, 'destroyed' or replaced. Either by adaptation of the conception (range of convenience extended) or by the suspension of debate eg. simply moving on to the next card, existing conceptions seem to be maintained in the ecosystem thus maintaining its heterogeneity. It is interesting in this respect that the blending conception seems to resonate with the girls interpretation of dominance and that this seems to result in the almost exclusive use of these conceptions in the later stages of the session. Indeed, the only other conception used is Tracey's conception of albino frequency in mouse families.

All three ecosystems are heterogeneous and are consequently highly resilient in the sense they are able to absorb change by damping out the effects of social/conceptual perturbations. However, it is interesting to observe that the girl's ecosystems are vulnerable to resonances set up by ideas from the text (dominance) which seem to amplify existing conceptions of mixture/blending. Perhaps this is achieved by giving the latter conception greater explanatory adequacy in the context of the problem or by being given more plausibility by the textual 'authority' of the dominance notion. Equally, the girls' desire to maintain positive working relationships through the accommodation of each others ideas may not only maintain the viability of ideas, and the heterogeneity of ecosystems but also allow the amplification of a conception as the other girls 'go along' with the idea.
5.2 Case Study 2.

This group of 12 year old boys, Ben, Nick and James, were classmates and friends. They sat side by side in front of a desk about twelve feet from the camera. The session was conducted in their own classroom while the rest of the class attended lessons in adjacent rooms. The first task was introduced by the researcher, during which the number of mouse offspring in a family was negotiated and the general nature of the problem was explained. The boys were asked to discuss the first card, after which the researcher engaged the boys in a brief discussion by way of facilitating interpersonal communication.

Card 1 (Grey x Grey)

12 B Right ..a black one
13 Int I'll leave you to it
14 N It doesn't have to be the same colour cause they might turn out different colour mighten they
15 J Mmmm
16 B Has to be the same colour doesn't it (no discussion for 7 seconds, the boys look up)
17 Int Just about finished with that then ..What do you think ..lets have a look before we move onto the next one..so what have you there
18 J Ehmm (laughs)
19 Int Other people have chosen them as well..what were you thinking about when you chose that
20 J Same colour
21 N Yeah .same colour
22 B same colour
23 N as parent
24 Int What about that one there
25 N Well cause I don't know.. they might be a variation of grey
26 Int What do you mean by variation..what are you thinking about there
27 N Well a different sort of grey
28 B that's brown though and that's black
29 N No that's brown
Ben is quickly off the mark at (12) as he suggests black offspring. Nick's disagreement at (14) is qualified with the implicit assumption that Ben is choosing offspring which are the same colour as the parents (Nick interpreting black as grey of parents) and that there can be variation in offspring colour. Nick presents a weak interaction frame at this point and Ben at (16) seems to restate his case for offspring/parent similarity. The boys look up at the interviewer signalling completion, effectively suspending the discussion. James says little at this stage and little effort is made by the others to involve him in the discussion.

During the interviewer's review of card 1 at (19) an effort is made to elicit James's view, he looks puzzled and not surprisingly a little nervous. At (20) he seems to be restating Ben's conception that the offspring will be the "same colour". Ben and Nick support this statement with Nick adding a qualification at (23), indicating that he may share a common frame with the others. At (25) Nick restates his idea of possible colour variation in the offspring but is unable at this point to explain to the interviewer his reasons for this although he does give a description of what he means by variation at (27). Ben questions Nick's colour recognition and its relationship to what Nick says about variation and his choices on the card (28-30). The debate is short-lived and although no explanation is offered Ben seems to accept Nick's defence.
The boys were next introduced to card 2 (Dark brown x Light brown + Dark brown offspring) and the presence of the offspring in this card explained. There was no audible discussion of this card although the boys did monitor each others choices visually. After 25-30 seconds the activity was suspended by the boys looking up at the researcher.

31 Int. Finished James
32 J Yeah
33 Int So what did you decide this time ..what did you choose..why did you choose that one for example
34 N that one
35 Int Yeah
36 N Well cause those two colours might make that sort of colour
37 B if they were mixed
38 N yeah
39 Int Yeah is that what you were thinking
40 B Mmm
41 Int James do you agree or what were you thinking
42 J (***) a mixture of these two colours all of them
43 Int Ok. Listen what I want to do now is let you see yourself and then let you get on by yourselves. (replay of session on video recorder)

Asked about his choices in card 2 Nick seems to offer a blending conception (36). His use of the word "make" is interesting and may indicate an experiential idea related to colouring, painting/mixing. Ben's support and qualification of this notion at (37) is based on mixing. James echos this at (42) in response to the interviewer's question.

Card 3 (Albino x Albino)

44 J Turn them all over
45 N turn them all over
46 J keep turning
47 B someone has taken ages to do all these
48 N well they're printed those aren't they

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After an initial period of task management and task awareness (44-53) Nick and Ben engage in an episode of competitive questioning. Ben’s choice of some grey mice seems to be at the root of Nick’s question (54) and Ben’s response at (55) seems to be prompted by the same implicit anomaly of why white mice should have grey (Ben) or black (Nick) offspring. At (56) Nick suggests that albinos are rare in their occurrence and seems to be using a conception about albino frequency. Ben’s tries make his ideas more explicit at (57) but is interrupted at (58) where Nick seems to be acknowledging what he believes to be Ben’s frame (the sameness of parents and offspring), and also qualifies his previous statement about albino rarity.

At (61) Ben manages to qualify his choice of light grey offspring. The use of “times” to mean ‘crossed with’ is interesting in terms of the relationship between ‘x’ in a genetical cross and ‘x’ in a mathematical context. It is not clear what Ben’s
conceptions are but the emphasis on "light" grey offspring (61) may indicate that he has a notion of familial similarity and offspring variability, the latter perhaps being influenced by his exchange with Nick during Card 1. Ben does not pursue the discussion and suspends the activity by indicating that they might move on to the next card (63).

Card 4 (Black x Light Brown)

65 N Black one...grey yeah get one of those...yeah that ones got a grey bottom though .try and find one without
66 B Ahh..blimey there's not..he must have just forgotten to colour it in
67 N (***
68 B Look it hasn't any but maybe if its white times white one might be a light grey
69 N that's what I've done
70 B no but light grey bottom
71 N no
72 B like his mother
73 N like one of those
74 B that one
75 N (***** don't put too many on..silly baby
76 J well they've got up to about eight
77 B they're usually quite varied aren't they
78 J eight babies
79 B so move on to the next one
80 N Don't don't don't wait ..same colour as that ok
81 B yeah I'm ready

During the discussion of this card there is much talking at 'cross purposes' between Nick and Ben. Their implicit conceptions make it difficult for them to share each others ideas. Ben's notion at (66, 68,70,72) is focused on his idea that the belly colours and main coat colour are independently capable of 'mixing'. Nick does not seem to get the drift of Ben's argument as he sticks to his own
implicit ideas. At (77) Ben maintains the strong interaction frame but seems to be offering to share with Nick the content frame related to their conception of variation in the offspring. Without further discussion, Ben signals the move to the next card at (79) suspending the debate. James plays very little part in the discussion; he seems quite happy to get on by himself without the need to talk about it. He does monitor visually the choices of the other two. James is censured by Nick at (75) for putting too many mice on the card; he defends this at (76) although this episode seems to reinforce James's isolation from the activities of the others.

Card 5 (Black x Black + Brown Offspring)

82 N  Black
83 B  black times black
84 N  equals black (laughs)
85 B  Why is that brown one in there
86 N  cause when they get brown genes might be different
      (no discussion for 1 minute boys restrict themselves to looking at each others choices)
87 B  Maybe light grey
88 N  light grey
89 B  maybe dark grey then...black times black
90 N  why would it be
91 B  don't know
92 N  go onto the next one
93 J  (********)
94 N  no it was in there already

At (82-83) Nick's completion of Ben's "times" rhyme allows him to lead strongly with his choice of black offspring. At (85) Ben seems to be aware of the anomaly presented by the presence of a brown offspring. This would perhaps indicate that his previous
conceptions of offspring variation are interactive with the blending conception, i.e. the limits of variation are set by the blending of the parental colours. It is interesting in this respect that at (89) when questioned about his choice, a plausible outcome of "black times black" is dark grey (product of parental coat and belly colours). Asked to justify this by Nick, Ben seems tentative and unsure. Nick does not seem to share Ben's notion of blending coat and belly colours. At (86) Nick's explanation using the word "genes" is interesting, revealing that he has some previous experience of 'inheritance' and 'genes', but seems unable to explain to Ben what he means by it. The discussion of this card is very tentative, and the long pause after Nick's 'explanation' at (86) seems to underline their uncertainty about their choices. Again suspension of the discussion by Nick (92) damps out further debate. The apparent anomaly of the brown mouse remains unresolved, Nick and Ben seemingly unable to articulate or justify the conceptions they are using nor share a common content frame. In describing this episode it may be that we have an insight into the inarticulateness associated with intuitive theories and the way that the lack of a 'communal' understanding affects the amount of interaction between their 'personal' conceptions.

Card 6 (Black x Speckled + Speckled Offspring)

95 J (****)
96 N Could get a black with that because that would turn into that
97 J there's a dark brown one
98 N dark brown
99 J haven't got any speckled one
100 N Oh yeah. very dark brown
101 B very dark brown
102 N that's the
103 B that's the darkest
104 N yeah that's the darkest brown
105 J What do you reckon black and grey would be called
106 N Black
107 B hey Nick
108 N black and brown
109 J black yeah
110 B yeah darkest grey..very dark grey
111 N no. but that's quite a light colour isn't it
112 B yeah I know it is but you know..yeah I know its a very light colour but its got black dots on it hasn't it
113 N Yeah
114 B Yellow bottoms
115 N Want a black without yellow bottoms
116 J dark brown with yellow bottoms
117 N there aren't any . turn some over
118 B Jamie you've gone miles ahead
119 N (*****)
120 B (***)
121 J dark grey with yellow bottom
122 B just get yellow one black one
123 N black one

At (95-104) Nick and Ben seem to re-establish a shared blending conception; the black parent's contribution to the blend manifesting itself in their debate about the "darkest" brown offspring choice.

This blending conception is used again by Ben at (112) in response to Nick's disagreement. It is interesting that Nick comments on the dilution of colour strength in the offspring as a result of the "light colour" (111). Ben's response that the black dots of the agouti parent will favour darker colours seems to be a plausible explanation of his choice and this is accepted by Nick. From (114-123) all three boys seems to be engaged in thinking out loud; this strategy has an 'experimental' quality in that offspring choices are articulated for public consumption as if to test the direction of the others thinking, to pick up on any conceptions that may
resonate with their choice, all at minimal 'cost' to their own conceptual ecosystem which remains implicit and insulated from 'error' and the need for adaptation. This pattern of interaction may enhance the resilience of their conceptual ecosystems by damping out conceptual interaction.

James is more involved at this stage in the discussion but is in fact working on card nine, out of step with the others. He is keen to help in task collaboration and makes an effort to elicit opinion (105) but is often ignored or censured by Ben in particular (118).

Card 7 (Brown x Brown + Albino)

(No discussion between the boys for 25-30 seconds)

124 J  I wonder if two dark browns make up a black
125 N  Yeah maybe ....I don't know if ..it is even might just be any old colour...could be
126 B    What
127 N  I don't know ..those colours
128 B    (***)
129 N  I don't know....dark brown
(No discussion for one minute 20 seconds)
130 N  Where are those ones without the grey stomach
131 J  without the grey stomachs
132 N  yeah
133 J  there aren't any
134 N  Oh yeah thats the one that I got wasn’t it
135 B  How are we meant to do this one
136 N  put them on...they've lost all of theirs haven't they
137 B  It hasn't got one has it
138 N  nor did the first one . yeah the first one didn’t
139 B  Look at this one there is nothing darker than black is there
140 N  No
141 J  if they've been put on they've been put on the square
142 B  I don't know
(15 seconds of silence)
143 B  Oh yeah I figure it
144 J  (***)
145 B  still on that
146 N  Yeah
(No discussion for 40 seconds)
147 B  Cor streuth
(10 second pause in discussion)
148 B are there any of them
149 J any of those grey bottoms
150 N they probably didn't do it
151 B it will just have to be grey bottoms then
152 J (*****)
153 B where...Oh no Jamie there must be one
154 B just have to use a grey bottom
155 N any dark browns
156 B only a few oh no

(50 second pause in the discussion)

157 N haven't got a grey with
158 J see what the last one is
159 B (*****)
160 N don't have to

(no dialogue for 23 seconds)

161 N are there any dark greys
162 B do you think white times white will be white or light grey
163 N could be

(No dialogue for 30 seconds)

164 N are any of those without grey
165 J No
166 B No I looked as well
167 N darker grey

(30 second pause in the discussion)

168 B I'm finished
169 N Yeah

After card 7 the discussion between the boys is increasingly fragmentary. All three follow their own conceptions in isolation and although there is some visual monitoring of each others choices they quickly get out of step with one another by determining their own pace through the cards. At (139) and (162) Ben seems to be persevering with his blending conception of coat and belly colours as the basis of offspring colour. His invitations to comment on his choice of offspring are not taken up by the others and he tends to receive tentative, rather passive responses (163). At (124) James seems to be using a blending conception. Nick's response at (125) is non-committal indeed his suggestion that any colour of offspring might be possible may reflect this
uncertainty and his own awareness of the limitations of the conceptions being used to predict the offspring. It is noteworthy that Nick's response may in fact increase the heterogeneity of his conceptual ecosystem. In spite of the task collaboration involved in finding offspring cut-outs there is little explicit discussion about their choices; they seem more intent in completing the task. It is interesting that although they may have become bored with the activity, which I doubt, this change in the pattern of interaction occurred after the anomaly presented by card 7. This may be a manifestation of the boys apparent inability to give an adequate explanation of the relationship between the parents and the offspring when the latter is markedly different from the parents. They may even be aware of the limitations of their existing conceptions in this context.

After being introduced to the reading task the boys read for 10 to 12 minutes, occasionally looking up, or whispering asides to one another. Again there was the feeling that this was a pattern of behaviour very close to the expectations of a classroom situation when they are given "reading to do".

170 B What are genes
171 N Eh
172 B Genes...what are they
173 N they are things inside you
174 B Oh
175 N see they're inside you ..they could be like our hair..
might be ...what
176 J (***) biological
177 N Biological
(all three read in silence for 25 seconds)
178 J bits it says ..by parts of genes
179 N no genes are things inside you though ..not they are part of you
180 J no. what is this
like people
people have probably got genes ...cause like black parents won't have a white child will they
No but it says (***) will receive one gene from the father and one from the mother making up a pair of genes
well then its not inside the body is it

In response to Ben's inquiry about genes (he may have remembered Nick using the word earlier) Nick qualifies what he has read with his own previous understanding of genes (173,175). The disagreement that develops between James and Nick about genes (178-186) seems to be based on Nick's previous knowledge of genes as being inside the body (in cells perhaps) and James's understanding of the text when it refers to the transmission of genes (in sperm and eggs) during reproduction, which James sees as genes going out of the body. Interestingly, this 'misunderstanding' gives Nick at least the opportunity to articulate his understanding of genes and his anecdote/example at (183) provides an interesting insight into the sort of social experiences that he may be using to support his conceptions. This particular idea that "black parents won't have a white child" may have some bearing on his previous responses in terms of the effectiveness of the anomalies presented by the mouse families with offspring with no parental similarity. Ben is supportive of Nick during his discussion with James to the extent of gently ridiculing James's inability to see the point (182).

The boys read on for about 7 minutes, whispering asides, occasionally looking up, but mainly reading the text in silence. They stopped reading at the same time and signalled their intention to move to the next activity by closing over their texts.
and "sitting up straight". Indeed the general pattern of behaviour
during this task seemed to be very much influenced by the
'traditional' style of classroom reading/private study.
The boys were familiar with the format of the family tree problem
and after a brief resume of the "rules" they began the task on
their own.

187  B  don't do black
188  N  why not it's an easy one
189  B  it's the wrong colour
190  N  it is it gets black
191  B  oh yeah you get black
192  N  black
193  J  can we kneel on the chairs
194  B  make it neater
195  J  is it ok if we kneel
196  B  will it be another black do you reckon
197  N  Yeah Mmm...we've got to do that one now
198  J  Grey
199  N  ok let's have two grey
200  B  it's unfair really we could do them all easy ones like
we could do grey times grey or black times black all
the way through it (awareness of researcher)
201  Int  Its up to you
202  N  dark grey did it say you could get
203  J  You can
204  N  no like that
205  J  No
206  N  can we look back in the book
207  B  white grey mice
208  N  mice with coloured coats albino mice they have got
209  B  they have
210  N  no it could be this no it won't be grey mice they
haven't told you
211  B  where
212  N  that they haven't got grey mice
213  B  yeah they have
214  N  (***)
215  B  it will probably just be grey Nick if if black times
black is black it must be grey
216  N  might as well do it dark grey then
A strong interaction frame is presented by all three boys. Ben seems aware of task strategies at (200) and it is interesting that "easy" selections are based on his 'ritual' ("times") conception. This implicit idea seems to be one of 'like begets like' or the blending of identical parents (215). Ben’s attachment to this conception and his continuous use of it to guide his choices may be an ongoing attempt to test its adequacy and utility. Indeed it may be part of an increasingly stable ecosystem of conceptions with a high degree of explanatory adequacy.

The literary experience of reading the text appears to be the basis of the discussion at (202-213) as the boys seek to authenticate/validate their choices. When compared to James, Ben is much more facilitatory in his collaboration with Nick.

217  B  so lock you've got those two now
218  N  you would get black wouldn't you because that's dominant over that
219  B  Oh yeah
220  N  yeah black..black black
221  B  and ...right got now to find a mate for this one as well
222  N  no do the other one first
223  J  what about that there
224  N  Mmm do another black
225  J  (***)
226  B  its lighter though isn't it
227  N  No . its lighter you wouldn't
228  B  if anything darker colours
229  N  a darker grey or
230  J  what if we put a lighter colour there
231  N  (***  dark grey
232  J  What if we put a lighter grey ..what about if we took ehm . put a lighter grey there and a darker grey there ...
233  B  You're just trying to make it more easy
234  N  put that one there ..where is that darker one
235  B  have a look at these there might be more
236  N  we need a dark grey one
237  J  dark grey pull it out there
238  N  that's not a dark grey one

- 199 -
At (218) Nick introduces the notion of 'dominance' into the discussion. He and Ben develop a consensus about choices centering on the 'dominance' of black coat colour. They emphasise the dominance of darker colours (228-229) as they develop their shared frame. It is interesting to speculate that their conception of 'dominance' as gleaned from the text is associated with the notion of strength of colour and the outcome of blending light and dark colours. Dominance as interpreted by the boys existing conceptions may be simply an amplification of an existing conception which resonates with their 'understanding' of the text information.

James's efforts to have his ideas accepted are not facilitated by the others as they extend their own ideas of dominance. At (234-243) it is worth noting that Ben and Nick have decided that the introduction of a black mouse in the cross will have definite consequences and that this action will produce more black offspring.

239  B  its not going to be dominant is it
240  N  no its not well
241  B  because its
242  N  we could do another black
243  B  we'll do another black
244  N  there aren't any more blacks
it will be black again won't it ..do you reckon it will be black because that's the dominant colour

I don't want to carry on doing black do it properly

you have to...it will be black again..I'll find some black....there are three..there and there.there's black

there's one black

what else do you want

there's two blacks ..I've got hundreds of blacks on mine

Black black

they'll all have to be blacks

Oh all right how many one two three black . nine blacks

well they'll be a family

No no we need one from here..we can't get a darker colour than that we are just carrying on doing blacks

Mmm

there you have some blacks

that's going to be dominant all the time

well it will just have to be blacks all the time won't it

From (245-262) the boys come to the growing realization that the family tree is made up of black mice and that this is the ultimate outcome of their strategy. Nick seems to have reservations that they are doing the problem "properly" (257) it may be that the uniformity conflicts with his expectations. Ben seems to be more realistic and seems able to convince Nick that they have no choice but to have black mice (263-4). Nick's correction of Ben at (266) indicates his awareness of black as the ultimate colour in terms of 'dominance' and colour 'strength'. Ben seems to be able to reconcile the number of black mice chosen by saying that they are after all a "family" (265). This may reflect on his previous conception of familial resemblance.

it will just have to be blacks all the time

oh no boring

let's start again

I'm not starting again

- 201 -
The reservation of Nick about the effects of 'black dominance' are raised again. At (276) Ben points out that having used a black mouse early on in the tree was a 'mistake'. Nick's reply at (277) restates the effect of dominance on later generations. It is interesting that the effect of dominance on their choices is seen by Nick and James (275) as a problem and it may be possible that such a phenotypically uniform tree conflicts with their existing conceptions and expectations.

279 N  oh no
280 B  let's start with light colour now
281 N  right .right not a black were not having a black
282 J  but he's got a yellow bottom..who owns him
283 N  that's going to be dominant over that isn't it so we're going to have those bee's (sic) again
284 J  oh no
285 B  we'll just get a darker colour won't we
286 J  oh no..what about one of those
287 N  no you couldn't no
288 J  might
289 B  Yeah its an idea Jamie .excellent idea
290 N  we've got no
291 B  Jamie Jamie we need one of those with a white bottom
292 N  why wouldn't you get black on it
293 J  look Jamie's about to solve the problem
294 B  look that's the only light darker colour that the darker colours
295 N  How would you get black though
296 B  if you know what I mean
297 N  how would you get black on it ..why would you get black on it
298 B  we're not just choosing one
299 N  you are stupid..its not logic
The boys decide to try again with the aim of not including black mice in the tree (281). They remove all previous choices from the board. At (283-285) they realise they are repeating their previous efforts. James chooses an agouti mouse at (286) as a compromise, this type having both light and dark colours in its coat. Although supported by Ben, Nick is very critical of this choice (299). Their activities are increasingly task orientated.

300 B we need a very dark brown
301 N we need a very dark brown ..we get another and get one of those with a white
302 B what do you want I'll find it
303 N do a darker grey it will be easier
304 B it will get darker and eventually end up with black well we'll just use black for them all
305 N put one of those. now what happens..dark brown dark brown
306 J don't panic my son..look I got a dark brown
307 B it'll be dark brown
308 N yeah pretty logical. get another dark brown..we need a dark brown there and a dark brown there..we need a dark brown there..dark browns are pretty popular

In spite of trying again the boys are once more faced with the 'dominance' of dark brown mice. Ben at (304) seems to be aware of the effect of dark colours in their crosses. In fact they end up in the same situation as before in which the family tree becomes increasingly dominated by dark colours, although this time it is dark brown mice (308).

309 J dark brown
310 B it'll just have to..cause if you change that it'll mess the whole thing
311 J there's another dark brown
312 N right dark brown
313 J there's a dark brown
314 B there will just have to be a third dark brown
we can put some blacks into it
here's another one
there are too many dark browns in it
well there's not going to be anything else unless the book is lying
now what we need
the book could be lying
this just follows the book rules doesn't it

Task orientation increases with all three boys collaborating in their 'hunt' for dark brown mice. There is a 'fateful acceptance' of the constraints imposed on their choices by the 'dominance' notion. Nick (317) is still critical of this homogeneity; James suggests that black mice could be used (315) but this is ignored, perhaps because it takes them back to square one. Ben's response to Nick's doubts about the number of dark brown mice in the tree is interesting in that it may be an insight into his acceptance of textual authority (318,321). James's suggestion that the book "could be lying" is ignored in spite of the fact that it might have opened up new lines of thinking. Perhaps a book lying is not particularly plausible.

5.2.1 Summary

The cognitive and social interaction between Ben and Nick is an early feature of the session. There is a collaborative style to the activities of these two boys as they present reasonably weak content and interaction frames. Ben seems eager to initiate and lead the discussion but is deferential to Nick's ideas. Both boys develop a conception of 'like begets like' in homozygous crosses
but it is interesting that in their discussion of card 1, Nick qualifies this during a disagreement with Ben about the notion that there will be some variation in the offspring. The content frame of this disagreement is weak with the 'variation' and the 'like begets like' conceptions remaining implicit. Aware of this disagreement both Ben and Nick establish a consensus around the use of a blending conception for offspring choices in card 2. This consensus orientation is a characteristic of their interactions and by card 3 Ben seems to be using Nick's conception of 'variation' along with the 'like begets like' conception. During their discussion of this card Nick elects to use a black offspring, which appears to present an anomaly to Ben who disagrees strongly with this choice. In terms of the conceptions used by Ben up to this point his disagreement is understandable, although his challenge to Nick's choice is only supported by his 'ritual' statement "white times white". This disagreement allows Nick to support his choice of a black mouse indirectly by referring to the rarity of albino mice. This exchange increases the heterogeneity of Nick's conceptual ecosystem, however, the boys do not sustain their debate and Ben suspends the discussion by moving to the next card.

Ben and Nick seem to develop a consensus again in the next card, however the strong interaction frames presented and the implicitness of their conceptions gives Ben the opportunity to develop the blending conception to include the coat and belly colours of the parent mice. Nick seems to understand this in terms of his conception of variation in the offspring and goes along with Ben without really understanding what he is getting at. Talking at
cross purposes in a collaborative environment may very well allow conceptions to develop.

At card 5 Nick exhibits his awareness of Ben's conceptions by supporting his conceptions and by using Nick's 'rhyme' of "black times black". Ben and Nick seem to have established a set of shared, interacting conceptions focused on blending, familial similarity, and colour variation in the offspring which in turn may represent an area of conceptual stability within their respective ecosystems. It is possible to speculate that stability in these terms may be a social factor related to consensus, agreement and collaboration, whilst in conceptual terms the inter-dependance and interconnectedness of conceptions within individual ecosystems may also contribute to a decrease in the heterogeneity and resilience of ecosystems. During the boys discussion of this card Ben becomes aware of an anomaly presented by the brown coloured offspring. This is an insight into his notion of offspring variability which seems to be set by the parental colours and the 'shades' of colour produced by blending. It seems that this may be the basis of the anomaly's effectiveness. Nick's explanation of "genes" does not seem to be adequate and although Ben and Nick make an effort to come up with a plausible explanation, the discussion is suspended as they decide to move on, perhaps dissatisfied with the knowledge that their present conceptions are inadequate. In their efforts to resolve the anomaly the fragmented character of the discussion is marked by silences and pauses; this is an interesting reflection on the possible absence of a 'communal' element to their personal understanding of the problem and the inability of Nick in
particular to make 'public' his conception of "genes". Conceptions may need this communal dimension if they are to have any utility for the individual and have any worth within his conceptual ecosystem.

Ben and Nick establish a consensus in the next card. Perhaps they are aware of the need to maintain their collaboration for although they compete to have their offspring choices accepted they seem to be sharing a common frame based on their blending conceptions. This consensus may result from their inadequate explanation of the anomaly and may reflect the need for the boys to re-establish the communal worth of their conceptions.

Card 7 presents the boys with the same problem card as 5. Again the dialogue fragments as they come to terms with the anomaly of the white offspring from brown parents. Long silences punctuate this episode. James for the first time, using a blending conception, makes an overt suggestion as to offspring colour. Nick seems to imply in his conception that offspring can be highly variable, the inference being that the colouring can be very different from the parents. It is interesting that this situation has brought James into the discussion and has encouraged Nick to add to the heterogeneity of his ecosystem. Nick's conception is not supported and he himself seems very unsure about it. Once again the discussion is suspended by moving on, with the 'problem' unresolved.

The remaining cards are discussed in a very fragmentary way with the boys largely following their own ideas. Task completion
seems to be the main consideration with little discussion and the use of strong interaction frames and implicit conceptions.

After completing the comprehension task the boys began on the third and final 'problem'. They seemed to have a very good awareness of the nature of the task and much of their activity was focused on the completion of the problem. Initially Ben uses his 'ritualised' "black times black" and its related conceptions as the basis of his choices. He sees this as an "easy" strategy and this may reflect on the confidence and stability of his ecosystem. Nick and James seem to accept Ben's leads on this basis, but when Nick qualifies their choice of darker and darker offspring with the notion of 'dominance', this idea becomes the only conception to be used in offspring selection. Nick's understanding of dominance has developed from his blending conception in which 'dominance' is understood in terms of strength of colour. The uptake of this conception by the boys and its apparent resonance may reflect its plausibility and intelligibility with existing conceptions. This factor, possibly coupled with the dissatisfaction generated by anomaly, may explain the impact of the dominance notion on the boys' ecosystems and its almost exclusive use for the rest of the activity. In conjunction with their inability to resolve the anomaly of dissimilar offspring, Nick's use of an everyday example during their reading of the text (black parents won't have a white child will they), may represent lay knowledge at the centre of the anomaly.

The boys' exclusive use of the dominance notion is initially fruitful as the basis for offspring choices. However, there is a
growing awareness that by the fourth generation in the tree all of
the mice are black and that all subsequent 'crosses' will be black.
Ben in particular seems to be uneasy with this outcome. It is
possible that the uniformity of the offspring conflicts with their
expectations of what family trees should look like. When they try
the problem again they end up in the same predicament this time
with dark brown mice. The 'extinction' of their previous
conceptions and the exclusive use of the dominance notion is very
interesting in terms of it producing apparently stable homogeneous
ecosystems. It is possible to speculate that the boys' conflict and
dissatisfaction with the outcomes of using a dominance conception
may facilitate the continued appraisal of its worth, and in fact
enhance the metastability of their conceptual ecosystems.
This group was made up of three 12 year old girls who were friends and classmates. The session took place in their usual teaching room whilst other class members attended lessons in adjacent classrooms. Justine, Julie and Scotty sat side by side about twelve feet away from the camera. They appeared to be relaxed and confident from the outset of the session. The first task was introduced by the researcher.

Int. 1 What sort of size of family do you think mouse families have
Jus 2 About eight
Jul 3 eight babies
Jus 4 eight young
Int 5 maybe not as many as that
Jus 6 around about six
Int 7 Ok five or six
Jus 8 what just to go with that
Sc 9 just to go with that
Int 10 Yes these are the parents and they've lost their family
Jus 11 just like that
Jul 12 little bo peep has lost her
Jus 13 a bit light
Int 14 try and give each other an idea of what you are doing so the others know why you've
Jus 15 is that brownish. that's brownyn
Sc 16 they wouldn't all be the same
Jus 17 they would they would sort of if
Sc 18 there's the two parents
Jus 19 they would not
Sc 16 sort of colour
Jus 17 well if the two parents were the same
Jul 20 if one was white and one was black they might be
Sc 21 black and white
Jus 18 Yeah
Jul 22 yeah
Sc 23 they might not be the same
Jul 24 well look..if you've got a black mum you're not going to turn out...you'd be a bit black
Sc 25 Yeah you do
...Yeah you're not going to be red, yellow are you
I'll be pink instead......cor
(inaudible)
Your pink...pinker now
are you doing all the same colours
I'm doing some light and some...
cos they're so often the same .
will they
They wouldn't...some of them would have a lighter
colour
(***)
Oh can we swap that one for
this one....there we are
Yes it so (****) ..makes pretty patterns
let's see how you are doing
there's only four Julie
so what have you got
Oh that one doesn't have a back on
what have you got there
I've got the same as Justines. but we haven't been
copying have we
we've all got the same
the same
except for our spacing
why have you chosen these
Well because
same as parents
They'd be the same .same type so the
same
so the babies look the same
Yeah
if they were a different thing they would be sort of
different

Card 1 (Grey x Grey)

The session began with the interviewer and the girls negotiating
the numbers of mice in a mouse family. Julie's nursery rhyme
response to the cueing of "lost" babies giving an indication of the
relaxed style of this group from the outset. At (16) Scotty
disagrees with Justine about the latter's choice of identical
offspring. Scotty seems to be implicitly using a conception of
colour variation in the offspring. A strong interaction frame is presented by Justine and Scotty as they disagree. Justine appears to be challenging Scotty's conception of variation with her own notion of 'like begets like' (19). There is a ritual feeling to their disagreement and in part the girls look as if they are giving a bit of a performance for the camera/researcher. Nevertheless, Scotty's challenge has made Justine's conception a little more explicit. At (20, 24 and 26) Julie seems to be arbitrating in Scotty and Julie's disagreement by using an example of 'like begets like' but with parents of different colours. This allows her to use a conception which seems to be an adaptation of 'like begets like' and which includes the notion of gender similarity between mother and daughter. This is a compromise which supports the notion of 'like begets like' but reconciles it with the possibility of offspring variation when the parents are heterogeneous. Her use of anecdotal/experiential examples and the appeal to 'common sense' - "you're not going to be red" - is particularly interesting in terms of the integration of conceptions and the appeal to the plausibility of these notions (26). The 'joky' episode (27-28) about "pink" and blushing/embarrassment may diffuse some of the 'antagonism' of the previous exchange. The perturbation set up by disagreement has allowed Julie to enhance the heterogeneity of her ecosystem in her role as arbiter. Scotty at (23) seems to be holding on to her variation conception and from (30-35) she and Justine disagree again as they challenge each others conceptions. Interestingly by the time the girls come to discuss their effort with the interviewer they all have identical choices. At (50-51)
Julie is quick to use the 'like begets like' conception in response to the interviewer's question and she is apparently supported by Scotty. At (54) Justine seems to be reiterating Julies conception of gender similarity used at (20). Scotty's variation conception is not offered as a justification for their choices.

Card 2 (Brown x Black + Brown Offspring)

55  Int   Ok let's put these in front of you and look at the next one
56  Jus  Aha.Hah
57  Int   there you are
58  Jus  yes
59  Int   (description of format of card)
60  Jus  that's one .....would you get them sort of mixed as well maybe
61  Int   What ever you think..its entirely up to you . there's no real right or wrong answer.there's just how you think you see the problem ..see what the others think
62  Sc   This is nice.....oh yeah
63  Int   work together
64  Sc   Julie if there was a dark one and a light one
65  Jul  What
66  Sc   a light would be darker
67  Jul  gee that's a point
68  Int   How are you getting on
69  Sc   Justine's she (**) look get a darker one Justine
70  Jul  yeah
71  Sc   because a dark brown and a light brown they mix together
72  Int   what do you mean by mix
73  Sc   well there's a light brown and a dark brown and when you mix light and brown it would make a darker light brown
74  Jul  If you mix black ...if you mix black and white together you get grey
75  Sc   and that a lighter black
76  Jus  and it might happen with mice..put mice together in a pot
77  Int   it might..I don't know
78  Jul  I thought we would be handling real mice
79  Int   oh would you like that
80  Jul  Yes
81  Int   yeah..but they get really upset when they are handled too much
82  Jus   I like mice I think they are sweet
83  Int   I'd like to but you wouldn't be able
84  Jus   to afford all the mice
85  Int   for this number I would need a mouse farm wouldn't I..how are we doing
86  Sc    yeah
87  Jus   that's my selection
88  Jul   I haven't done one yet I'm trying to find
89  Int   do you think there are a few more
90  Jul   no I'm trying to find one that's got that colour stomach with brown dashes on it. multicoloured
91  Sc    what do you mean ..like that
92  Jul   Yeah without the grey stomach
93  Sc    would there be one
94  Jul   a grey tumach (sic)
95  Int   see if there are any
96  Sc    maybe
97  Jul   they've all got grey stomachs or orange stomachs it must

At (60) Scotty leads the discussion of card 2 with the notion of mixing. Perhaps remembering Julie's example of black and white parents previously she elicits Julie's support at (64) and goes on to elaborate and make explicit her blending conception (66,69,71 and 73). Julie supports Scotty's ideas, returning to her example of black and white parents (74). It is interesting that using the same exemplar Julie's conceptions of 'like begets like' and blending have mutual tolerance and that she apparently sees no conflict between them in this situation. At (76) Justine makes explicit her perceptions of what the other two are doing in terms of the blending conception. Her reference to "it might happen with mice..put them together in a pot", highlights the similarity between their experience of mixing paint/colours and the blending conception. Her sceptical use of this analogy externalises and gives an insight into the process of extending the range of
convenience of existing conceptions (painting/colour mixing), their colonization of new situations and how existing conceptions can be used to make sense of the 'new'. Interestingly, Scotty and Julie seem to ignore Justine's perception of their blending conceptions, perhaps all three are aware of the analogical element in the blending conception, but whilst recognising its fruitfulness in the problem context they are aware that it is different from painting.

Card 3 (Albino x Albino)

98 Jul  B ee
99 Sc   You're only supposed to have four
100 Jus four there's my four
101 Jul I can't count
102 Jus when your finished
103 Jul You just sort of throw it away

The discussion of card 3 was very restricted, all three girls found four albino mice from the pile and then moved on. Perhaps this is an indication of their shared frame and the consensus born out of it, or the uncertainty which now surrounds the painting analogy after Justine's 'revelations'. The conception being used is not obvious with the content frame being weak. This level of implicitness may keep the girls options open whilst insulating them from error in a competitive interpersonal environment; in terms of maintaining the integrity of their conceptions (explanatory adequacy, plausibility) this may be one way of achieving a 'low cost' consensus.
Card 4 (Black x Brown)

104 Sc  Right now we'll all decide. Oh look at this one this one Julie look
105 Jus  Its going to be
106 Jul  oh no we've still got the same problem..its all done in the worst possible taste
107 Sc  look they've all got white stomachs the ones on the basic cards
108 Jul  what's the point
(pause in the discussion for 10 seconds)
109 Jus  you need a brown one with a white
110 Jul  keep it to four its easier
111 Jul  (###)
112 Jus  we will
113 Sc  what about this grey colour
114 Jus  No I don't think so. I think that will be that that's all because

Scotty is very keen to motivate and chair the activities of the others (104,113). It seems that the girls have lost their way a little; their conceptions remain very implicit and they seem content to make their choices without discussion. Audience awareness (camera) during this episode may have combined with the general uncertainty about the task and the adequacy of the painting analogy, (106) to produce this rather distant, detached level of interaction. At (113-4) Scotty and Justine compete for the floor but the basis of their disagreement over the grey colour remains implicit.

Card 5 (Black x Black + Dark Brown Offspring)

115 Jul  I've done it..black times black would be
116 Jus  black and black equals black look there's one
117 Jul  oh look we aren't on TV anymore
118 Jus  oh we're probably (******) I don't know
119 Jus  (**) they've got brown on theirs that must mean they have a brown baby
120 Jul  I haven't got a brown one

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well yours hasn't had a brown baby has it

Sc has yours got one Justine
Jus Yes
Sc so has mine
Sc that must be the square one that you found must be the one for Julie
Jus no that was mine..you gave it to me
Jul Pinow......w (makes a noise)..I reckon we're still being recorded but not on the screen
Jus Yeah
Jus so we can't pose in front of you
Jul Poseu........rrrr (laughs)
Jus it has to be dark brown with black on it
Sc hey this one..it doesn't really matter about the grey stomach
Jus its a bit light a bit light
Jul (#####) too light
Jus too light
Jul and a grey
Sc Grey
Jus Yeah yeah
Jul It might have had a white grandfather
Jus grey one
Jul yeah black times black equals.....red
Jus and if they've got brown
Jul they might have had a grey grandfather
Sc What about having one like this
Jus its a bit too light
Sc this
Jus its a bit like black
Sc have you got four on yours Justine
Jul Pinow......w I have
Sc and there's one for you Justine
Jus I'll have another black one, black one black one
Jul Pinow......w
Sc right next one folks

At (115 and 116) Julie's solution to the "problem" (perhaps their uncertainty about paint mixing as an analogical base to their conceptions) seems to be the use of a 'mathematical' analogy based on the 'times' sign between parent mice. Justine seems supportive of this lead although she seems to be 'adding' black to black to "equal" black. This 'new' analogy may in some way give their choices renewed plausibility as long as it is not 'exploded' again.
At (119) Justine seems to be using a conception of sibling similarity and at (131 and 133) a blending conception involving parents and offspring. It is interesting that Justine makes no comment about black parents giving rise to brown offspring. Scotty seems happy to facilitate task activities and lend support to Justine.

At (136) Julie's "grey" choice of offspring may indicate that she is aware of the potential anomaly presented by card 5 perhaps in terms of her previous 'like begets like' and blending conceptions. Scotty's questioning of her choice (137) allows Julie to elaborate her conception of grandparental influence and make it more explicit. Interestingly the origins of the grey offspring chosen by Julie seem to be in a blend of "a white grandfather" and a black parent. At (141) Julie may be questioning the utility of her "black times black" notion by mocking it; at (143) she again offers the grandparental conception but it is not supported by Justine or Scotty who seem to be continuing their collaborative competition focused on a blending conception (144-7). Shortly afterwards Scotty suspends the discussion by chairing and signalling the move to the next card (153).

Card 6 (Black x Speckled + Speckled Offspring)

154 Sc  Ah they've got a speckled one
155 Jus  Ah they've got a speckled one ..and it hasn't got any grey stomach
156 Jul  that's pretty peculiar don't you think
157 Sc  It might have a grey stomach because there's a black
158 Jus  Yeah and they might have a black with an orange stomach from the orange in that one
159 Sc  Yeah good idea

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160 Jul  don't see any orange
161 Jus  no well the orange came from there
162 Sc  and then they'd
       ..have maybe a dark brown one like that yeah
163 Jus  dark brown definitely dark brown
164 Sc  How many have you got Justine
165 Jus  three four five
166 Sc  I'm only putting four on....what about a grey one
167 Jus  right I'm getting one of them
         (Scotty and Justine move on to next card)

Scotty and Justine seem to 'cement' their collaboration during this
episode. They present strong interaction frames to one another and
seem to be sharing a content frame of blending conceptions (162-
167). The emphasis on dark brown (162-3) perhaps indicates the
influence of the black parent in their offspring blend. Julie's
questioning of Scotty's choice at (160) is defended by Justine;
Julie seems peripheral to the consensus developing between the
other two girls.

Card 7 (Brown x Brown + Albino Offspring)

168 Sc  Hey Justine look its got a white one
169 Jus  Eh..that got a white..they must have some cross-
breeding...wrong couple (laughs)
170 Jul  They're grandfather (laughs) was you know
171 Jus  I think they'll have a grey one
172 Sc  white and light grey..maybe a speckledy one
173 Jus  one as well. because as they get white
         or a lighter
174 Sc  a speckled one as well
175 Jul  this is like mixing colours you know
176 Sc  there you are what about a speckledy one
177 Jus  yes that's about right
178 Jul  do you think they'll have.I think they'll have Mmm.
179 Sc  thats about it..got the same Justine
The discussion of card 7 starts with Scotty drawing Justine's attention to her observation that brown parents have had a white offspring (168). This may represent an anomalous situation for Scotty in the context of the conceptions she has used to date, and it is possible to speculate that the effectiveness of this anomaly may have a great deal to do with the albino condition. This cannot be easily explained in terms of blending, 'like begets like' and/or variation conceptions in which the parental phenotype is the yardstick which determines the colour of the offspring choices.

Justine's response at (169) uses the description "cross-breeding" a term that she may associate with her experiences of domestic animals with mixed parentage or with a high degree of phenotypic variability. The others do not pick up on this phrase, however Justine's qualification of "wrong couple" and its inference of infidelity triggers a series of embarrassed looks and laughter among the girls which effectively diffuses the impact of her contribution. Julie reintroduces her conception of grandparental influence with humorous overtones and perhaps racial inferences (170). From (171-176) Scotty and Justine seem to be using a blending conception as the basis for their choices. Scotty seems keen to develop a consensus with Justine within the context of their strong interaction frames. It is interesting that Julie seems to be monitoring their activities and 'confronts' them with Justine's earlier 'revelation' about "mixing colours" (paints) (175). This contribution and Julie's next effort to elicit information (178) seems to be ignored by the others as they accelerate their consensus and Scotty suspends the discussion. Task
orientation/completion may now be the main priority with the most fruitful and unambiguous conceptions being deployed in spite of any uncertainty about their plausibility in novel contexts. Again the possibilities of conflict produced by anomaly situations, which may set doubts in the minds of the girls about the adequacy of their blending ideas, are damped out by the heterogeneity of their conceptions and perhaps their reluctance to abandon something that 'works' at a personal and social level.

Card 8 (Agouti x Agouti + Black Offspring)

180 Jul then look at the next one
181 Jus I think they'll have one of those again. I think
182 Sc speckedly and speckedly and a grey one ..they've got a grey stomach
183 Jus and a grey one yeah if they've got a dark grey one
184 Jul a grey stomach maybe
185 Sc what. a grey yeah if they've got a dark grey one
186 Jus a dark grey one alright
187 Jul I'd say a light grey one
188 Sc Oh yeah
189 Jus light grey one
190 Jul everyone's agreeing..let's have a white one you know
191 Jus no. I think they'll have that one again because they've slightly lighter
192 Sc You're going on the wrong
193 Jul I'm not (****) ehm
194 Sc a black one with a
195 Jul what about yeah what about
196 Sc what about this ..a brown one
197 Jul let's ask the mice
198 Sc have you got a black one with a orange stomach
199 Jus Yeah I reckon
200 Sc no I don't think so
201 Jus I do because (****) black with that bit of orange
202 Sc black is yeah and then yeah...have you got any white ones on yours
203 Jus I've got four
204 Sc I've got four one two three four oh yeah
205 Jul I've got four
206 Jus Oh you
207 Sc just copy Justine
Scotty and Justine actively compete for the floor as they competitively collaborate over the choice of offspring. They seem more concerned with the harmony of their working relationship than with the reasons for their choices. Consequently the content frame being used is very weak. Julie at (190) is conscious of the uncritical consensus between Scotty and Justine but her efforts to disturb this are censured (191-2), (206-7). Julie seems frustrated by the closed cycle of leads and acceptances inherent in the other girls' collaboration.

Card 9 (Grey x Black)

208 Jus Oh grey
209 Sc some grey
210 Jus does it have a grey one
211 Sc yeah a dark grey one
212 Jus a black one
213 Sc and a dark grey one
214 Jus a dark grey a very dark grey
215 Sc Yeah
216 Jus maybe a white one . they might have a white one
217 Sc I wouldn't have thought so
218 Jul I don't think so no
219 Jus No
220 Sc what about one of those speckly ones shall we put on a speckly one
221 Jus no there isn't any brown in the family though is there
222 Jul or any orange
223 Jus I reckon they've sort of
224 Sc they've got a lot of grey
225 Jus I reckon they'll have a browny grey
226 Sc yeah and then what else..what about these
227 Jus well no
228 Jul I've got three different shades of grey I've got three different shades
229 Jus a black
230 Sc Yeah thats it ..thats right
Justine and Scotty continue their active collaboration during the early part of the discussion (208-15). They seem to be using their conceptions of blending, the black parental contribution giving rise to the stress on "dark" colours (213-4). At (215) Justine tentatively suggests a white offspring. She may be revisiting her ideas of cross-breeding or imitating the situation in card 7. Scotty and Julie offer no support for this suggestion (217-8) and Justine seems to accept their reservations without challenge.

At (221) Justine qualifies and gives authority to her rejection of Scotty's choice by using the notion of traits running "in the family". This is an interesting overlap of lay science and the conception of blending being used by the girls. It may be that a blending conception constrained in terms of offspring phenotype by the parental inputs can be validated by reference to family traits.

Once again Julie seems to be providing a metacommentary of the others' activities; at (228) she makes explicit the blending conception being used by making explicit the "shades" of grey. Julie may still be uncertain of the applicability and the plausibility of this conception.

Card 10 (Black x Brown + Black Offspring)

231 Sc Oh look they've got orange stomachs
232 Jus oh orange stomachs
233 Sc there's a speckly one definitely
234 Jus and one of these as well...a speckly one
235 Jul no call them thrushes its easier
236 Sc two black ones with an orange
237 Jus Oh well right two black ones
238 Jul are we still being filmed..oh no
239 Jus thats what I've done...right next one
Card 11 (Brown x Brown + Light Brown)

240 Jul what have you done that I wouldn't like to say
241 Sc that and that that and that
242 Jus two brown and two light brown
243 Sc Julie can I just have a look at yours
244 Jus they wouldn't have an orange dark
245 Sc what about dark brown with a white stomach
246 Jus no a light brown with
247 Sc dark brown dark
248 Jus yeah dark lightly dark ones
249 Jul look I've got three different shades of brown
250 Sc yeah one of those
251 Jus right next one

Card 12 (Agouti x Albino)

252 Sc oh last one a speckly and a white
253 Jul and a white one
254 Sc and a white
255 Jul speckly one I reckon grey
256 Sc grey
257 Jul I don't
258 Jus I do cos its got a grey stomach
259 Jul I'm having that cos thats got a grey stomach
260 Sc Yeah and that that's it
261 Jul We've done it
262 Sc that's it
263 Jus we've done it

In the discussion of cards 10, 11 and 12, strong interaction frames are presented by all three girls. Task completion seems uppermost in their minds, and their conceptions become increasingly implicit. Competition for the floor, collaboration, and competition to have their choices accepted result in a cycle of leads, acceptances or transient disagreements followed by more leads. Julie continues to be rather sceptical about the whole activity and she seems removed from the enterprise. Justine and Scotty maintain their
collaboration and are slightly reproving in their interactions with Julie. Although the content frames being used in the discussion are very weak it is possible to speculate that the like begets like and blending conceptions and their analogic underpinnings are the basis on which Justine and Scotty's consensus is built. These conceptions may have achieved a degree of stability derived from their fruitfulness in maintaining interpersonal relationships and giving answers to the 'problem'.

Following on from the first task the girls were now asked to read through the text material. They tended to read out loud and together; giving a bit of a performance at the same time.

264 Jul genes...yes you know things you put on
(silence as girls read 10-12 seconds)
265 Jus the gene which black colour (**) brown
266 Jul why has it got an orange spot on it
267 Jus oh if there's a brown if there's a parent that's black yeah and a parent that's white
268 Sc children be grey
269 Jus will be black because the black is the stronger colour
270 Sc strongest colour...but not all of them will be black
271 Jus it would be black
272 Sc black and some of them may be grey because they made one (*** way..Mmm
273 Jus the black gene is stronger..this one . this one is just then the brown gene
274 Sc yes I know but this ..are they could be the same type of ..Mmm
275 Jus same same black one..that might be because it has black in it..it will be
276 Sc the same weakness or strong sort of
277 Jus I think these others these
278 Jul Yes I quite agree (laughs)
279 Sc where am I
At (267) Justine reads from the text, Scotty picks up the "a parent that's black yeah and a parent that's white" and completes the sentence for Justine with "children be grey" (268). Scotty seems to be using her blending conception but is quickly contradicted at (269) by Justine who has gleaned from the text the idea of black dominance which is interpreted as strength of colour. Scotty at (270) seems to be accepting Justine's lead but is also trying to accommodate her blending conception; she finds it difficult to articulate her ideas and reservations (274) and eventually seems to align herself with Justine's view. Interestingly it was Scotty who used the conception of variation in the offspring during the first problem and perhaps this coupled with the variations explicit in some of the cards is the basis of her reservations. Julie (278) aware of the difficulties of the developing frame between Scotty and Justine seems to be mocking their communication problem.

280 Sc what where are you
281 Jus dominant over the albino gene so that gene b is more powerful than that gene so it will be that sort of gene there
282 Jul yeah what about a jumper
283 Jus not quite Julie
284 Sc stop trying to be funny Julie
285 Jul Oh look I've just found some mice. take it home and train it
286 Jus dark chocolate colour
287 Jul oh nice one
288 Jus if a mouse receives a non-agouti gene from each parent the mouse will have a coat made up of only one colour and a white belly sometime mice can have the gene A.
289 Sc which gives
290 Jus gives non-agouti mice with tan bellies
The synchrony between the girls and their reading of the text eventually gives way to 'flicking through' the pages. Julie seems to be very aware of the camera and is censured by the others for "being funny". She is either bored or not convinced about the task. There is very little discussion of the text and what it means. Scotty finishes first with Julie taking her cue to stop work. Justine carries on reading for a few minutes then stops.

After a brief discussion of the text which the girls described as "very complicated" they were introduced to the final activity. They were familiar with the format of the family tree problem relating it to Henry VIII and his family of Tudor kings and queens.

291 Jus shall we do a black shall we do those two
292 Sc right. black is the stronger colour yeah
293 Jus sort of black
294 Sc ah Julie
295 Jul I'm not touching you
296 Sc you're chair was
297 Jus it wouldn't be tan it would be sort of mixed
298 Jul it would be very very dark
299 Jus very very dark brown yeah
300 Sc no. yeah that now those two have was it those
301 Jus no no just put another one there. two families there
302 Sc let's have a speckly one I like them
303 Jus and a tan
304 Sc and that's a stronger colour
305 Jus that's stronger than that
306 Sc let's say it would be black
307 Jus it wouldn't be
308 Sc it would be that one
309 Jus sorry
310 Sc that's ok don't let it happen again
311 Jul and a dark colour. not one of those
312 Sc yes yes ...and one of those two get married and what do they make
313 Jus eh. a dark brown
314 Sc I think they would make this definitely
315 Jul Yeah
316 Jus no no
317 Sc between them I reckon they'd make a black one
318 Jus so do I .I reckon that and that
At (291-2) Justine's choice of black mice is supported and qualified by Scotty who now seems to have the notion of black being 'a strong colour'. It is interesting that black is selected and that in the context of a 'paint box' ecosystem of conceptions there is a certain degree of resonance (plausibility) in the idea that it 'dominates' other colours. In addition it is possible to speculate that the assimilation of this idea represents an adaptation of their blending conceptions to allow for strength of colour: the 'new' being interpreted through the 'old'. At (298 and 299) Justine and Julie's blending conceptions seem to be active although the use of "very very" may indicate that it is now interacting with the notion of colour strength. At (304-312) there is a debate between the girls about strength of colour and its effect on offspring colour. Scotty seems to be advocating the dominance of black while the others seem to be using a modified blending conception. Justine's leads seem to hold sway over the discussion and it is interesting how this may damp out Scotty's efforts to imitate what was originally Justine's conception of 'dominance'.

During this episode, everyday ideas of 'marriage' (313) and families are used by the girls and this may be cued by their previous experiences of family trees.

320 Sc   no no that's too light
321 Jul  no I don't know
322 Jus  Yeah let's put that down

323 Jul  put it there and make those two have kids
324 Jus  it's dark grey so the dark grey would be stronger dark
grey...no put a white in there
and a speckly one there

Jus no no you can't cos that has to be one of the children
oh yes

Jus a black one black and black
Sc no a grey
Jus a grey yes
Sc yes light grey
Jus dark grey
Sc that's not dark
Jus right dark grey...yes right
Sc black and black
Jus wait we've still got to decide
Jul it doesn't matter...well let's just keep going down
the one side
Jus black and dark grey
Jul no then the other two would be easy because it would
be just black black black (laughs)
Jus no no we'll do these two we'll have a black and a dark
grey
Jul it's not possible
Jus yeah black

At (324) Justine seems to be using the dominance/strength of
colour conception which is accepted by Scotty but which is also
simultaneously active in her ecosystem with her blending
conceptions (331). Their conceptions remain implicit as they
competitively collaborate. Julie does make explicit her conception
of dominance and its consequences at (339). She seems to have
reservations about the invariability of the offspring after
crossing black with dark grey; it is difficult to say whether this
is motivated by task consideration or by conflicts with her
conceptions of phenotypic variability.

Jus Right now a black and a brown put black on that side
and brown on that
Sc put a black one there
Jus no it would be a dark brown wouldn't it
Jul that one its that one
Sc there you are
Jul families get bigger and bigger
At (343 and 345) Justine seems to be using her conception of dominance/blending; at (352) she acknowledges the consequences of their choices based on this conception (disappearance of albino mice after [3]) and the need to reintroduce white into the tree at [9]. At (352-355) Justine's suggestion that an albino may result from an albino/brown cross is challenged by Julie who refers to the notion of dominance. Justine's suggestion that they might have "at least one" (albino) may indicate that she is still operating her idea of cross-breeds. Julie seems to be applying the dominance conception in spite of her earlier notions about variation and grand parental influence. Her disagreement with Justine may be more of a reflection on the 'social' climate between herself and the others. At (356) she again makes explicit the analogic basis of their activities and perhaps her continuing reservations about its plausibility.

5.3.1 Summary

The discussion of card 1 begins with Justine and Scotty challenging their respective conceptions of 'like begets like' and
phenotypic variation in the offspring. Their disagreement allows Julie to introduce a 'compromise' conception based on her example of parents of different colours who have offspring which take after one or other of the parents. Thus 'like begets like' but black and white parents will have black and white offspring i.e. offspring of different colours. Julie thus supports Justine's conception but presents Scotty with an opportunity to accommodate her conception within it. Interestingly, Julie supports the 'like begets like' conception by using an example which suggests that if Scotty had a black mother "you'd be a bit black", perhaps implying a gender component to the inherited trait. Scotty seems reluctant to give up her ideas and the disagreement with Justine about their choice of mice goes on without any effort to support their conceptions or make them more explicit. Justine and Scotty compete for the floor and continue their disagreement but by the end of the discussion of card 1 Scotty seems to have accepted the 'like begets like' conception, collaborative needs perhaps outweighing her personal conviction.

Justine leads in the next card with a blending conception but her interaction frame is weak and she seems tentative. Scotty and Julie support this conception and a consensus of opinion seems to develop. However, Julie makes explicit the analogical basis of her blending conception (painting/mixing colours) and seems to be questioning the adequacy of her conception and its plausibility in this 'new' context, "and it might happen with mice...put mice together in a pot". Following this 'revelation' the girls seem very uncertain about what they should do. In the next card their
discussion is fragmented and sparse and a 'low cost' consensus develops where they all seem to agree about the choice of offspring but do not say why. Throughout this period Julie seems to be aware of the "problem" associated with the paint box analogy and the 'solution' which she offers seems to be a 'mathematical' analogy (perhaps cued by the parental cross-x on the cards). "Black times black would be black" is offered as basis of predicting offspring and this is picked up by Justine who seems to be adding rather than multiplying; "black and black equals black". It is interesting to speculate that what we are observing in these instances is the 'experimental' colonization of a new situation by the extension/adaptation of existing conceptions.

Arising concurrently with these mathematical analogies the potential anomaly presented by card 5 allows Julie to put forward an explanation of black parents and their brown offspring, based on the conception of grandparental influence. Justine seems to be putting forward the conception that sibling similarity is also a viable theory on which to base offspring choices. The anomaly in terms of their previous conceptions of 'like begets like' and blending introduces new conceptions into their conceptual ecosystems, and these form the basis of the girls' competitive collaboration during the discussion of card 5. There is no attempt to discuss the relative merits of these conceptions and after the girls have achieved a consensus they suspend their discussion.

In the next card Justine and Scotty develop a consensus centred on the shared conception of blending. While they actively collaborate Julie seems distant from the discussion and seems to

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be rather isolated from the activities of the others. Card 7 reintroduces the anomaly of non-familial resemblance, this time it being brown parents and a white offspring. Julie brings her conception of grandparental influence to bear again, and Justine explains the 'problem' in terms of cross-breeding which seems to have a notion of infidelity linked to it. Julie is ignored by the others in terms of her conception and Justine does not explain what she means by cross-breed. After this initial response to card 7 Scotty and Justine seem to revert to their consensus based on their blending conceptions, in spite of the fact that Julie reminds them of the painting analogy. In doing this she may be expressing her own reservations about this conception or her puzzlement why Justine and Scotty continue to use it. At this point it is interesting to speculate that in spite of the girls awareness of the anomaly, and Julie and Justine's ability to provide explanations based on grandparents or cross-breeding, there is no resonance between these ideas and other conceptions nor are they picked up in conversation between the girls. Perhaps in their task orientated situation, the fruitfulness of the blending conception in providing an answer, and a consensus outweighs their concerns about its plausibility and its explanatory adequacy in this novel context. This situation may also determine the way that the girls respond to 'new' conceptions. In the case of Julie's conception of grandparental influence and of Justine's cross-breeding, these may be adequate and plausible explanations in an everyday context, but are in fact perceived as having little use in solving the problem. The heterogeneity of the girl's conceptual ecosystems may thus
provide a way of damping out the impact of anomalies, and thereby insulating those conceptions which have problem solving utility from change. It would be interesting to speculate what might happen if Justine and Julie's ideas were to interact and overlap, and how this might affect the other conceptions within their respective ecosystems.

Julie is aware of the consensus forming around the blending conception and in particular the non-critical collaboration between Justine and Scotty. She still has her reservations about the paint box analogy and the blending conception and increasingly she seems to lose interest in the activity. Her scepticism is largely ignored by the others and they become critical of Julie's actions. Scotty and Justine continue their shared frame and seem to be actively maintaining their consensus. When Justine suggests a white offspring from non albino parents, Julie disagrees. Equally, Justine's suggestion of brown speckled offspring from grey and black parents, is challenged by Julie on the basis that there is no brown "in the family". It is interesting how this common expression is used to support Justine's blending conception and how it is accepted with little articulation of what she means.

During the reading task Justine interprets the notion of dominance in terms of strength of colour. Black is interpreted as a very strong colour (dominant) and it may be possible to infer that her comprehension of the text in this way is derived from her existing conception of blending. Scotty seems to accept the notion of 'dominance' as it relates to strength of colour but she seems to have difficulty in reconciling it with the notion that as a result
there will be no colour variation amongst the offspring. This interaction between Scotty's conceptions may give an insight into the way that her blending conception overlaps with her conception of offspring variability. 'Dominance' may resonate with the colour blending conception but may not be easily reconciled with the loss of 'shades' of offspring which result from the 'tyranny' of dark (strong) colours. This conflict seems to be resolved by Scotty in the course of the family tree problem during which she and Justine develop what appears to be a common conception. It seems that they have adapted the blending conception to take account of colour strength, thus retaining shades of coloured offspring but with the emphasis on the 'darkening' effects of dark coloured parents rather than the corollary of this situation. It may be that in this way not only is the existing conception used to interpret the 'new', but also that 'old' and 'new' conceptions are kept simultaneously active without the need to replace or refute existing ideas ie. Scotty's conception of offspring variability.

While Justine and Scotty competitively collaborate during the family tree problem, 'cementing' their shared content frame, Julie is aware of their conceptions but seems uncertain about its plausibility. She once again makes explicit the colour mixing analogy being used by the girls, and this may indicate that Julie remains unconvinced about the transference of their painting experiences to this novel situation. These considerations may explain Julie's rather limited engagement with the task and her apparent lack of commitment.
5.4 Case Study 4.

This group consisted of three boys aged 12+. All three were classmates and were accustomed to working with one another in the context of classwork. The session took place in their classroom while the rest of the class used an adjacent room. The boys (Luke, Simon and Peter) sat side by side in front of a table, facing the camera which was in view about twelve feet away. The researcher sat close to the camera monitoring the equipment in view of the boys. The discussion started with the researcher introducing the first task. Cards 1 and 2 were used for this purpose.

Card 1 (Grey x Grey)

1 S (inaudible)
2 I Right. I'll tell you about that one in a second..If you have that for the moment..Try that first one first of all and see how you get on
3 P I think.....I think it will be this one
4 L Yeah
5 P cos they're dark..two dark coloured ones and kind of dark coloured cos the darkest colour turns into that
6 L everybody the same
7 P Yeah
8 S its still the same size as that
9 P yeah
10 S that one
11 P Yeah but the parents are the same size as the children (laughs) that'd be (**) as the children..yeah that's it
12 S (inaudible)
13 P this is one on the black look next one says two that's right
14 I How are you doing..could you find them all...do you think they had one of a family or do you think they had more...
15 P Yeah
16 I you thought five or six Pete
17 P I'm going to put yeah
18 S (inaudible) look they're the same
19 P its like there's two..no suppose some of them would be a bit different though wouldn't they some of these just a bit lighter some would be darker ..some would be grey....yeah

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that's five...give them six this time..yeah could be.
couldn't in terms of the numbers in the family..I've done it
I Ok lets wait for the others
P couldn't they have say six or seven couldn't they
I yeah its up to you
P it doesn't matter does it

Pete takes the lead at the beginning of the discussion. At (5) the
conception that he uses is unclear but seems to be based on his
notion of colour blending. Luke seems keen to agree with Pete and
at (6) he seems to be monitoring the choices of the group. Simon
at (8) questions the size of the offspring inferring that they
should be smaller than the parent mice. Pete's 'explanation' (11) of
this does not satisfy Simon but he does not pursue the point. At
(18) Simon draws attention to Pete's choices of offspring and their
sameness. Pete's response (19) to Simon's observation seems to
indicate that he would expect there to be some variation in the
offspring. Peter appears to link this in some way to the numbers
of mice in the family.

The change in format represented in card 2 was explained to
the boys before they continued their discussion.

Card 2 (Brown x Black + Brown Offspring)

P Ehm...ehm
S look that one looks about half between them
P Yeah...get a few of them actually it could. do you think you
could have one like that there
S we're not doing that one
P I know I'm just trying to saying
S I think
P they could have a black one
L how about the
S the line
L this one this one
P what I've put that one on already
L (inaudible)
P must have used a lot of pens doing these
37 S probably more brown ones
38 P Mmm
39 S dark ones
40 P thats thats that one done
41 S they can well I think it is what
42 P yeah I suppose thats right yeah..it hasn't got a yellow(***)
    that..it doesn't have to be does it I mean it does have to be
43 S do all these have to be the same on each one
44 P no
45 I you decide its up to you they dont have to be the same
    you might want to have a word with the others if they are
    not and see what you think

At (25) Simon’s lead seems to indicate that he is using a blending
conception; "half between them" perhaps describing the relationship
between the offspring and the colour of its parents. This blending
conception is supported by Pete (26) and is used again by Simon at
(37 and 39). The qualification "dark ones" (39) being perhaps an
insight into Simon’s conception. Pete at (30) suggests that a black
offspring is a possibility and he uses his offspring choices from
card 1 to support this idea. The conception being used by Pete is
vague and he and Simon seem more concerned with getting on with
the task rather than talking about it (40).

Card 3 (Albino x Albino)

46 P let’s try and use up all of them
47 S oh no . well they’ll be white
48 P some might not be if they, they might have a few grey ones
    because that’s a light colour
49 S No
50 P I’m going to put a few grey ones in
51 S got one with spots on..that are white
52 P I’m having two grey ones ...with pink eyes. which are twins
    two grey ones with pink..they have pink eyes you know
53 L does it matter .oh yeah. ehm these are
54 S albinos
55 L yeah
56 P yeah yeah look they’ve got twins here actually there won't
    be many albinos will there
Simon leads at (47) with what seems to be a 'like begets like' conception. Peter disagrees with this in part and challenges Simon's idea with his conception of variation in the offspring. His qualification of his choice of grey as possible offspring, "because that's a light colour", is interesting as it may indicate some limit to the amount of variation and a possible overlap with conceptions focusing on the sameness of parents and offspring. Simon disagrees at (49) but does not pursue the argument. Both boys seem content to differ but at (52) Peter restates his idea about grey offspring and supports his choice with the idea of them being "twins". The implicit idea here seems to be that the twins will be identical and that this may justify Peter's choice of two grey mice. Luke seems to be aware of the disagreement between the other two and seems to be questioning the basis for it (53). Simon's use of "albinos" may be a response to Peter's challenge by bringing the 'authority' of this word to the support of his idea (54). Peter at (56) keeps up his challenge by referring to the frequency of albinos; Simon seems unmoved by this and restates his position at (58). Perhaps aware of relationships, Peter seems to accept that there will be some albinos (59) before drawing the discussion to a close by moving on (61).
The disagreement between Peter and Simon, and Peter's challenging of Simon's conception gives an insight into the heterogeneity and resilience of Peter's ecosystem. In spite of this interaction Simon's ideas are not refuted absolutely and he seems to be able to stick to his notion of 'like begets like'. Peter's acceptance that there will be some albinos provides the basis of some sort of consensus/ arbitration.

Card 4 (Black x Brown)

64 S look that looks like..yeah this one this one
65 P yeah this one I reckon that one
66 S what
67 P this one
68 S that's a bit (***)
69 P different (***), a bit different from all the rest
70 S what about that because some of them are exactly the same as their
71 P their parents yeah, yeah like that those two and those two cos that's slightly different there
72 L I can show some that are just slightly different
73 P they're by a different parent (laughs)
74 S so that could be darker
75 P where's that grey type
76 L where's one like that
77 S they've got spots on
78 P yeah because they're a cross-breed (laughs)
79 L well could be
80 P they've got seven seven children must have been hard (laughs)
81 S turn to the next one

The discussion of this card starts with an episode of competitive collaboration between Peter and Simon. Peter at (69) and Simon at (70) seem to continue with their respective use of variation and 'like begets like' conceptions. Peter seems to be able to accommodate both conceptions in his choice of offspring (71). At (73) and (78)
Peter seems to be setting limits to the amount of variation one might expect in the offspring when compared to the parental phenotype. His inference at (73) seems to be hinting at 'infidelity' as one reason for offspring not being similar to the parents, and at (78) the use of cross-breed may have similar connotations. It is interesting how these notions overlap with his conceptions of familial similarity and variation, and how Peter seems to be using the analogy of human relationships/families (80). Luke seems to accept the plausibility of Peter's cross-breed notion as an explanation of offspring/parent differences.

Card 5 (Black x Black + Brown)

82 S have they all got to be the same
83 P yeah...there'd be a black one wouldn't
84 S yeah
85 P do you think there wouldn't be any one like that cause there's nothing the same about them apart from the ears and tail so that there wouldn't be
86 S the same
87 P all these tails are the same
88 S quite dark colours yeah
89 P yeah that'd be ok..isn't it
90 S I don't think quite like that
91 P Mmm . might have one like that yeah put that one down no not all of them
92 S most of them will be yeah. take off that then dark colours not that its too light
93 L is this ok
94 P hey wait I've only done (***)

Peter and Simon agree initially that black offspring are a possibility (82-84), perhaps on the basis of their conceptions of familial similarity. At (85) Peter invites Simon to comment on the anomaly of the brown offspring. He seems to be questioning the fact that they have no common coat colour, only the tails and ears.
are the same, and how plausible this situation would be. Peter and Simon seem uncertain about this card although they seem to arrive at a consensus based on dark coloured offspring (88 and 93). This may represent an adaptation of their 'like begets like' conception to allow for general colour similarity ie. dark as opposed to black. It is interesting that Peter does not use his conception of variation in the offspring to 'explain' the anomaly nor does he reflect on previous ideas about infidelity or cross-breeds.

Card 6 (Black x Agouti + Agouti)

95 P  Mmm that one that kind
96 S  Yeah
97 L  that one
98 P  there's that one as well
99 S  look that's stupid that's got a white mouse (laughs)
100 P  maybe one like that
101 S  yeah but most of them will be about that
102 P  yeah
103 S  most dark
104 L  its dead

Discussion of card 6 is very tentative, vague and uncertain with the boys making choices with little or no explanation. The conceptions being used are implicit and under-articulated. It is interesting to speculate that this uncertainty may be a consequence of their previous experience with card 5 in which some of their negotiated ideas were questioned or modified.

At (99) Simon looks ahead to card 7; his reaction seems to be a recognition of what for him may be an anomalous situation (white offspring from brown parents). In the context of his 'like begets like' conception this situation may indeed be an anomaly:
interestingly this more overt example seems to be more powerful than that shown in card 5 and this may relate to the influence of Peter's notion of offspring variation.

Card 7 (Brown x Brown + Albino)

105 P lift them up at high speed, there's a bit of stupid parents
106 S right that's slightly lighter isn't it
107 P look they're all (inaudible)
108 S stop it
109 P there's white cause
110 S look that's half between those two
111 P oh yeah
112 S most of them will be dark or light, that colour
113 P dark
114 S no this colour
115 P some of them are going to be like that
116 S no they won't be like that
117 P why have they got one like that
118 S don't know
119 L they're queer (laughs) because they like each other
120 P what
121 L supposed to be funny
122 S what's that what have you got there
123 L he's got a disease (laughs)
124 S Peter one two three four five six seven, lets take a few off...no leave

During the discussion of this card a strong interaction frame develops between Simon and Peter. They seem to have difficulty in explaining the white offspring. Simon reintroduces his blending notion at (110) but he seems to be suggesting that the blend is now between parents and the given offspring. Simon and Peter competitively collaborate over their choices (114-116) but they fail to come up with an explanation for the anomaly of the white mouse (117 and 118). At (119) Luke seems to respond to this problem by inferring that the white offspring is strange; his use
of "queer" and its homosexual overtones become part of a joke on the word. Luke follows this with another joke based on the idea that the white mouse is diseased. The other boys seem to ignore him and it gives an insight into Luke's isolation within the group, and perhaps the inhibiting effect of Peter and Simon's 'monopoly' of the task.

Card 8 (Agouti x Agouti + Black)

125 L you're behind Peter
126 S it's in between those two if they've got
127 P like that wouldn't they because that's in between them
128 S yeah. (**)
129 P colour. (**

then take that mouse take away that

mouse you'd get that nothing (laughs)
130 S look those two are nearly the same as their parents but they've got different
131 P Mmm
132 S and some are exactly the same
133 P one two three four five...put one more...brown ones
134 S which ones
135 P they wouldn't have any white
136 S No I know
137 P they might
138 S don't put any white ones on then...we need one like that

with a white bit there
139 P Mmm
140 L this one
141 P where did you get that from. upside down
142 L hasn't got any
143 S can't see any can't see any. I've got to find one of these
with a white bottom
144 P turn them all up the right way round
145 L don't be so stupid
146 P I'm not being stupid
147 S there aren't any of those can't do it. right
148 P right

At (126) Simon again uses what appears to be a blending conception as the basis of prediction. Peter seems to share Simon's frame as he echoes the idea. Peter tries a mathematical analogy of adding and
subtracting at (129) but he seems to be less than serious about the plausibility of this strategy; "in between" may have mathematical connotations for him and might have acted as a cue. At (130) Simon completes the frame sharing by using the conception of variation in the offspring and this seems to be now linked with his 'like beget like' notions (132). Simon seems to be using all three conceptions simultaneously, and this may represent a sharing of his own ideas and those of Peter and the 'cementing' of their consensus/working relationship.

Peter, perhaps influenced by previous cards, denies the possibility of a white offspring at (135) then contradicts himself at (137). Simon seems keen to avoid this issue and its attendant 'problems'; he may be aware that they still have not explained the appearance of white mice from non-albino parents.

Luke remains rather isolated and in response to censure by Peter (144) a slightly aggressive episode develops (144-6). It is quickly diffused as Simon moves on to the next card.

Card 9 (Grey x Black)

149 S that
150 P there there will be some brown ones here wouldn't there. brown because its ..in between
151 S that's sort of black there
152 L you wouldn't get an in between because the colours wrong
153 S maybe that colour not brown that colours no where near.. they're usually dark they're usually
154 L this one
155 S some like the parents
156 L this one
157 P no not that in between
158 S some like their parents and some in between so thats dark grey no that one. I dont think they'd have brown
159 P yeah they would (*** get brown on this one I could put orange with purple spots on (*** (inaudible)

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L don't put too many on
P I've only got three left
L how have you got three left I've got two...oh you

Peter makes a strong lead at (150) justifying his choice of offspring by using Simon's words "in between". Luke disagrees with this revealing perhaps that Peter does not share Simon's conception and that he does (152). Peter has his own ideas about "in between" offspring, but up to this point his acceptance of Simon's viewpoint and the vagueness of this idea has allowed Simon's meaning to be developed. Simon supports Luke and gives an exposition of "in between" and the blending notion contained within it (153 and 158). Again Simon uses familial similarity as the basis for some of his choices. Peter does not make his ideas about "in between" explicit and although Simon's disagreement over his choice of brown is not dogmatic he responds defensively (159). His defence of his choice is vague although he seems to be advocating a much wider degree of offspring variation albeit using a rather extreme example.

Card 10 (Black and Tan x Brown and Tan + Black and Tan)

L oh yeah definitely have this one
P yeah
L no
P yes they would
(no discussion for 10 seconds)
L that's about it

Card 10 produces little discussion amongst the boys. Peter and Luke compete for the floor with Luke apparently initiating an 'argument' with Peter. This strong interaction frame leads to a suspension of the discussion during which the boys make their own choices. Luke's
involvement in the session seems to be increasing and it is he who suggests that they move to the next card.

Card 11 (Brown x Brown + Light Brown)

168 S see if there's a black one what there
169 P take that one ..take that one there would be some black ones wouldn't there
170 S no..I don't think there would be black that's much darker
171 P oh they'd be lighter
172 L there might be some albinos
173 P yeah there would be
174 S just sometimes not lots of them
175 P I'm going to put one on...change actually
176 P its like that then look these two here
177 S (inaudible)
178 P actually there would be two like the parents I think
179 S oh yeah
180 P yeah

At (169) Peter's lead seem to revisit his earlier implicit ideas about "in between" offspring. Simon disagrees with the choice of black (170) as this probably conflicts with his blending conception where parental colour determines offspring colour. Peter seems to accept this (171) and does not support his choice. The 'cue' of "lighter" (171) allows Luke to suggest albino mice as offspring possibilities which picks up on a term used earlier by Simon. Peter and Simon accept this and the latter qualifies this idea with reference to Peter's earlier ideas of albino frequency (174). The boys seems to be developing a consensus, and this is reinforced by Peter's use of the 'like begets like' conception (178) which Simon readily accepts (179). This conciliatory and co-operative episode may give an insight into the boys desire to maintain and monitor their interpersonal relationship within the
task context. This may have a stabilising effect on the conceptions that they use.

Card 12 (Agouti x Albino)

181 P there would be some like its parents first..this one
182 S I don't think they'd be . I don't think they'd be with these black spots though
183 P (**) one with that yeah...white
184 S one with a white bottom
185 P there aren't any like that
186 S there's none left..grey another grey
187 P yeah there'd be a (***)
188 S I don't think they'd be like that
189 L there would be
190 P there would be ...there might be..well how do you know you haven't been studying mice have you
191 L nor have you
192 P No..there would be some grey ones and that's
193 S and a lot of brown
194 P a bit squishy. seven eight. right finished

Peter leads with his 'like begets like' conception (181) which in previous discussions has been accepted by Simon as a plausible and fruitful conception; perhaps to his surprise Simon does not agree with this (182). Simon and Peter present strong interaction frames but the basis of their disagreement does not emerge from the weak content frames used by the boys. Luke is drawn into the exchange at (189) in what seems to be the role of arbiter supporting Peter at (189) and Simon at (191). The slightly aggressive overtones of Peter's comment to Simon at (190) may again be symptomatic of a situation where no agreed viewpoint is reached and no stable set of conceptions forms the basis of their offspring choices.
On completion of this activity the reading task was explained to the boys. They read in silence for 5 minutes monitoring each other progress through the task visually. The family tree 'problem' was then explained to the boys.

195 I this is a skeleton of a family tree..do you know what I mean by that
196 P yeah
197 S yeah
198 I what sort of family trees have you come across
199 P I've seen ..my uncles done one we seen that
200 I of the family
201 P yeah our family
202 I yeah that's interesting with all the aunts and uncles shown on it
203 P yeah
204 I have you seen some
205 L Yeah
206 I what sort have you seen
207 S the royal family
208 I right you see that on all sorts of things.....well what I want you to do now is to make a mouse family tree..I want you to work together on this and sort of decide what the mouse family tree should look like..there is no right or wrong family tree its up to you..there could be hundreds of different families....so lets take a look ..lets take any two hand me that one and that one..these two would have ..how many babies
209 P two
210 L two
211 I and so on two I think you've got the idea
212 P yeah
213 L yeah
214 I right I'll let you get on
215 L (**) one died when it was born
216 P (inaudible)
217 S do you start with two
218 L this one would be . it would be
219 P main genes
220 L no you wouldn't necessarily have two of them because they might not be
221 P I think it would be an agouti (sic) gene
222 L this one might be lighter
223 P yeah
224 S no
225 P it wouldn't be lighter or darker than any of its parents would it
226 L well it will be black then
227 P its darker than both of those two
Peter at (219) and (221) uses words picked up from the text material but this seems to be more of a performance rather than a genuine effort to contribute to the discussion. At (225) Peter seems to be using a blending conception where the parental colours set the limits of offspring coat colour; this may be what he means by "in between". From (229-233) the boys competitively collaborate within a strong interaction frame. The conceptions being used are vague.

The discussion at this point seems to centre on the notion of offspring being similar to the parents and the degrees of colour associated with blends of parental colour. The discussion is very
fragmented with the boys at 'sixes and sevens'; they are uncertain and seem reluctant to support their reasoning. They are thinking out loud without really getting into a collaborative style of work. Typical of this style is when Simon draws their attention to the two grey parents at [31 (241) and seems to be suggesting that the offspring should be the same. Luke disagrees and supports the inclusion of another colour on the basis of his conception of offspring variability.

251 P oh yeah lets say its that one
252 S no. I doubt it
253 P no have an albino one we haven't had one of them
254 S I do one of them later on
255 L I don't get this oh yes that
256 P they could
257 L can't get (**) very well
258 S where does it say it in these
259 P it says they could have them I reckon
260 S maybe (**) it says
261 P that just means the average
262 S (inaudible)
263 P it would be this one definitely
264 S wait a minute
265 P wait wait...wait
266 S let's have another dark one
267 P dark one
268 S yeah but you see when .when in this thing you said that the black ones would be much powerful more than
269 L they could have that
270 P they could have an albino
271 S they'd be darker because they'd be dark colours
272 P yes oh blimey..that goes there then
273 S but eh
274 L no
275 S but both these two would be dark because he's got really dark parents and in this it says that

The boys seem uncertain of what they are doing as they compete to have their choices accepted. The content frame being used by all three is initially very weak and Luke at (255) is unable to follow
the activities of the others. At (268, 271 and 275) Simon seems to be using the authority of the text to support his idea that the black mice are likely to have dark offspring because they are more "powerful". His use of "powerful" may be his translation of the dominance/strength idea introduced in the text.

Simon extends his explanation of 'dominance' in this exchange with Peter (276-81). This conception may be different from the blending conception used earlier for now black does not darken the offspring but makes them "mainly black" (279 and 281). It is interesting to speculate on Simon's assimilation of this notion in relation to his existing ideas of like begets like and blending; the 'dominance' of black parents may be a plausible synthesis of the former conceptions.
All three boys competitively collaborate over the selection of offspring, but at [8] with grey and black parents Simon seems to be using his conception of 'dominance' and blending at (293) and (295) respectively. The latter conception has utility in the context of the 'problem' but also seems to be a basis for agreement between Peter and Simon (283-4) and (293-296).

297 L but thats brown though
298 P but it doesn't have to it could be..have one grey as well
299 L no have a brown
300 S No
301 P have brown its darker
302 S cos there isn't any browns in those two though
303 L have that those two ..that's actually more than darker
304 S dont think they'd be any brown in it because there's no brown in that
305 P have a black one

Luke questions Peter's choice of a brown offspring at [8] his response at (298 and 301) seems uncertain. Simon also disagrees with the choice of brown offspring and he supports this by refering to the fact that the parents do not have any brown colouration (302 and 304). Interestingly he does not consider previous generations as a source of 'brown' he is apparently concerned with one generation. Peter's suggestion of a black one (305) instead of a brown offspring is a tacit acceptance of Simon's viewpoint. Again there is an interesting interrelationship between Simon's ideas about parental input and familial resemblance with his conceptions of blending, the 'dominance' of black and familial similarity.

306 S ehm..agouti because they're a mix of different colours
307 L they might have an albino
308 S no
309 P yeah they could
310 S they could but they are not going to
311 L yes they are
312 P they've had one now
313 S have one of those
314 P no they've had an albino now get another of those
315 L eck
316 P no change it for that one
317 L no no that one's good ..oh no you wouldn't have this one
318 P he's falling off
319 S it doesn't have an albino because
320 P yes you could
321 S because they are both dark colours..why would
322 P it be an albino though
323 L because albinos can happen sort of anytime
324 S it could happen
325 S that makes more sense

At (306) Simon suggests that agouti mice are possible offspring in
[10]. His description of them as "a mix of different colours" may
be based on his blending conception, this being cued by the
appearance of the agouti type. Luke suggests an albino and he and
Peter seems to agree that this is a possibility (307 and 309).
Simon's response to this is very dogmatic perhaps he sees this as
a challenge to his gatekeeping role in recent discussions (310).
Peter and Simon support one another and place an albino on the
board. Interestingly Peter seems to be using his conception of
albino rarity to prevent Luke from choosing another (314). At (319)
Simon disagrees with the choice of an albino, it seems that he is
unable to reconcile this with the dark coloured parents and perhaps
his current conceptions (321). Peter responds by making his
conception of albino rarity/frequency more explicit (322) and with
Luke's support this is accepted by Simon as a plausible
explanation; perhaps because he himself used this notion in an
earlier discussion and it may be part of his conceptual ecosystem, although not active during this particular exchange.

325 P oh no that's not sensible..I don't think
326 S it is cos that
327 P that isn't that isn't
328 L that isn't . that's not like any of that
329 S yes it is
330 L yeah they wouldn't have an albino
331 P they would
332 L wouldn't usually
333 P I've finished
334 S and that would be darker
335 P I've finished
336 L no it wouldn't
337 S see look look
338 P finished

The debate about the albino continues with Peter and Luke apparently uncertain about their decision to have an albino (325 and 330). Peter and Luke end up disagreeing (330-2) and Simon seems to revert to his blending/dominance notions (334). Peter seems eager to suspend the discussion between Luke and Simon as he declares the task complete (333, 335 and 338). All three boys look up from the board inviting the researcher to attend to them.

5.4.1 Summary

In the opening minutes of the discussions the boys orientate themselves towards the requirements of the task. The number of offspring each family should have is an initial focus for discussion. Simon's observations that they have chosen offspring which are the same as the parents in card 1, leads to Peter challenging this outcome with his conception of offspring
variability. It would seem that in spite of the parents being the same colour he expects their offspring to be a "bit different", "a bit lighter some would be darker".

Simon takes the lead in card 2 during which he introduces his idea of "in between". This appears to be a blending conception where offspring are a blend of parental coat colours and are therefore an "in between" colour. Simon also seems to be suggesting that some of the offspring will look like the parents but at this stage the boys seem more concerned with choosing their own offspring and competing with one another to voice their thoughts. The boys present strong interaction frames at this time and their competitive collaboration is based on weak content frames. This may be an effective way for them to 'experiment' with their ideas in an uncertain and novel situation.

In card 3 Simon's lead seems to be based on his conception of 'like begets like'. This is challenged by Peter who qualifies his disagreement on the basis of his conception of offspring variability. The disagreement between these two boys at this point gives an insight into the heterogeneity of Peter's conceptual ecosystem. In the face of Simon's intransigence Peter supports his choice of grey and his notion of variability with the idea that albinos are infrequent in families. Interestingly, this conception may have been cued by Simon who initially uses the term albino, perhaps by way of giving his choice some authority. Peter affects a compromise by accepting that there will be some albinos but justifies his choice of two grey offspring by calling them twins. This is an interesting compromise which maintains the integrity of
Peter's conceptions and preserves his relationship with Simon. The heterogeneity of Peter's ecosystem in this episode may thus contribute to its resilience.

The discussion of the next card starts with Peter accepting Simon's 'like begets like' conception whilst reconciling it with his conception of offspring variability. It seems that he is able to accommodate both these conceptions within his ecosystem. Luke seems happy to facilitate the others activities at this point, and by showing Peter card 7 he seems to be questioning the plausibility of Peter's variability conception (ie. albino offspring from brown parents). Peter's response to this is to infer 'infidelity' and cross-breeding which is the focus for some embarrassed laughter amongst the boys. Again the heterogeneity of Peter's ecosystem seems to be able to diffuse the potential anomaly of the albino mouse and its brown parents whilst 'protecting' the plausibility of his conception of variability in the offspring.

The potential anomaly presented by card 5 (black parents + brown offspring) seems to register with Peter as he elicits the other's opinions. He seems to question whether they might expect another brown offspring when it has nothing in common with its parents "apart from ears and tail". Simon apparently adapts his conception of familial similarity in response to this anomaly, and proposes a more general similarity of "dark" offspring from dark parents. Simon uses this conception in card 6 but it is noteworthy that as he looks ahead to card 7 (brown parents + albino offspring) he seems to decide that the situation portrayed in the card is "stupid". This may reflect the fact that it cannot be
explained in terms of familial similarity nor his recent adaptation of this conception to accommodate general colouring.

The discussion of card 7 sees Peter and Simon presenting strong frames and using their respective conceptions of variability and familial similarity. However, they seem unconvinced about their theories and eventually admit to one another that they don't know why "they have got one like that" is an albino. It is interesting that previous ideas such as infidelity/cross-breed are not used in this context, and that these ideas are not simultaneously active with other conceptions. The fact that Simon and Peter are stuck for an explanation allows Luke to break into their monopoly of the conversation with his joke about it being "queer". This is ignored by Peter and Simon perhaps exhibiting gatekeeping with regard to their control of the discussion.

At card 8 Simon and Peter compete for the floor as they 'cement' their consensus. Simon uses Peter's conception of variability, Peter uses the phrase "in between" to echo Simon's conception. During this episode they remain conscious of the albino anomaly from the previous card but the problem remains unresolved. The aggressive disagreement between Peter and Luke at the end of this episode may reflect Luke's apparent isolation and lack of involvement in the discussion.

Peter leads the discussion into card 9. He supports his choice of offspring by referring to Simon's notion of "in between". Luke disagrees with this, challenging it on the basis that brown offspring are not "in between" grey and black. Simon supports Luke and disagrees with Peter suggesting that some offspring will look...
like the parents and some will be "dark grey" and "in between". The latter blending conception seems to be different from Peter's notion of what "in between" means. His failure to explain to Simon and Luke why brown is "in between" results in Peter taking the defensive line that he can choose what he wants.

Perhaps as a result of their 'strained' working relationship the discussion of the next card is brief and punctuated by a 10 second silence before Luke suspends their activities and they move on. At card 11 better relationships between the boys emerge as they accept each other's ideas and choices in a more conciliatory way. Luke's suggestion of choosing an albino offspring is readily accepted by Peter in this instance, and interestingly, it is supported by Simon who reconciles it with the notion of albino rarity/frequency used earlier by Peter. Peter leads with the conception of 'like begets like' and its acceptance by Simon seems to re-establish their consensus. The 'social stability' of the group may be in part determined by the overlap of their conceptions and their interpersonal relations.

The fluidity of their interpersonal interaction again emerges in the discussion of the last card. Simon seems to be gatekeeping with regard to what are acceptable choices of offspring and a cycle of lead/disagreement between Peter and Simon develops. Luke gets caught up in this disagreement as he and Peter dispute their claims to knowledge. Before the argument develops, Peter suspends their activities by declaring the task "finished".

The reading task was conducted in silence in spite of the researcher's invitation to talk to each other about the content of
the books. After five minutes or so the boys indicated that they were ready to go on.

The family tree format was familiar to the boys although none of them had actually made up a tree. They quickly became involved in the task. Peter's use of words such as "agoati" (sic) and "genes" which he has drawn from the text, seems to be more for effect than anything else. They competitively collaborate with one another to get their choices on the board but the content frames used are initially very weak. It seems that blending, 'like begets like' and variation conceptions are being used by all three boys but these are 'submerged' in a rapid succession of leads, disagreements, acceptances and task orientated activities. Simon appears to take on a gatekeeping role with regard to those choices which stay on the board but his efforts have limited success in stemming the tide of activity. By [?] Simon has introduced his conception of 'dominance' which focuses on the powerfullness of black coat colour. The intelligibility and plausibility of this notion, gleaned from the text, and Simon's comprehension of it, may be related to his current conceptions. Black is seen as a dominant colour which will make the offspring black, but equally Simon also sees it as having a darkening effect in the context of his blending conception. The other boys seem to accept this as a plausible and fruitful strategy.

Before completing this task Peter suggests that an albino should appear in the tree, but this is met with disagreement from Simon. His challenge is based on the notion that dark parents will not have white offspring. Peter's defence of his choice makes
explicit his conception that albinos "can happen sort of anytime". Although this is accepted by Simon as a plausible explanation the boys, including Peter, seem to have doubts about the inclusion of an albino. The discussion of this matter is suspended as they reach the end of the task perhaps reflecting the fact that they have not quite explained the appearance of albinos in non-albino families. It is interesting to speculate that the assimilation of 'dominance' and its association of colour strength may interact with blending conceptions. In this way it may be more difficult and confusing to explain albino offspring in the context of dark coloured parents.
This group consisted of two boys and a girl, aged 12 + years. All three were classmates. The session took place in the school library, in the presence of the 'interviewer', while the rest of the class were engaged in normal lessons. Jane, Darren and Andrew sat in an open semi-circle facing the camera which was positioned about twelve feet away from the group. The researcher sat in view of the group monitoring the equipment.

The nature of the session was explained to the group and any questions answered. The first task was introduced and the format of the cards explained. The group began their discussion.

Card 1 (Grey x Grey)

1 D They wouldn't be the same colour would they
2 J they might be
3 A yes they would
4 D they might not be
5 J there was that dog on Blue Peter it turned out the same different
6 A its more likely its more likely to be the same colour because of the parents
7 D cos dogs aren't the same as mice are they
8 A that's what I've done

Darren invites the others to comment on his strong lead that the offspring won't be the same as the parents (1). Jane seems to think that they might be the same as the parents, and supports this by reference to an anecdote about Blue Peter dogs (5). (Dogs on this TV programme and their litters of puppies are canine 'stars'). However, in her description of the dogs Jane seems confused
whether they turned out the same or different (5). Andrew seems more confident in this matter (3 and 6) and he suggests that offspring will be the same as the parents. Darren questions Jane's anecdote on analogical grounds as he draws her attention to the difference between mice and dogs (7). Andrew seems to stick to his own ideas and suspends further discussion by moving on (8). Jane and Darren follow; the group's respective positions/ideas apparently intact and their difference of opinion unresolved.

Card 2 (Dark Brown x Light Brown + Dark Brown)

9 A well if the parents are brown
10 J the... multicoloured yeah
11 A yeah the other one would be multicoloured
12 D brown and white
13 J that colour
14 A yeah but say they're three in the litter right so you get one brown one from the father one sort of browny one from the mother
15 D and perhaps
16 A then you get the child the same two colours. a multicoloured one cos its a twin
17 D there wouldn't be
18 A both of them
19 D probably lets have a look at that. that that could be it cos...its got pink ears body
20 J they've all got pink ears
21 A that's stupid Darren
22 D no its not no if you've got a dark brown one with a light bit in..it could be one ..have they got a multicoloured one
23 J cos look if you mix both of them colours together
24 D no. that's the same colour as that though isn't it
25 J yeah but that isn't the same colour
26 A but if you mix both of these colours the darkly colour. so you're more likely to get that sort of colour
27 D yeah you want a more darker colour than that
28 A which are the same..yeah it be that
29 J and that..but you wouldn't get them all the same
30 D I can't get a darker one
31 J like that
32 A more darker than that..I say like that..cos that's the
darker colour so you're more likely to get that one than the lighter colour

33 J I'm thinking of half-cast actually
34 A oh right let's go on to the next one right we'll go on now

Andrew and Jane take the lead at the beginning of this discussion. Jane introduces the word "multicoloured" at (10) to describe the agouti pattern. Andrew accepts and echos this idea and goes on to qualify and justify this choice (11,14 and 16). He seems to be using a 'like begets like conception and a blending conception 'simultaneously; whereby in a litter of three mice one takes after each parent and one offspring is a "mix" of both parents. Andrew's reference to "twins" is vague but it may be that he is trying to denote how the multicoloured offspring are the products (twins) of two parents.

Darren competes for the floor with Andrew and he seems to disagree with Andrew's conception (17). At (19) he appears to be looking for other traits to base his prediction on, such as "pink ears". Andrew and Jane censure this strongly and Darren's defence of his idea is uncertain. Jane tries to explain her conception of blending to Darren at (23). Darren disagrees with her idea on the basis that the given offspring is dark brown and not a 'mix' of the parents (25). Andrew at (26 and 28) supports Jane and adapts his blending conception to include the strength of colour. At (32) he seems to be suggesting that darker coloured offspring will be more likely from crosses involving dark and light coloured parents. Jane seems to be challenging Andrew's conception at (33), her conception of blending does not appear to consider strength of colour. Her use
of the term "half-cast" may describe a more hybrid form of offspring where parental colour contributions are equal. Andrew appears to acknowledge this, but perhaps by way of gatekeeping, he suspends any discussion by suggesting they move to the next card (34).

Card 3 (Albino x Albino)

35 D right this is pretty obvious
36 A yeah but is there any white ones
37 D I can't see any white ones oh yes I can
38 J they could be
39 D Yessss
40 J we could get a different coloured one
41 A yeah but it would have to be a light colour
42 J cos no. but if that went back in the family
43 A yeah but if that was a family tree yeah you might but it isn't
44 D but they're both the same colour. they're not
45 A what's that got to do with this...you don't know
46 D they're both the same colour. so ...probably the same colour as the babies
47 J it is ...get white
48 A yeah if they did have babies it would probably be a light colour ...next one

At (35) Darren's "pretty obvious" seems to indicate that the situation depicted in the card is unambiguous. He and Andrew appear to agree that the offspring will be like the parents (35-37). Jane offers an alternative suggestion at (38 and 40) that the offspring could be coloured. Andrew's response to this is interesting in that he accepts Jane's idea but his qualification that "they would have to be a light colour", may reflect the interaction of this notion with his blending and familial similarity conceptions. These conceptions may set the limits of offspring variation that Andrew sees as being plausible. It is also an insight into Andrew's
gatekeeping activities with regard to his 'control' of the group's activities.

At (42) Jane disagrees with Andrew and seems to be using a conception about grandparental influence on offspring colour. Andrew challenges her conception by making reference to the nature of the task, and perhaps having seen the family tree problem board, he seems to be suggesting that her idea is out of context. Darren does not seem to follow their argument and restates his 'like begets like' conception (44 and 46), referring to the difference between this card and card 2 where the parents are a different colour. His 'naivety' is censured by Andrew but he and Jane seem to accept that there will be white offspring. Perhaps characteristically Andrew restates his belief that they would be a "light colour" (like the parents but slightly different) implicitly challenging Jane's notion of coloured offspring. Thus he gets the last word before he suspends the discussion by moving to the next card (48).

Card 4 (Black x Brown)

49 A we've come across this one before
50 J Eh it would be black wouldn't it because it would come out
51 D ehh na
52 A it's the stronger colour
53 D will I
54 A brown and
55 J yeah
56 D brown sort of brown
57 A yeah brown dark brown
58 D ish
59 J wait a minute they've got a black one though
60 D yeah but
61 J I reckon they'll both be black
62 A Mmm

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At (50) Jane leads with what seems to be a 'dominance' conception. This is qualified by Andrew at (52). Jane's use of this conception may be influenced by the plausibility of this notion and the fact that it can be shared with Andrew. Darren's suggestion of a brown offspring is picked up by Andrew who qualifies this with "dark brown" (57). Andrew seems to be using a blending conception at this point. This appears to conflict with Jane's expectations and her 'dominance' conception; she expects the offspring to be black (59 and 61). She seems surprised at Andrew accepting dark brown as a possibility, particularly when he was the first to use the idea of 'dominance'. Andrew's response to Jane's challenge perhaps indicating that he is aware of this 'conflict' (62).

Darren seems to be working out some conception related paternal gender but he is not given support by the others (63-65) and his idea remains latent and under articulated.

Andrew and Jane go on to make some more offspring choices accepting each other's selections in a rather passive way (69-70).
Darren challenges their choices on the basis that the offspring have no colours which are derived from the parents, "nothing in the family with grey" (71). Jane returns to her original idea of black offspring (74) and this is accepted by Darren and Andrew, perhaps aware that they can all agree on this selection. Andrew again moves them on to the next card.

Card 5 (Black x Black + Brown)

78  J  see I told you it could go back in the family again brown then
79  A  that's right cos brown..you're right it could be a family tree
80  J  I reckon the other two are black
81  D  Mmm cos that one's half cast
82  J  how can it be half cast when them two are black
83  A  but if it does run back in the family tree
84  D  in..in our family
85  J  otherwise if it
86  A  I think it would be like that colour to that one...its sort of similar colour
87  D  if the mum is black in our family
88  A  I'll put this one down
89  D  the baby will come out black won't it so its the same. we don't know which one
90  J  if the husband is white it would be half cast
91  A  I'll put it like that
92  D  Yeah it would be chocolate..black and white
93  A  no
94  J  ok its that I reckon
95  D  I don't think there should be any yellow in it
96  J  nor do I
97  A  right go on to the next one

At (78) Jane has her previous conception of grandparental influence 'confirmed' by card 5. The brown offspring from black parents is explained in terms of her notion that earlier generations affect the offspring coat colour. Andrew (79) acknowledges and accepts this idea and using his description of "family tree" which he used
earlier to dispute Jane's conception. Jane seems to be using a 'like begets like' conception to predict the other offspring in the family (80).

At (81) Darren uses the term "half-cast", used earlier by Jane, to describe one of his offspring choices. Jane disagrees with this description (82) and qualifies her point by referring Darren to the parents which are "both black"; half-cast for Jane is the 'blended' product of heterozygous parents. Darren seems unsure but at (87 and 89), using a 'human' example, he appears to be suggesting that black mothers give rise to black children. This may relate to his earlier and his present desire to know which parent was the male or female, and may relate to a gender related conception of 'like begetting like'. Jane's interjection at (90) completes Darren's human analogy with her description of half-cast and the need for a white parent to go with the black one. The extent of Darren's analogy based on matings of black and white humans is revealed at (92) where he makes the implicit connection between the "chocolate" skin colour of these human offspring and the brown colour of the mouse in card 5; black and white in the context of human skin colour make brown babies. It is possible that Darren may see the white bellies of the mice contributing to the colour 'equation', or he does not seem to see the limitation pointed out by Jane that both the parents in card 5 are black.

Throughout Jane and Darren's discussion Andrew seems content to make his offspring choices on the basis of parental similarity. Jane's use of this conception immediately after the vindication of her notions about grandparental influence (80), maintains the
consensus between Andrew and herself. Even more interestingly, there is no overt refutation of a conception 'like begets like' even in the face of black parents having brown offspring. Jane's conception of grandparental influence may have limited interaction with her conception of familial similarity. It may be possible to speculate that in the context of the card problem, not knowing the colour of the grandparents, may limit the problem solving utility of this conception when compared with the alternatives.

Card 6 (Black x Speckled + Speckled)

98 A Darrens not ready
99 D yes I will. ah spotty
100 J or maybe
101 A I reckon one of each
102 J one of each . what each colour
103 A yeah
104 D say there's a black one there
105 A like that
106 D like if there's a black one there I think that should be right..but there might not be
107 J I can't find any of them ones
108 D dark but
109 J no grey but on . yeah there was one back there with that colour it was that colour and a plain one of these
110 D Mmm
111 J that could have been ..that colour with
112 D Yeah because black spots cos that the that's the whatever it is the mummy or daddy
113 J its more likely to be like that than it would have been
114 A just black
115 J yeah
116 D yeah
117 A yeah but you can't find the ones with white in there all grey oh here's one
118 D no they're not
119 J what do you think
120 D Mmm.. yeah probably
121 A I just think you get black
122 J I think black look cos there is black on him and he's completely black
123 A yeah apart from the white
124 D no but they've got that baby no haven't they
125 A yeah but
what baby

yeah but they're more likely to...they've got a bit of black each so I reckon it's black

she hasn't got one of them

come here...must have fallen off. where is it

I'm putting two blacks down

I'm not

here's two white

because they've both well they've both got black on them

next one you're always last

Jane and Andrew seem to be using their conceptions of familial similarity as a basis for their offspring choices (101 and 102). At (112) Darren appears to be justifying Andrew and Jane's choices to himself on the basis of his gender conception of parental influence. Picking up on Jane's lead (113) all three seem to reach agreement on the likelihood of more black offspring. At (121) Andrew restates his choice of black and qualifies this using a blending conception (127). Although not made explicit it is interesting to speculate on the relationship between Andrew's conceptions at this point and his earlier notion of 'dominance' with regard to black parents. Jane supports Andrew in his choice of black offspring (134). Darren does not agree with their consensus (131). Andrew in his gatekeeping/chairing role prevents any elaboration of this disagreement by moving them to the next card and censuring Darren for his tardiness at the same time (135).

Card 7 (Brown x Brown + Albino)

oh what...brown one and they've got a white one

(all three laugh)

well they have got both got white

yeah (***) stomachs...I don't know what they are called

how can a white mouse have a white spot (laughs)

you are funny...maybe how about

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The potential anomaly presented by card 7 appears to be recognised by Darren (136) and the group's laughter may indicate their joint awareness of the 'problem' that it presents to their existing conceptions and previous strategies. At (137) Jane appears to recognise the difference between parents and offspring but that
there is familial similarity in the colour of their (white) stomachs. Darren returns to his consideration of parental gender (141) and again it seems to be closely linked to the analogy of human skin colour and the relationship between black, white and brown skin tones. Jane questions this at (142) drawing Darren's attention to the two brown parents, and implicitly, the absence of any black colour.

At (143 and 147) Darren develops a blending conception with the white bellies being the focus rather than the main coat colour. This may extend the explanatory adequacy of an existing conception in the face of an anomaly. Jane at (144) seems to view this as plausible and echoes Darren's idea. All three students present strong interaction frames as they compete for the floor and to have their ideas accepted. Andrew seems to be competing with Darren and there is a reluctance to accept his notion of "mixing in" the belly colours of the parents. As an alternative, Andrew suggests a black and tan offspring at (153), but Darren disagrees on the basis that there is no tan colour ("orange") "in the family" (156). Jane supports Andrew by suggesting that there is considerable offspring variability and that the albino offspring in card 7 is an example of colour variability (159). At (162-66) Darren and Andrew compete to have their choices accepted. Eventually Darren appears to accept Andrew's choice. Jane then disagrees with Andrew (167 and 169) over his choice of a dark brown offspring which seems to conflict with her expectations. All three seem uncertain about their conceptions in the context of card 7, which in turn seems to increase their dissatisfaction with any
particular individual explanation. This dissatisfaction may reside in their reservations about the explanatory adequacy of each other's ideas. Andrew suspends the discussion by moving on (171).

Card 8 (Agouti x Agouti + Black)

172 D its done it again
173 J why
174 D like we had before
175 J no but that was look because they had black spots maybe that was a reason why they got that so I reckon the rest might be
176 D I reckon the spots should be black
177 J so do I
178 D cos the spots come after them
179 J yeah they would be black
180 D yeah
181 A there are a few blacks there
182 J if we can find them..one of these.. there's grey here
183 D here's one look carefully
184 J got any black ones Andy
185 D they're all at the bottom.. there's one keep looking under these ones
186 A here's a black one .two
187 J they black. they're grey
188 A oh
189 J they're grey
190 A blacky grey
191 J blacky grey
192 A there's a black
193 D I'll stick with these
194 J oh yeah sorry
195 D I think it should be those..four
196 J it can have four can't it
197 D yeah ..I think it should be cos it mixes in with that brown and makes it dark brown
198 A I'm putting five..sometimes you must have..what you have just done a few here
199 D like that yeah
200 A next one..grey and black

At (172 and 174) Darren comments on the similarity between card 8 and the previous card in which agouti mice appeared. Jane seems to see card 8 as a vindication of the blending conception whereby the black spots on the agouti parents contribute to the black offspring.
She and Darren appear to agree on this as the basis for their choices of offspring (179-80). Andrew at this point seems to support this strategy through his involvement in task activities (181, 186 and 190). At (197) Darren uses his blending conception to justify his choice of dark brown which he sees as the product of light brown and black. Andrew seems to be competing with Darren at (198); choosing five offspring to Darren's four but apparently agreeing over the colours chosen. Andrew again moves the group to the next card.

Card 9 (Grey x Black)

| 201 | D | I reckon it should be that colour cos it mixes in don't it if you put that in |
| 202 | A | yeah |
| 203 | J | mixes in but its not paint is it |
| 204 | A | no but no but it mixes in sort of thing..a bit darker than that |
| 205 | D | if you put that colour on to there |
| 206 | J | yes but surely black is stronger so they come out black |
| 207 | D | well no I reckon it should be like that |
| 208 | A | like that |
| 209 | J | as there are no black we'll have them |
| 210 | D | how about a lighter grey for one of them |
| 211 | A | oh it don't matter |
| 212 | J | yeah |
| 213 | D | cos it comes after there right..they could have another |
| 214 | A | black cos the mothers |
| 215 | D | we don't know anything about mice really |
| 216 | J | we should do shouldn't we |
| 217 | A | yeah what about one of them colours or would that be more |
| 218 | J | brown |
| 219 | A | black for Darren |
| 220 | D | how about that colour |
| 221 | A | I'm going to |
| 222 | D | it doesn't really mix in does it. I reckon it |
| 223 | A | should be that |

- 275 -
At (201) Darren leads with his blending conception of "mixes in". His exclusive use of this conception in recent discussion, may indicate that for him it is a very adequate explanation of events and a good basis for solving the 'problem'. Jane picks up on Darren's use of "mixes in" and challenges the painting analogy which she sees as being the basis for his predictions. Her overt reference to this analogy may indicate that she has reservations about its applicability in the context of mouse breeding (203). Andrew appears to defend the 'paint' blending conception by echoing Darren's strategy of "mixing in", but Jane's reference to the analogical basis of this conception seems to be largely ignored.

At (206) Jane challenges the blending conception with her notion of black 'dominance'. Darren disagrees as he sticks to his own conception (207), although he seems to accept Jane's choice of black by justifying it in terms of his own conception of parental gender influence (213). This heterogeneity in Darren's conceptual ecosystem also allows him to diffuse the disagreement with Jane and maintain their working relationship.

At (214) Andrew appears to be reflecting on his lack of knowledge about mice. His recent contributions to the discussion or the lack of them, and Jane's overt reference to the 'paint' analogy, may have left him with a feeling of uncertainty. Darren seems more positive about what they should and should not know (215) and presses on with his use of the blending conception (220). Andrew suspends the discussion by moving on (223).

Card 10 (Black and Tan x Brown and Tan + Black and Tan)
Jane seems to interpret card 10 as an example of black 'dominance' and perhaps justification of her previous conception (225). Darren's response, perhaps by way of challenging Jane's notion, is to use his blending conception (226). At (227) Jane works out the consequence of "mixing in" and may be questioning the plausibility of the offspring's "murky" colour. Darren at (228) seems to be striking a compromise with Jane with his "murky blackish" description, with Jane pressing home her 'advantage' by restating that Darren's choice was her original selection (229). Darren defends his position at (230) perhaps not wanting to be seen to be 'wrong'.

Jane suggests brown as an alternative offspring colour (231). Andrew's response at (232) describes black as the "stronger" colour, as he echoes Jane's 'dominance' conception. Andrew seems to have incorporated the idea of the frequency of black offspring into his earlier conception of 'dominance'; black offspring are now more
likely than brown as opposed to black being the only type of offspring. Jane indicates the move to the next card (238) with all three apparently in agreement over the choice of offspring.

Card 11 (Dark Brown x Dark Brown + Light Brown)

240 A ah this is funny I know
241 D how could it be
242 J cos back in the family there might have been
243 A but its lost the orange
244 D you don't know that do you ..that's there's the same colours and they've come out different weird
245 J cos on Blue Peter they said that all them dogs
246 D but dogs are different from mice aren't they
247 J why should they be
248 A because the size
249 J why do you say the black mice and the white mice come out half-cast and you get a black one and a light brown like in a half-cast
250 A I think this one should be
251 D if you had a black black man and a white woman you would both would come out not spotty but (laughs) ..but chocolate
252 A yeah..like half-cast
253 D he's got a black dad and a white mum

Darren is puzzled by the situation depicted in card 11 (241 and 244). It is possible to speculate that dark brown parents with a light brown offspring represents an anomaly in the context of his blending conception. Jane's 'explanation' refers to her conception of previous generations influencing the colour of offspring, and she seems to be supporting this notion with reference to events on a popular children's TV programme (Blue Peter) (245). Darren disagrees with her on the basis that her example is based on dogs and not mice (246). Andrew supports Darren but seems to miss the point with his reference to size (248). Jane defends her dog analogy by questioning the half-cast/human exemplars used by
Darren (249). This challenge leads to Darren qualifying his notion of half-cast (251), and perhaps gives an insight into the overlap between colour mixing and the social experience of inter-racial marriages which make up his blending conception (253).

254 A yeah I reckon it should be brown because it's the main thing in the parents
255 D yeah cos that one that one's just an odd one
256 A yeah
257 D that came out odd
258 J it ought to come out like that
259 D that came out odd I reckon
260 A in a litter you're not likely to get them all the same
261 D no not likely to get them all the same so why can't you have a brown one instead..not black
262 J I'm putting that I'm happy with that
263 D I reckon it should be that and another brown one however the brown is
264 A oh no I've put brown
265 D oh there I reckon it should be that
266 A yeah I'm sorry I put in an extra one another brown
267 D that one that one there we are
268 A I reckon its that
269 D you've put too many in
270 J why
271 A its more likely to be the parents
272 D yeah
273 A there's black there its darker . you might get one yeah but there's black there cos that's a strong colour
274 D dark brown I want there let's have a couple of them
275 A I've got three of those and one of them
276 J two browns one of them a sort of mixture between these three
277 A I don't know.. yeah you've got a point there
278 D yeah like that
279 A Mmm that's a darker one isn't it
280 J no not with an orange stomach
281 A that. like that Darren
282 D this one I've got one
283 A yeah like that
284 D that's what I think it should be
285 A yip
286 D alright happy
287 A I'm happy

Andrew suggests that they should choose brown like the parents on the basis that it is the "main thing" (colour) (254 and 271).
Darren agrees with this lead and 'explains' the lack of similarity between offspring and parental coat colour by describing the former as an "odd one" (255, 257 and 259). Darren's use of this 'explanation' may be based on the notion that "odd" or strange offspring can occasionally arise in families. At (258) Jane seems to support Darren's conception whilst agreeing with Andrew's initial lead.

Andrew uses his conception of familial variation at (260) which seems to support Darren's notion of the "odd" offspring. Darren echoes this notion of variation (261) but censures Jane for her choice of a black mouse. It seems that at this point Darren accepts variation in the offspring that centres on brown variants (263). Jane sticks with her choice of black (262) but Andrew using Card 10 as an example tries to persuade her that brown offspring like the parents are more likely (271 and 273). Jane seems to deflect this disagreement by suggesting a blending conception involving all three of the 'given' mice on card 11 (276). Jane and the boys seem to agree on this conception (277-78) and they establish a consensus of opinion.

Card 12 (Agouti x Albino)

288 D is there a white with spots black spots
289 A no..look perhaps it leaves its spots. its the
290 J yeah..mother..mother
291 D from the mother there with the white
292 A yeah that brown
293 D perhaps it could be. I reckon we should have one of them
294 J I think it should be that
295 A that's what I've got
296 D I reckon
297 J its darker
298 D I reckon that's
Darren seems to use a blending conception at (288) with the others competitively collaborating to have their ideas accepted. Jane's 'cue' of "mother" allows Darren to introduce his conception of parent gender influence (291). On this basis he selects a white offspring (like the mother) and it seem that this conception is linked to his notion of colour being "from the family" (307).

At (292-304) there is competitive collaboration which seems to be based on the student's interpretations of blending the agouti and albino parents. Jane makes explicit the potential for different coloured offspring from this mating (305). Andrew uses his blending conception to justify his choice of grey and brown mice (310). All three agree to differ in their actual choices (306, 311-313) in spite of Darren's gatekeeping (311). Andrew looks up at the researcher inviting him to join the group.

After a few minutes the group were introduced to the second task.

(Andrew starts to read the text aloud)
genes
I don't know
what do genes mean
is it from its parents
the coat colours come from the genes
(Darren reads the next page aloud)
(Jane reads the next page followed by Andrew)
(Darren reads the next page followed by Jane)

Yeah
we got that
that's what everyone said
yeah
that's what we mixed in didn't we
mice with coloured coats
(Andrew reads page 7 aloud)
but if we had had this one wouldn't if that wouldn't it
come out a darker colour than we put
well it has hasn't it apart from that one
I didn't..I put a light one
you didn't you put light colours
yeah but that's not exactly that dark
no but you've got white colour there
more spots in that one
its dark let's keep reading
we've done that
(Darren reads aloud)
(Jane reads aloud)
that's . its white white with pink eyes
we're not finished reading
(Jane reads on)
mice with light coloured coats (reads from text) that's
what I said wasn't it
dark coloured mice (reads text)
yeah that's right light coloured mice is dark mice and
the darkest is strongest right
(Jane reads aloud followed by Andrew)
look look agouti non agouti that eh you know capital
A and small a bigger A is stronger one so it will be
agouti
which is that
is that agouti
that's agouti
oh I see
finished

The group take it in turns to read each page of the text aloud.
This seems to be the way they read in public during class
activities. From (319-23) Darren and Andrew 'confirm' from the text
that their blending strategy is 'correct'. Jane challenges this,
(325) and seems to be using the text information to support the idea that dark colours will be 'dominant' over light colours. At (326-30) they refer back to their previous selections with the boys defending their choices in a rather vague way. Darren suspends this debate by suggesting that they read on (332). By (336 and 338) Darren has used the text to confirm his blending conception and seems to accept the 'dominance' of dark colours. Andrew seems to have developed an understanding of the geneticsymbolism used in the text (339).

The group were introduced to the final task. They were familiar with the family tree format, referring to Royal Family trees and a TV game show they had watched recently.

345 D  right let's go . . . dark colour
346 A  let's say
347 J  any colour
347 D  let's say
348 J  any two right, no pick two simple colours to start with
349 D  yeah
350 A  yeah well they're dark . . . you might that's the
351 J  one without an orange bit
352 A  yeah that'll do...right get one a dark colour
353 J  you got to get two here there
354 D  yeah that seems about right mixed in
355 A  yeah
356 J  not mixed in
357 D  it could be
358 A  you'll get that sort
359 J  that's the more dominant colour
360 D  yeah
361 J  on that one you'd get
362 D  perhaps perhaps that one could be
363 J  black with brown with grey
364 D  how about that one, what if those spots had mixed in like that
365 A  yeah grey sort of belly
366 J  you never know
367 A  yeah you're likely to
368 D  eh
369 A  one of each
The group begin task 3 competitively collaborating over the choice of offspring. Jane seems to have some task awareness (348) as they decide on the matings in 1. Darren seems to be gatekeeping and 'justifies' their choice of offspring in 1 with his blending conception (354). Andrew accepts this but Jane again challenges Darren's conception with her own notion of 'dominance'. Darren appears to accept the selection of a dark mouse but holds out for a product of blending at (364). They seem to reach a compromise over the choices (365-7) with Andrew's suggestion of "one of each" (369) and its implicit reference to familial similarity. This conception seems to be acceptable to both Darren and Jane and diffuses their disagreement.

370 J right these two mate and have
371 A cos that's the darker colour, so
372 D so these two are mating right so they are going to get babies so you want to get a grey
373 A a grey
374 D it would mix in
375 A we just read in the book
376 J these two
377 A the darker colour dominates the lighter colour so the brown
378 D so you want to do these two have babies
379 A that one to mate with
380 J no you don't
381 D no you don't
382 A but yeah there's something there cos that one's got a mate with that something like that and make that one to get those
383 J yeah but hold on a minute

At (371) Andrew seems to pick up on Jane's conception of 'dominance'. Darren again challenges this conception and puts forward his own blending notion (372 and 374). Andrew is puzzled by Darren's choice of grey (373) for 4 involving as it does the
mating of a dark brown with a light brown mouse. Andrew appears to justify his disagreement with Darren by referring to the text (375). Interestingly he uses the present tense "dominates", as opposed to the word dominance used in the text, to describe the effect of dark colours on matings (377). Andrew is successful in getting two dark brown offspring on the board at [4]. Darren moves to [3] without further consideration of this choice (378).

384 A we've got to put something there  
385 D let's put say that to mate with that  
386 A that grey yeah that would be a good  
387 J so these two  
388 A it doesn't matter cos its not connected to the others  
389 J no you don't I thought you had one from there and one on there and then so those two  
390 A mate yeah  
391 J and they would get what colour  
392 D ehm  
393 A I reckon they'd  
394 J grey with a grey belly but  
395 D grey with a grey belly  
396 J why have you got three mice on there  
397 A I just put it on cos I thought it would be that one  
398 J yeah  
399 D let's have  
400 J no put that back  
401 D you can't have three parents can you  
402 J could  
403 D funny funnee (sic)  
404 J I reckon it would be that one  
405 D let's have another one let's say what mixes in cos its the darker colours that go  

The group seem tentative and uncertain about their choice of offspring for [3]. Having chosen a slate grey parent to go with the agouti parent they appear reluctant to commit themselves beyond making 'experimental choices' (394 and 404). At (405) Darren takes the lead and qualifies his choice with reference to his blending conception. Interestingly, he seems to have adapted this to include
the notion of 'dominance' by dark colours. He is perhaps aware of
the previous challenges to his "mixing in" notion and the need to
accommodate the ideas of the others and of the text.

406 A right now. those two put together make a dark brown
407 D those two mate right..dark colour
408 A dark brown
409 D just a minute
410 A look just see..the black and brown and grey is more like a
dark brown
411 D yeah
412 A I'll do dark brown then
413 D let's go over here now
414 J I don't I don't think it would be dark brown because what
is the stronger colour of them two
415 A grey
416 J grey but that's got black on it and grey
417 A well that's got black on it and grey
418 J that's what I mean black on it and grey
419 A that's right that's got to be grey then
420 D you're probably wrong
421 A dark grey
422 J yeah
423 A don't you agree
424 J yeah yeah I do

The debate about choices for C3 goes on with Andrew and Darren
apparently agreeing to have a dark brown mouse and sharing a
conception of 'dominance' (406-13). Darren tries to suspend the
debate at (413) but Jane disagrees with the boys' choice of brown.
She seems to be questioning which colour is the darkest in the
parents and which colour should be 'dominant' (414). She draws the
boys' attention to the black spots on the agouti parent (416) as
being the darkest. At (418) she seems to be using a blending
conception which accommodates the strength of colour. Andrew on
the other hand appears to be working on the assumption that the
darkest parent determines the colour of the offspring. Darren
supports Jane's disagreement (420) and Andrew seems to compromise
with his suggestion of dark grey (421) which seems to satisfy Jane
(424). This compromise is in effect Andrew's original choice of
grey blended/darkened by the black spots of the agouti parent and
represents a synthesis of 'dominance' and blending conceptions.

425 D  right these two are having babies now right
426 J  ah
427 D  these two are having babies ok so
428 J  then brown is the stronger colour
429 A  yeah but its got black there as well..you might get that
say that
430 D  I'd say
431 J  I don't think so I'd think black
432 A  oh well alright black get one then
433 J  no I don't ...I think dark grey
434 D  yeah dark grey like that can we use the ones on the card
435 J  no you don't have to have them the same
436 D  (** mixed
437 A  I think black black have a black one. plain black
438 D  we'll put that one there let's sort this one out
439 J  that one's the stronger colour
440 D  brown
441 J  a murky brown
442 D  yeah cos it mixes in ...let's have a darker one and a
lighter one like that
443 A  I reckon
444 J  hold on a minute I was going to say one of these could
turn out the colour of one of these back here

The group turn their attention to [5]. Jane decides that the brown
(parent) is the stronger colour (428). Andrew, using the same
argument as Jane used against him in the previous episode, draws
her attention to the black spots of the other (agouti) parent
(429). Andrew suggests a dark grey colour, perhaps aware that this
blending/dominance conception was the basis of agreement in the
previous discussion. In response, Jane seems to be using a
conception of black 'dominance' and not blending (431). Faced with
this apparent contrariness Andrew seems to accept this suggestion (432) only to have Jane change her mind again to his original choice (433). Jane uses her conception of familial variation at (435) and this appears to give Darren scope to apply his own particular colour choices and conceptions. Jane sticks with the notion of stronger colours, and Darren uses his blending conception (442). Jane justifies the range of offspring that result, and her earlier idea of offspring variation by referring to previous generation (444).

At (446) Darren is aware of the number of brown mice on the board, and he describes this as "runs in the family". Andrew connects this with brown being the stronger colour and seems to be explaining Darren's observation in terms of his 'dominance' conception (449, 450 and 453). This notion seems to exist side by side with Andrew's blending conception (456). Jane refers back to the notion
of "cross-breeds" at (459), which in previous discussions overlapped with her blending conception and gave rise to offspring that were an obvious blend of both parents ie. no allowance was made for strength of colour.

462 A or like that dark brown dark brown
463 D yeah I think cos its the same cos running in the family again
464 A yeah dark browns all up there
465 J yeah
466 D right these are having babies again
467 J and one of them
468 A I think we've got to find a mate
469 J I think its one of them
470 A well you pick one
471 D you can't
472 A you can't put one there he's mating with him
473 J with his sister
474 D he's mating with him
475 J you just said
476 D he's mating with her so he wants four babies come on
477 J I reckon that one of them really
478 A I've got one which it says in the thing
479 J its got to have a grey one somewhere because if you go back
480 D it runs in the family...no we should have one like that
481 J I reckon we should take this one away
482 A no black is the stronger colour
483 J then you've got a lot of white
484 A his father is black as well
485 D perhaps we should have a grey

Darren and Andrew return to their description of family resemblance and the frequency of brown mice in the tree (462-4).

Darren, 'chairing' the discussion moves them to the next branch of the tree (8) (466). Andrew and Darren's 'chauvinism' is exposed at (472 and 474) as they seem to be suggesting that two male mice mate. Jane's response is interesting in that she corrects this 'mistake' without actually making the error explicit (473 and 475).
They competitively collaborate over offspring choices using blending (Darren 485), 'dominance' (Andrew 482) and family resemblance (Jane and Darren 479-80) conceptions. All of these notions seems to be simultaneously active.

486 D right let's move over we've got another one there
487 J oh we just had that last time I think some should suddenly turn out white
488 D yeah runs in the family
489 J its only got one white in the whole of the family
490 D I think we should have a white cos he could have a baby and it could come out white
491 A look read the book again. the dominant colour is stronger
492 J yeah
493 A yeah but it might come out odd you don't know that
494 D yeah but brown white brown white my names Irish but I'm not Irish
495 A well brown white brown white my names Irish but I'm not Irish
496 J you're names Irish
497 A no. yes Kelly that's ages ago yet I'm still not Irish don't sound like Irish
498 D my name's Irish mine's I don't know what mine is I'm half Irish
499 J but it could go right the way back to there its possible (bell for morning break sounds)

Jane seems to be aware of the similarities in the offspring chosen by the group and advocates that by way of a change they might have an albino. Her use of "suddenly" may indicate she is using her notion of albino frequency, their unpredictability and comparative rarity (487). Darren sees albinos as running in the family, but his use of this idea to justify the choice of an albino is challenged by Jane (489). Darren tries again at (490) and justifies the albino choice in the face of Andrew's challenge (491) by referring to the occurrence of "odd" mice (494). Andrew challenges the albino choice and supports this by referring to the 'authority' of the text on
'dominance'. He sees brown as dominant over the white in (91) and simultaneously he contests the notion of 'in the family' with an analogy involving his own ancestry (495 and 497). Darren comments on his "half-Irish" name; perhaps an interesting insight into another aspect of his conceptual ecosystem relating to inheritance. At (499) Jane seems to be suggesting that the albino at (1) is still a possible way of explaining the appearance of another at (9).

5.5.1 Summary.

Darren leads the discussion with the idea of colour variation amongst the offspring, to which the others agree readily. Perhaps aware of this ready consensus, Darren questions his own initial suggestion which invites the others to comment. Jane uses the 'Blue Peter' dogs as an example of breeding animals, but seems confused about which viewpoint this supports. She is perhaps more concerned to agree with Darren than to be accurate in her description. Andrew also seems to follow Darren's lead by revising his support for variable offspring and qualifies this by suggesting that offspring are more "likely" to be the same as the parents. Darren appears to be 'experimenting' with his ideas perhaps trying to pick up the direction from which the others will approach this task. Andrew and Jane seem to be similarly disposed but prepared to follow Darren's lead at this point.

In their discussion of card 2, Andrew and Jane seem to agree on a blending conception which results in "multicoloured" offspring.
In qualifying this notion Andrew and Jane use "mix" and "mixing" to
describe how each parent contributes to the appearance of the
offspring. Darren challenges this conception using Andrew's
previous idea that the offspring should look like the parents.
Andrew's response to this is to further elaborate his blending
conception, which encapsulates a notion of colour strength and the
effects of dark colours on the "mix" of parental coat colours. It is
possible that Andrew's conception of 'like begets like' used in card
1, where the parents are the same colour, can also be 'explained' in
terms of a "mix" of the same colours. Andrew's blending and 'like
begets like' conceptions may in this way be interrelated and not in
conflict. During this episode Darren's continued 'experimentation'
with alternative ways of looking at the problem are censured and
challenged by the others. Jane appears to accepts Andrew's
blending ideas and interrelates this with her notion of offspring
variability/ colour variation used initially by Darren.

Interestingly, Jane's conception of blending seems to be less
influenced by Andrew's notion of colour strength. In her challenge
to his preference for dark coloured offspring in card 2, she makes
explicit her notion of blending which she relates to being "half-
cast". This may provide an interesting insight into the interaction
between a lay scientific idea and Jane's conception of blending. It
is possible to speculate that her notion of offspring as being a
'true' blend of parental colours may be influenced by her experience
of half-casts intermediate between parental phenotypes. Andrew on
the other hand may not be 'constrained' by this type of interaction
as he extends the paint mixing analogy to take account of colour
strength. He suspends any discussion of what Jane may mean by "half-cast" by moving on to the next card and suspending the discussion.

Darren interprets card 3 (albino x albino) as being "pretty obvious" and leads strongly with his conception of familial similarity. Jane suggestion that some of the offspring could be coloured is partially accepted by Andrew with the proviso that they are "light coloured". Implicitly this qualification of Jane's idea may relate to his blending conception. Jane disagrees with this constraint on offspring colour and uses her conception of genealogy and previous generations to explain how coloured offspring might come about. Andrew contests the relevance of this notion in the context of the problem format, and reiterates his own ideas apparently trying to take on the role of gatekeeper as to what is an 'acceptable' idea. Darren seems puzzled by the anomaly of white parents having coloured offspring. He tries to make Andrew aware of the conflict between coloured offspring and the conception of 'like begets like' but he is censured and his 'reservations' are ignored by Andrew. Andrew moves them on to the next card with Darren's questions unresolved.

Perhaps aware of their differing viewpoints, in the next card the group seem to establish a consensus of opinion about offspring choices on the basis of a shared conception of blending and colour strength. Darren seems to be developing his own conception of parental gender influences at this time and is concerned with discriminating between the mother and the father.
Card 5 (Black x Black + Brown) is 'explained' by Jane's conception of genealogical influences and she stresses how this card vindicates her earlier suggestion that this was a possibility in determining offspring colour. Andrew accepts this and acknowledges that Jane was 'right'. Darren again tries to pick up on previous ideas by using the phrase half-cast to describe the brown offspring. Jane challenges his use of this notion indicating that her conception of half-cast may be strongly related to human, black and white, interracial matings and their progeny. Jane explains to Darren that both parents on the card are black and therefore they cannot have half-casts. Darren perseveres with his notion of gender influence, indicating that if the mother is black the children will be black. In spite of Jane's explanation Darren also seems to persevere with his notion of half-cast as an explanation of the brown mouse in card 5.

The next card sees the group develop a vague consensus about offspring choice. They appear to compromise by having a selection of offspring some of which are like the parents, some which are a blend, and others which are the result of black being a strong colour. They appear to be tolerant of a range of conceptions as they competitively collaborate with one another to make their offspring choices. Andrew and Jane in particular seem confident about being able to justify their choice, Darren less so.

Card 7 (Brown X Brown + Albino) is met with some surprised laughter. There is a good bit of competition for the floor as each of the students put forward their ideas for offspring choices. They seem uncertain about their explanations and the adequacy of their
blending conceptions in particular. Darren seems to be adapting existing notions of blending to include offspring and parents to arrive at his choice of offspring, while Jane interprets the card as being indicative of the unpredictability and variability of offspring. All three students appear to be aware of the anomalous nature of this card in the context of their respective blending conceptions, but seem to persevere with this conception nonetheless. Each student makes their choices of offspring but as Andrew moves on to the next card their ideas about why there should be an albino are apparently inconclusive.

In their discussion of the next card a consensus develops based on their conceptions of blending. All three seem happy to accept each others choices as plausible and there is considerable task co-operation and collaboration. It is interesting to speculate that this behaviour may result from the uncertainty experienced in the previous discussion and the need to re-establish their confidence and their working relationship.

Darren leads their discussion of card 9 with his conception of blending. At this point Jane, perhaps sensitive to Darren's continual use of the phrase "mix in", makes explicit the painting analogy which she perceives as underpinning his ideas, and challenges its plausibility in the context of the problem. She is apparently ignored, and she does not pursue the matter. Indeed she seems happy to use the notion of black 'dominance' in blending immediately after her challenge. Interestingly, shortly after this, Andrew states that they don't really know anything about mice to which Darren responds that they should.
In their discussion of the next card all three seem to use blending as the basis of their choices. Andrew makes explicit his ideas about the 'dominance' of black in determining offspring colour. Jane at this point appears to be using a blending conception which does not consider colour strength. Her challenge to Andrew that there may be alternatives to black offspring is met with a further qualification of his conception. This considers the frequency of black offspring and the fact that there will be more offspring of this strong colour than any other. This interrelationship between strength of colour and frequency of offspring may be an interesting extension and adaptation of Andrew's conceptions relating to 'strength' in a social context as well as those relating to dark colours. It may also be an insight into the continuous qualitative changes that conceptions undergo.

Card 11 (Dark Brown x Dark Brown + Light Brown) revisits the potential anomaly of card 7. Darren and Andrew seem to perceive the anomaly of this situation immediately. Jane, perhaps having thought it through since their previous encounter, suggests that it can be 'explained' by her conception of the influence of previous generations. Again she uses the example of the dogs on Blue Peter to support this idea, and again this is challenged by the boys on the grounds that mice are not the same as dogs. Jane defends her example by asking Darren why he uses the example of half-casts. The implication being that he is using human exemplars. Darren qualifies his blending notion in relation to this challenge and perhaps reveals the relationship between blending and his experience of the "chocolate" children of black and white men and
women. Half-casts seem to enhance the plausibility of Darren's blending conception. As for the anomaly of card 11 Darren seems to explain the light brown offspring as an "odd" one and that subsequent offspring should be more like their parents. Andrew accepts Darren's suggestion and the two boys develop a consensus around their respective blending conceptions and that there will be a degree of variation in the colour of the offspring. The latter conception may also allow the group to accept variations in each others offspring selections and thus maintains their working relationships. The final card sees the three students choosing their own offspring with some certainty. It may be that offspring selections can now be explained by one conception or another in ways that are at least plausible to the others. Blending being the most acceptable, apparently fruitful and adequate explanation of the problem.

The reading task was carried out in what seemed to be a classroom style of taking it in turns to read aloud a page at a time. Their comprehension of the text seemed to be largely in terms of their existing ideas about blending and colour strength. The text 'confirmed' these ideas and was seen as reinforcement of the latter conceptions. The text information was apparently 'all things to all men' (and woman).

The family tree task began with Jane challenging Darren's blending conception with her conception of 'dominance'. She disagrees with Darren's strategy of "mixes in" and advocates offspring choices based on what she describes as "the more dominant colour". Darren and Jane fail to agree on their offspring
choices for [1] and it is at this point that Andrew acting in the fashion of an honest broker suggests that they have offspring which take after each of the parents. This is tacitly accepted by Darren and Jane and is an interesting insight into how disagreement and challenge can be diffused by conceptual heterogeneity and the actions of a third party.

As they move to another area of the board (3) Jane and Andrew appear to be using their conceptions of 'dominance' to make their offspring selections. Darren perhaps aware of the challenges to his blending conception seems to be adapting this to take account of colour strength. All three compete to have their offspring choices accepted but there is some uncertainty about the 'dominant' colour and the appearance of the offspring. At [5] the discussion again centres on the 'dominant' colour and the colour of the offspring. Perhaps aware of the disagreements arising from trying to decide on the outcome of 'dominance', Jane and Andrew seem to compromise by using their blending conceptions to choose offspring 'in between' the parental colours. As they move on Andrew and Darren seem to agree on their blending conceptions as the basis for offspring choices. Jane on the other hand seems to be acting in a contrary fashion by using her conceptions of 'dominance', offspring variability and the influence of previous generations to compete with the boys' ideas. Darren seems to pick up on the latter notion and suggests that the progressive darkening of the colours in the family tree and the frequency of the brown colour, are evidence of brown "running in the family". Darren's efforts to apply this notion to the problem of predicting offspring is challenged by
Andrew who uses his Irish decent as an analogy of how things do not run in the family. Jane suggests that the family might have some albinos and implicit in this idea is that the incidence of these white mice will be unpredictable. Darren observes that an albino appears at (2) and that this colour will also run in the family. Andrew challenges this idea on the grounds of the 'dominance' of dark colours and refers to the text as authority for this view. Andrew's response is to justify the albino as being an "odd" one with the implication that they can occur by chance and outside the normal 'rules' of inheritance.

In these latter stages of task 3 a very fluid situation exists between the students. A number of conceptions are being used simultaneously and there is considerable competition between individuals and their ideas. However, the level of interaction between conceptions seems to be limited. Strong interaction frames are presented by all three students but the content frame being used is weak. Ideas remain largely implicit with the students apparently 'experimenting' and testing the worth of their respective notions without making an absolute commitment to them.
From the previous case studies a number of significant results begin to emerge in relation to children's conceptual ecosystems.

Children possess a variety of existing conceptions about inheritance phenomena. These are frequently expressed in a vague and indeterminate way and are deployed with little apparent commitment. Conceptions are often introduced into social discourse in an experimental, speculative and competitive way. Students deploy their intuitive theories in a serial or simultaneous fashion and although contradiction between these conceptions often emerge during discussion, conflict and disagreements are rarely experienced. Explanations offered in response to inheritance problems are frequently selected on the basis of their social and interpersonal worth rather than on their problem solving utility.

Conceptual change within this social and personal dynamic seems to be more a case of selecting from a range of heterogeneous ideas rather than actually swapping or discarding one idea for another.

In Chapters 6 and 7 I will develop an ecosystemic perspective on these research findings based on my research model. The aim of this activity is to provide a descriptive framework which will allow me to develop an understanding of how these components of ecosystems might influence the nature of conceptual processes and conceptual change.
6.1 Colonizing Conceptual Ecosystems.

The research model described in Chapter 2, communicated the notion that ecosystems are constructed from individual conceptual ecologies. These provide the learner with a background of existing conceptions and experiences against which currently unsolved problems can be 'understood'. Case study analysis has revealed a pool of conceptions which are commonly used by students to construct conceptual ecosystems of inheritance. The problem context can be seen to exert a selective influence on the ideas which the student brings to bear on the situation; the student speculating with ideas from her conceptual ecology as she constructs an ecosystem relating to the inheritance 'problem'.

A conception which emerges readily from conceptual ecologies, and which is a vigourous 'colonizer' of individual ecosystems, is the notion that mouse offspring are a blend or a 'mixture' of the parental coat colours. The foundations of this conception for many students would seem to be their experiences of colour mixing when painting or drawing, coupled with the notion of reproduction and parental contribution. The children's choice of offspring on the basis of a parental colour blend, seems to be a relatively spontaneous response to the problem of dissimilar parents and their progeny.

In problem situations where the parent mice were identical, an intuitive response by many students was to predict the colour of the offspring on the basis that they would look like their parents.
From the learner's viewpoint, children 'take after' their parents - "white parents have white children" and 'like begets like'.

In the context of the problem tasks presented to the students, both of these conceptions represent a fruitful way of predicting the outcomes of parental matings, and provide a 'solution' to the problem (many a pre-Mendelian biologist would have thought so anyway). However, these conceptions were not the only colonizers of individual ecosystems and it was common for a number of other ideas to be elicited by the group's activities. Conceptions of familial variation were often interwoven with conceptions of familial similarity; the limits of colour variation (shades) within families sometimes being determined by the parental inputs or what colours were seen as being 'in the family'. Describing this latter conception of familial variation as being interwoven with the idea that offspring look like their parents seems to provoke, in the observer's mind at least, the view that these notions are incompatible and inconsistent within a single ecosystem. However, it seems very much in the nature of children's conceptual systems that these ideas can interact and co-exist without mutual interference or conflict.

Other conceptions used in the colonization of ecosystems related to the notion of sibling similarity, half-cast or crossbred offspring, the 'chance' occurrence of albinos and the possibility of infidelity between parents. These conceptions were common in many but not all ecosystems.

The prevailing impression is that conceptual ecosystems are not colonized by one or even two ideas but a number of conceptions
which are not co-active but do co-exist. These conceptions fluctuate in their use within localised domains of problem solving utility and are selected by the task context and the group dynamic. Conceptions of blending inheritance co-exist with notions of familial similarity, these conceptions being used simultaneously or in turn (not simultaneously active) to predict the colour of offspring. In such an ecosystem it is also possible for the student's conception of 'dominance' to conflict or not to conflict with existing conceptions of family variation or blending. In the former case if the student has found some problem solving utility in his notion of blending, then a conception of 'dominance' (the dominance of one colour, usually black) can challenge this idea. However, equally likely is the adaptation of the blending conception to incorporate the notion of 'dominance' and interpret it as being related to colour strength. For example, a cross between a dark brown and a white parent no longer results in 'chocolate' offspring but gives rise to dark brown ones, because that "is the stronger colour'. Blending conceptions in particular seem to be very "permeable" to a range of experiences eg. half-cast children are a blend of black and white parents: interestingly this rationale often leads to a prediction of grey mice in spite of the children's awareness that it gives brown skin colour to human half-cast offspring. Equally the conception that like begets like can be explained as a blend of the same coat colours.

It would seem that individual ecosystems can maintain a number of interrelated conceptions in a relatively autonomous and independent way. Ecosystems are capable of great conceptual
heterogeneity and appears to be able to maintain that heterogeneity through what appear to be almost transient phases of integration and conceptual overlap. Watts and Pope (1985) draw attention to Kelly's (1970) emphasis on serial inconsistencies and his observation that during debate or in the course of problem solving, people are often aware of inconsistencies in their own conceptual systems and in those of others. Kelly was particularly interested in fragmentation as it applied to children's thought and the creative potential afforded the individual by stepping outside the 'straight jacket' of consistency to find out what might happen.

The nice thing about hypotheses is that you don't have to believe them. This, I think, is a key to the genius of scientific method. It permits you to be inconsistent with what you know long enough to see what will happen. Children do that. What is wonderful about the language of hypothesis is its refreshing ability to free the scientist from the entangling consistencies of adulthood. For a few precarious moments he can think again like a child, and, like a child, learn from his experience. (Kelly, 1970)

6.2 Interactions between Conceptions.

The nature of the overlap and interdependencies between student's conceptions of inheritance seem to vary considerably. Experiences of mixing colours overlap with the conception that offspring are a mixture of parental characteristics; "I get my good looks from my mother but my temper from my father". Alternatively a statement such as, "most of the mice will take after their parents but there might be the occasional odd one (albino)", might acknowledge some overlap between the frequency of
albino mice and notions of familial similarity. Claxton (1984) in his description of the overlap between "gut" and "lay" science comments on how these two domains of understanding can provide explanations of the same phenomena yet be unconnected and uncorrelated. Gut science may conflict with lay science mini-theories, but because of the lack of integration between the two, no conflict is experienced by the learner. Claxton (1984) describes the latter type of interaction between mini-theories as being "laminated" whereas in situations where gut and lay science have been reconciled, they are seen as being "integrated". The analysis of children's conceptual ecosystems relating to inheritance, and the identification of interactive but non-integrated conceptions within ecosystems lends support to the view that conceptions can be 'organized' in this way.

6.3 The Nature of Conceptions within Ecosystems.

The conceptions which colonize ecosystems, often seem from the observer's viewpoint, indeterminate and indefinite meaning structures. Each member of the group interprets what the other is saying in terms of their own ecosystem, and on reflection, constructs his or her own interpretation of what has been said and meant. 'Vague' conceptions, under-articulated ideas, and indeterminate meanings are very much the stuff of group interaction. The researcher, in the privileged position of being able to revisit the dialogue of the group time and again, is not in the same position as the participants. Whilst the
researcher/observer wrestles with ambiguity and meaning, the conversation in real life has moved on and so have the participant's understandings of what has been said and meant. In spite of the fact that this may be a limiting factor in group 'efficiency' and 'productivity', the indefiniteness of conceptions within ecosystems allows each student a considerable degree of flexibility in constructing and adapting his own conceptual ecosystem.

In an ecosystem where blending and familial similarity have been used as a basis for offspring prediction, the conception of dominance could be seen as presenting a potential conflict to these conceptions (e.g. all of the offspring might now have to be dark or perhaps black). However, given the apparent indeterminate nature of these conceptions in the minds of the students and their lack of commitment to one hard and fast idea, 'dominance' can be interpreted as colour strength which in turn is assimilated into the blending conception. In such cases the "range of convenience" of existing ideas can be extended without anyone being seen to 'have been wrong'. More or less knowing what you mean and what others mean, whilst not making one's conceptions too explicit or too determinate, may be from the learner's viewpoint a very desirable characteristic of conceptual ecosystems. In this state, one's options are kept open and flexible. The learner does not make his conceptions immune to change and adaptation nor does he have to discard existing conceptions in the face of 'new' experiences.

A fluctuating ecosystem, driven by the heterogeneity and flexibility of conceptions within it, allows ideas to come and go.
depending on their utility and fruitfulness in problem solving contexts. Conceptions can be insulated from refutation by moving in and out of the 'action' depending on the cues and triggers presented by other students or task situations. This in turn preserves the viability of a number of conceptions whilst maintaining the heterogeneity of the ecosystem as a whole.

Given the 'fragmented' nature of conceptual organization, it would seem desirable that the learning process should encourage the child to test his conceptions and to reconcile existing notions with one another and with new ideas. In situations where multiple conceptions of the same phenomena exist within ecosystems, perhaps the ideal response would be for the learner to combine this compendium of experiences in one or two overarching conceptions. This process would be unique to the individual and would require the learner to test, experiment and evaluate the explanatory adequacy of his conceptions with other ideas. This individual initiative may result in the integration of conceptions, but before they become acceptable to the learner they often have to be tested in a communal setting. Conceptions which reconcile conflict between existing experiences and ideas can for example be tried out on others as a possible solution to a communal problem. Matching a conception with someone sharing the same problem as yourself, is an effective test of a conception's worth at a collective and personal level. The character of this negotiation of knowledge is discussed in the following sections.

6.4 Consensus.
A common pattern of interaction between group members was to seldom express disagreement with each other's point of view. In situations where there seemed to be opposing personal viewpoints and conflicting conceptions, the need to maintain smooth interpersonal relationships often diffused such situations. In this context, disagreement between individuals and challenges to their conceptions were rarely allowed to 'develop' sufficiently to the point where the tension between conflicting ideas were brought out into the open and actually experienced by the learners. In many instances one group member would accept unquestioningly the indeterminate conception of another without any attempt to ask for qualification or clarification of the idea. Often, in the face of anomalies, the apparent need for consensus between group members would damp out the variety and the intensity of ideas put forward as possible solutions. In some cases, if the individual 'gets his conception in first' then there is every chance of the others accepting it in spite of their own reservations. Thus, the opportunity for debate and discussion is diminished and the testing of conceptions within the group forum is made more difficult.

Patterns of consensus behaviour have definite effects on the number and quality of the opportunities for individuals to come to terms with their own conceptions in a social context. However, 'going along with an idea' even though you may not agree with it, does allow the proposer of that conception to travel with it and to test its explanatory potential. In what might be seen as following a 'garden path', a conception can develop positively or can run into
difficulties, depending on the circumstances which unfold within the problem context. A conception can be killed at birth by disagreement and conflict; equally it may be allowed to live out its life and to test its potential in resolving personal and communal problems.

An interesting adjunct to group consensus behaviour is the way that individuals within the group often collaborate in determining the pace with which they move through the tasks. While working on Task 1 (IAI type cards), the verbal or non-verbal cues given by a group member to move to the next card in the series are often accepted by the others. The signal to move on can be at the culmination of the group's activities on a particular card, but often it is used to diffuse disagreement or difficulties associated with a set of ideas or particular offspring choices. Individual group members can affect the quality and the quantity of discussion, agreement, disagreement and debate within the group by controlling the pace of the groups activities. Where the maintenance of good relationships seems to be important, interpersonal conflict based on differing viewpoints can be effectively damped out by 'simply' suggesting that the group move to the next card, page, or part of the family tree.

6.5 Disagreement and Challenge.

When one group member disagrees with another it can be a case of Andrew - "we should have a black mouse there"
Ben - "no we shouldn't"
Andrew - "yes we should"
or a more elaborate exchange where conceptions are presented by one participant only to have it questioned by another on the grounds of logic, applicability or utility. A challenge to the notion that all offspring will be black if one of the parents is black ('dominance') by a child who holds the idea that offspring are a blend of parental colours, is one such case. The outcomes of these disagreements and challenges are varied. In the latter example a typical response is for the proposer of the 'dominance' conception not to defend her idea but to use another conception, eg. the notion that parental gender is the determinant of offspring coat colour. In many cases this type of interaction results in the introduction of 'new' conceptions and may increase the heterogeneity of individual ecosystems. The activity of a group member prepared to play the honest broker by balancing the pros and cons of conceptions can have a very positive effect on this sort of outcome. In some cases a compromise conception is reached where for example, blending and 'dominance' conceptions are united in the notion of colour strength. This scenario also has the effect of smoothing interpersonal relationships and diffusing disagreements.

Challenges to conceptions and interpersonal disagreement often results in conceptions becoming more explicit as one child tries to explain what he means to another. In defence of an idea, anecdotes and personal experiences are often brought to bear on the debate with a range of examples such as pet mice, Blue Peter dogs, the boy down the road whose mum is white but his dad is black, ape-men etc. being used. Individual learners engaged in this process often
seem to raise their own conceptual awareness as well as that of the other group members.

In some groups one often gets the impression that disagreement and the challenging of someone's conception(s) becomes part of a ritual with a strong performance element. The audience for this being other group members, the video camera and the observer. However, one should not dismiss this type of interaction as simply 'being put on' for it may serve to mimic the problems associated with particular conceptions and the limits of their explanatory adequacy. In many groups competitive collaboration seemed to be a low cost way for individuals to get involved in the milieu of agreement/disagreement. In these situations, individuals seemed to experiment with their ideas by thinking out loud in the hope that they would resonate with another group member's conceptions. Conceptions were rarely made explicit in these exchanges and were therefore protected from public refutation, although they may have been put to the test privately. Competitive collaboration may insulate conceptions from communal testing while maintaining the conceptual heterogeneity and viability of individual ecosystems.

Lastly, it must be noted that there is another outcome of disagreement between individuals. That is, when it reaches a certain level the talking stops! When a student is censured by his peers or when he is accused of "being a wally" or "being stupid" relationships are strained. In these situations it is not uncommon for the conception(s) at the focus of the disagreement to disappear from the learner's public repertoire. If children are going to take
a 'risk' by making their ideas explicit, a supportive social environment may be a necessary prerequisite.

The interaction between individuals allows the observer to describe a number of interesting features which seem to be present within ecosystems. In the following section a number of these features which emerge from personal and communal group activities will be described.

6.6 Anomalies

Part of the design of the research instrument was to confront individual students with potential anomalies. In the first task students were confronted with mouse families in which the offspring were a different colour from the parents. In the case of black parents with a brown offspring, it was interesting that this was often not perceived as an anomaly in spite of prevailing conceptions of colour blending and like begets like. In this situation the heterogeneity of individual ecosystems appeared to diffuse the potential challenge to existing ideas by 'explaining' the anomaly in terms of another conception. For example, the brown mouse "comes from the grandparents" or "brown is nearly black and you always get some variations in families". In this way anomalies can stimulate the heterogeneity of ecosystems without threatening or eradicating existing conceptions.

In terms of providing an effective challenge to existing ideas, the presence of a white offspring with brown parents seemed to have the greatest potential. In the face of this problem, which
blending and 'like begets like' conceptions found difficult to 'explain', the utility and plausibility of these conceptions were often publicly and privately tested. However, the pressure on these conceptions was often relieved by the heterogeneity of the learner's ecosystem which provided a number of alternative conceptions such as the notion that albinos occur by chance and can "turn up" in families on rare occasions. Thus the effectiveness of this anomaly, in terms of questioning existing conceptions, often seemed to be reduced.

Anomalous situations often raised the students awareness of their current conceptions and in many cases caused them to support these ideas with examples and anecdotes. In this way anomalies can form a locus of debate and discussion about the fruitfulness of current conceptions. However, they also result in uncertainty and anxiety about existing theories, and in some cases caused the group to stop talking. Confronted by a situation where the existing pool of conceptions seems to be 'wrong', the response is sometimes not to reconcile the problem but to keep ones ideas to oneself and to carry on with existing ideas privately. In such contexts indefinite, under-articulated conceptions are insulated from this type of 'error', indeed indeterminateness may be one outcome of previously experiencing effective anomalies.

Effective anomalies can induce failure in existing conceptions and cause individual students to review the plausibility of their conceptions. The student who affirms that "you don't get black babies from white parents" in defence of her blending or 'like begets like' conceptions is perturbed by the presence of albino
offspring in brown families. Nevertheless, the response to what is for her an effective anomaly, may not require that she review the adequacy of existing ideas; there are a number of reasonable alternatives open to her. She may acknowledge but ignore the problem, explain it by using an alternative conception derived from her own ecosystem or that of another student. An important feature of small groups is that collective ecosystems provide a supply of conceptions that individual students may not possess. Looking at a problem from someone else's viewpoint may allow the individual to refine his own conceptions. Echoing another's conception may be a passive act but it may also provide the missing element in the formulation of a personal theory. In addition, it is interesting to speculate that if a learner 'borrows' an idea from the communal pool of conceptions, selection pressures acting against it (anomalies, challenges) may be directed toward the group rather than threatening individual conceptions.

6.7 Analogies.

As similarities between conceptions, analogies are often extended during the construction of ecosystems. The most common analogy used in the construction of inheritance ecosystems was the similarity between painting (mixing colours) and the way parental contributions are blended in the offspring. This analogy was rarely referred to explicitly by group members but did seem to underpin their blending conceptions. In situations where it was made explicit, "this is just like painting" or "its not like painting you
know", individuals using the blending conception seemed uncertain and uncomfortable when their tacit strategy was 'revealed'. Accompanying this response, there was often a reduction in the amount of subsequent discussion.

It is possible that the 'paint box' analogy is extended as a way of dealing with a novel problem. Its over-extension and the limits of its plausibility are balanced against its fruitfulness in providing a basis for offspring prediction. A number of factors are operating within this equation. Over-extension of the 'paint box'/blending analogy may result in conflict or the reduction of its plausibility, but this can be diffused by the heterogeneity of the ecosystem. Using a painting analogy may have personal utility within an individual ecosystem, in spite of the learner's awareness that it is only an analogy. However, when the 'paint box' analogy is made explicit in a communal context, the worth of the blending conception is tested in public. The plausibility of mouse inheritance being like 'mixing paints' is questioned and subsequently the explanatory adequacy of the blending conception is challenged. In these circumstances the group could talk about the nature of the relationship between painting and their conceptions of inheritance, but more often than not the issue is ignored and allowed to disappear from the public repertoire. Conceptions may have considerable personal worth within ecosystems, but it seems likely that they have increased value to the individual if they pass the test of public scrutiny. This communal testing of conceptions takes considerable confidence and courage on the part of the individual. Keeping the idea to oneself or tacitly
acknowledging the analogical underpinnings of a conception, may offer a path of less resistance.

Before leaving analogies and their role in conceptual systems, it is interesting to observe the effects of the reading task on the children's conceptions. Although this activity was planned as a 'break' in problem solving activity, the word 'dominance' was often incorporated into subsequent discussions. The resonance between blending conceptions and the idea of strong colours ('dominance') was an insight into conceptual organization which the text admirably highlighted. However, in some cases the textual authority accorded the word dominance often 'swamped' discussions by reifying the blending/dominance notion. The effect of the text is initially at a verbal level but 'dominance' was rapidly incorporated into the paint-box analogy at an experiential level. The selection of textual information by students was determined by their individual states of awareness and their active conceptions. What was extracted from the text was either used to support a previously used conception or alternatively as a problem solving 'ready reckoner'. Whatever the effect, the text was used selectively and for a purpose by the students; the effect of the content on their subsequent problem solving was transient except in cases where they perceived the words to have some bearing on their prior conceptions, i.e. it was not what was said but the words that were used. This observation must have considerable bearing on the vocabulary of science and the words with which we describe scientific concepts to children.
7.1 Introduction

In Chapters 5 and 6 an ecosystemic model of children's conceptions was used to interpret the cognitive and social interactions when a group of children try to solve a problem. This model provided a way of thinking about conceptions and about those aggregates of ideas, analogies, metaphors and anomalies which make up the learners' conceptual ecosystems. This ecosystemic perspective has given an insight into the behaviour of children's conceptions and in particular allows an hypothesis to be put forward about the nature of conceptual change. In the following chapter this hypothesis will be described along with the evidence which supports this view of conceptual change.

7.2 Characteristics of Conceptual Ecosystems.

Confronted by a novel situation, that of predicting the coat colours which offspring inherit from their parents, learners bring existing conceptions to bear on the problem. This 'colonization' of the problem niche by the student, leads to the construction of a unique conceptual ecosystem. The conceptions which children use to colonize their ecosystems are made up of a family of ideas, brought to mind by a specific set of context related cues which the learner perceives as being related to the problem situation. Existing conceptions which have analogous or metaphorical relationships with the problem context are one source of conceptions, as are ideas drawn directly from previous experiences and similar
problems. In this way ecosystems are populated by a range of conceptions drawn from a pool of experiences which I have called the child's conceptual ecology. The diversity of this ecology results in the construction of an ecosystem which has a heterogeneous population of conceptions. This heterogeneity may be a manifestation of the context bound nature of children's conceptions, and when this is transposed into a particular ecosystem it takes the form of a mixture of loosely inter-related ideas which seem to overlap but in the process do not lose their individual integrity. Instead of a stable web of inter-related conceptions formulated into one coherent, integrated whole, children's conceptions appear to preserve an 'optimal distance' from one another: close enough to acknowledge a relationship and lend occasional support, but not close enough to be come a set of overarch ing conceptions.

Conceptual heterogeneity is a very characteristic feature of children's conceptual ecosystems. Indeed heterogeneity and the conceptual flexibility with which it is associated, are fundamental to the learner's ability to construct an ecosystem and to subsequently use it to make sense of an unpredictable world. The ability to cope with the unknown is part of the 'skill' of learning and this in turn depends on the 'creative' use of existing conceptions. These qualities are conferred on the learner by a heterogeneous and flexibly 'organized' conceptual ecosystem. Thus the maintenance of conceptual heterogeneity and flexibility is an inherent characteristic of conceptual ecosystems.
Children's conceptions are rarely refuted or discredited absolutely, even in the face of difficulties associated with their explanatory adequacy, they are often put to one side rather than being dismantled, and their place is taken by another conception which provides an 'alternative' explanation. Children in this research study had little difficulty in calling up a conception to take the place of one which had been temporarily discredited by cognitive and/or social events. This is one way in which the heterogeneity of the ecosystem is preserved. Heterogeneity over time is another facet of this behaviour. This is reflected in the way students use one conception in a particular context and yet another in the same or a similar context which they experience later on in the problem. By fluctuating in this way a number of conceptions can be maintained within the ecosystem in spite of the fact that they seem to be competing for the same sort of conceptual niche.

The fluctuating, flexible and heterogeneous 'organization' of a conceptual ecosystem gives the learner the ability to 'get a handle on' any problem that may confront him. Perceiving the problems in this study to be like mixing paints and then relating this to a blending notion of inheritance, gives an insight into the sorts of transpositions or metatransitions that heterogeneous and flexible systems make possible. It is from this base that the learner begins to develop his understanding and to test the plausibility and the utility of existing ideas. This in turn may lead to the adaptation of existing conceptions. However, this adaptation may not proceed with perfect freedom, for a consequence of conceptual
flexibility and heterogeneity is that it makes the ecosystem highly resilient. Resilience is a product of conceptual 'organization' and it confers on ecosystems the ability to maintain their existing conceptual relationships and to absorb change.

The resilience of conceptual ecosystems is most clearly shown in the way that challenges to existing ideas are diffused by the system. When a conception is challenged by another idea or when its inadequacies are exposed by a perceived anomaly, the emerging conflict is damped out by the use of an alternative conception drawn from the ecosystemic pool. Existing conceptions which are 'put on the spot' are not eradicated from the ecosystem but 'retired' and replaced by conceptions which are unaffected by the conflict. These replacement conceptions may be closely related to discredited ideas but in an ecosystemic context they will always be distant enough not to be affected by the same conflicts. In situations where the learner is confronted by challenges which threaten existing ideas the resilience of conceptual ecosystems damps out these effects.

The double-edged character of conceptual ecosystems allows conceptions to adapt and transform well and to resist change at the same time. This complementarity is reflected in the negotiation of knowledge which takes place between learners. In the previous chapter I have described how disagreement between students can lead to a situation where conceptions become more explicit and as a result become more open to testing and adaptation. However, it is equally likely that this same situation can lead to the cessation of discourse and the decay of the interpersonal interactions which
can result in conceptual adaptation. Similarly, consensus within the group may allow an idea to 'live out its life' and subsequently become adapted by experience, whilst on the other hand the same consensus may keep conceptions vague, under-articulated, implicit and insulated from change. These 'social manifestations' of resilience and adaptiveness are a feature of conceptual ecosystems and they reflect the heterogeneous and flexible character of these systems.

A paradox seems to pose itself here, for conceptual ecosystems seem to be organized in such a way that the same features which confer resilience on the system also enable it to bring about change within that ecosystem. However, in the next section this apparent paradox will be resolved by describing the nature of conceptual change within ecosystems.

7.3 Change within Ecosystems.

Two fundamental points need to be made about conceptual change within ecosystems. Firstly, change originates from within ecosystems and is the personal responsibility of the active learner. Conceptual change cannot be forced upon the individual, because the conditions which bring it about are not found in the logic of scientific ideas or in the 'rightness' of their explanations, but in the characteristics of the learner's ecosystem. Conceptual change is about the conditions which prevail within ecosystems and the ways in which conceptions interact with learning environments.
One condition for conceptual change to occur would be the necessity for children to act on what they know. Awareness raising helps make conceptions explicit because ideas have to come out into the open if they are to be affected by new experiences. Once conceptions become active in the ecosystem they have to be maintained in this condition; held at the front of the learner's mind and part of the current pool of communal ideas being discussed and tested. As with the children in this study, conceptions can generate considerable interpersonal activity in the form of discussion, conflict, agreement and disagreement. It is essential for conceptual change that this milieu be maintained and amplified by individuals in the face of strategies which may reduce the ecosystem's potential to bring about conceptual change. It is not being suggested that children be encouraged to disagree and fight out conceptual battles, we have seen how this often results in a situation where the talking stops; and given the primacy of communication in bringing about change this would be equivalent to cutting off the energy flow into conceptual systems. The notion being advanced is that given learning tasks which engage students in debate and discussion; given an environment where the learner's own conceptions can be actively tested by anomalies, metaphors and the critical but non-threatening appraisal of peers; given that conceptions remain co-active and interactive within ecosystems, then these 'amplifications' will bring about change from within the system.

In this research study there was no evidence of conceptual change involving the rejection of a specific conception. However,
this is not to say that change did not occur, indeed the impression is that where children's ecosystems are active they are in a state of continual change. The rate of conceptual change has often been determined by the time taken for alternative conceptions to become 'scientific'. In an ecosystemic context, it is inappropriate to mark off such a course. What one has to be prepared to do is to accept that change within conceptual ecosystems may be a series of near continuous qualitative modifications to a set of existing conceptions. In an unknown world, where the learner finds herself within a turbulent ecosystem of new ideas, conflicts and challenges to existing conceptions, the place to be is in a position close to the boundaries of conceptual stability. In this position one can more easily make the transition to a new level of understanding, although metaphorically speaking, this may be achieved rapidly by jumping over the cliff or more slowly, by sliding down the rock face. This metaphor illustrates what is a fundamental issue in many theories of conceptual change. One the one hand there are models of change which emphasise the importance of conceptual conflict and relate this to situations where the learner can no longer tolerate the inadequacies of his existing ideas and subsequently makes the conceptual 'leap' to the scientific view. Alternatively, other conceptual change theories describe a series of 'small scale' adaptations whereby existing ideas are used to assimilate new experiences which in turn leads to the transformation of the original notion. The model of change which emerges from this study proposes that 'radical' and adaptive change are part of the same dynamic.
In this thesis conceptual ecosystems have been described as unstable environments where conceptions are always close to stability boundaries, in other words ecosystems are flexible, heterogeneous and fluctuating systems. If change occurs within ecosystems it has to happen against a background of resilience. I have described how resilience tends to damp out change, but it can also be seen as a way of 'inviting' more powerful conflicts and challenges to act on existing conceptions. Over a period of time the resilience of the learner's ecosystem is able to absorb the effects of anomalies and searching discussion up to the point where perhaps a single experience or a word from a fellow student brings about a 'crisis' for a particular conception. The limits of resilience are exceeded and the only way for the student to remove the 'threat' of the new idea is to discard his existing conception. This situation may occur within conceptual ecosystems and indeed may explain the Eureka effect of sudden conceptual enlightenment. However, I would suggest that as teachers, the focus of our attention should be placed not upon the 'catastrophic event' which results in this dramatic form of conceptual change but on the series of metatransitions which conceptions undergo and which are part of the same process of change. I would suggest that these adaptations of existing ideas are what can be observed and facilitated by teachers and researchers. In this study it has been possible to describe subtle conceptual adaptations where for example, a conception of blending inheritance is modified to take account of 'dominance' or where it is adapted to take account of phenotypic variation. These adaptations are as much a part of

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conceptual change as the more obvious 'radical' events described above.

Without the effects of resilience conceptual change might occur in a very direct fashion every time a new set of experiences resonate or come into conflict with the learner's ecosystem. If this were the case, the child would be continuously thrown into crisis situations where existing conceptions failed to explain new experiences. However, if we consider resilience to be part of a change equation then what we may have is an ecosystem which can affect a 'dynamic balance' between change and persistence. In such a system perturbations are diffused and not allowed to assume threatening proportions, but at the same time there is a near continuous qualitative change affecting conceptions within the ecosystem. As long as the child's ecosystem interacts with the learning environment, existing conceptions are progressively and unavoidably modified by experience. Change within such a system can be seen as a set of balanced conceptual transformations set in a background of apparent permanence. Change in this context is a series of metatransitions involving the subtle and gradual refinement of personal theories.

Describing the 'displacement of concepts' Schon (1963) comments that it "tends to go unnoticed because of its long time span, and it tends to have so long a time span because it goes unnoticed". It is likely that conceptual change within ecosystems also goes on largely unnoticed because of the nature of the subtle transitions affected by the learner. This may seem to suggest that
as teachers we may have to improve the resolution of the ways in which we assess and manage the process of conceptual change.
Chapter 8

The Management of Conceptual Ecosystems
8.1 Introduction

Resilience and conceptual change are opposite sides of the same coin. The ability to absorb change and to have one's conceptions persist goes hand in hand with the processes involved in conceptual change. This relationship between resilience and change will have a significant influence on the outcomes of teaching and learning in science. Consequently, an ecosystemic perspective should figure largely in the ways that we reconcile the student's existing conceptions with the received scientific view of natural phenomena. The management of this situation from a teaching and learning perspective is the main concern of this chapter.

8.2 Learning about Ecosystems.

The management of conceptual ecosystems begins with learning as much as possible about the nature of these systems and how to facilitate change in the form of 'metatransitions' carried out by active learners operating in a self-organizing way.

An objective of science teaching is to help students integrate their everyday experiences of life with scientific explanations of the same phenomena. If these viewpoints are to be reconciled, teachers and pupils have to be able to stimulate, encourage, amplify and facilitate the processes of conceptual change which originate from within ecosystems. These activities should not be seen as the equivalent of shaking nuts and bolts in a dustbin and
hoping to get a bicycle, nor for that matter the derivation of Mendel's Laws from the learner's intuitive theories about inheritance. What it does do is to place an emphasis on the learner's existing conceptions and their 'organization' and ways of making these ideas interact with scientific conceptions. Teaching strategies sympathetic to an ecosystemic view of children's conceptions and conceptual change would tend to focus on the following pedagogic practices.

8.3 Identifying Children's Conceptions.

Until recently identifying children's science has been an activity carried out by researchers. With the development of programmes such as the Learning in Science Project (LISP), the Children's Learning in Science Project (CLISP) and the Secondary Science Curriculum Review, a more collaborative approach to children's scientific ideas, involving both teachers and researchers, is emerging. It is unlikely that busy teachers will regularly find the time to explore every aspect of children's understanding of scientific concepts. In this respect researchers can still help fill in the many gaps which exist in our understanding of the range of children's alternative conceptions. However, the advantage of the above curriculum initiatives is that they increase the relevance of this research to the class teacher and underline the problems facing the teacher when she takes alternative conceptions into account. Research surveys of a particular topic area alert teachers to the sorts of ideas children
are likely to bring to their learning activities. As teacher involvement increases in this field there may be a transition toward 'research methods' which are even more firmly rooted in the everyday activities of teachers and students. The research instrument used in this study was designed with this principle in mind. Offspring prediction and family trees are strongly associated with traditional teaching strategies in genetics, but as demonstrated in this study, they can also be used as an effective elicitation procedure for gaining insights into children's conceptions of inheritance.

Identifying and taking children's conceptions into account is not an esoteric research activity but fundamental to a conceptual change view of learning. Before the teacher can become a 'conceptual ecologist' he has to be able to identify the conceptions and the behaviours associated with ecosystems. There has to be an awareness of the learner's perspective so that when scientific ideas are introduced it is done in such a way that they become active within the student's conceptual ecosystem. Planning a teaching strategy or designing a learning sequence cannot hope to be effective in bringing about change if it fails to consider alternative conceptions in an ecosystemic context. Hewson (1981) comments

"...it is instructive to examine some common teaching practices. In these the ideal is to present the desired material in a logical sequence, bolstered by suitable experiences of which appropriate explanations are provided. No alternative conceptions are considered - after all why consider something which has not been taught explicitly? In terms of the model, there is every reason to expect that a presentation of this nature might be intelligible to the student. But if he or she holds a plausible alternative conception which contradicts that
which is presented, the model indicates that the new material cannot be meaningfully incorporated because it is not plausible. What is more, the student is given no planned assistance in identifying the cause of the problem and how to overcome it. Of course some students will do that for themselves, but experience shows that the majority do not."

Teachers of science need to address their students’ alternative conceptions as a first step in facilitating conceptual change. Research projects such as CLISP lend considerable support to teachers by providing information on common conceptions in specific topic areas. However, if these are placed in an ecosystemic context then more than ever we are dealing with a unique and idiosyncratic form of conceptual ‘organization’ where universals do not apply. In these circumstances teachers must be sensitive to the multiple conceptions of individual students and not just those that can be easily spotted because of their relationship with known ‘misconceptions’. Consequently, the teaching focus is shifted away from situations where individual conceptions are identified and engaged by learning activities, to one where multiple, interactive conceptions are encouraged to become cognitively active within the student’s conceptual ecosystem. This strategy allows teachers to observe conceptions against a background of their ecosystemic relationships.

8.4 Syllabus Content and Lesson Design.

The learner’s viewpoint is the starting point of lesson design. The content of the lesson must relate to the child’s conceptual
ecosystem in order that the scientific view can at least begin to communicate with this environment. The model of conceptual change proposed by the Cornell Group (Posner et al. 1982) suggests that dissatisfaction with an existing conception and the plausibility of an alternative (scientific) concept begins the communication process between the received view and the learner's ecosystem. At this point it is suggested that the learner may find the new idea a fruitful way of solving current problems and this subsequently leads to conceptual change. This description is broadly consistent with an ecosystemic view of change, but needs to be qualified in the light of what actually goes on within ecosystems.

The intelligibility of a scientific concept can be seen as its ability to get inside the child's ecosystem of existing ideas; Hewson (1981) refers to this as "conceptual capture". For this to happen it has to resonate, at least initially, with a conception within the ecosystem. For example, dominance in strict Mendelian terms seems to resonate with many children's blending conceptions of inheritance. Put another way dominance is 'understood' in terms of colour strength and gains access to the ecosystem in this way. This 'misconception' is a long way from the biological notion of dominance but what it does represent is the beginning of a process which allows the learner to develop and test his conception of 'dominance' within his own ecosystem. By understanding dominance in this way existing ideas interact with new experiences. The quality of this interaction allows the learner to go on testing this conception against subsequent experiences, which in turn may allow him to make the transition to the scientific viewpoint. The role of
the teacher in this situation is to encourage the learner's continued engagement with the 'problem' to the point where he can test the alignment of his conceptions with the scientific view.

Resonance between existing conceptions and scientific concepts is not difficult to achieve given the diversity and heterogeneity of children's ideas. Conceptual ecosystems have a great number of 'hooks' on which to hang new ideas. Indeed a major aim of the teacher should be to develop, foster and reward conceptual heterogeneity.

Dissatisfaction with existing conceptions is often seen to run parallel with the intelligibility of new concepts. Indeed, in many teaching schemes designed to bring about conceptual change, dissatisfaction, conflict, or cognitive dissonance are used early on in the teaching sequence (Nussbaum and Novick, 1981) or after a period of initial awareness raising (Rowell and Dawson, 1984). It is interesting that many of these strategies have been subsequently refined in order to overcome the 'problem' of children hybridising old and new ideas. However, I believe that this only serves to reinforce the contention that new ideas have to resonate with the old before they begin to interact with the child's conceptual ecosystem. Dissatisfaction with existing ideas is a desirable goal for the teacher interested in bringing about conceptual change but it has to be generated from within conceptual ecosystems, not orchestrated and imposed on the system as if it were part of curricular theory.

In the history of science there are many examples of dissatisfaction leading to conceptual change. These models of
change are perceived by the expert scientist as having the same sort of influence on the learner. However, confronting the 'naive' learner with new conceptions in the hope that he sees the conflict and shares the dissatisfaction of those who have already made the ideas part of their ecosystem, remains a very different matter.

"The theory of conceptual change (as articulated by Posner et al.) holds that the state of readiness for conceptual change ought best to arise from the learner's own attempts to make sense of experience... Yet a troublesome aspect of the way in which their work has been transformed into an instructional method is that the topics addressed arise from the wisdom of the curricularists, not the curiosity of the learner. The teacher is asked to rush students to readiness by posing a question... that probably never occurred to the students, and then induce dissatisfaction with their own explanations by confrontation. The result is a kind of "cognitive assault" in which students are forced to confront and abandon a part of self that has been, and is, serving them reasonably well."

(Clark. In Watts and Pope, 1985)

The power of interactive metaphors (Petrie, 1974), anomalies or analogies have to be measured in these same terms; unless they mean something to the learner and arise from within his ecosystem they are unlikely to have any impact on conceptual change. New ideas can be made to resonate with existing conceptions if children are given the opportunities to incorporate them into their ecosystems. If this happens the plausibility and fruitfulness of conceptions may be put to the test. No matter how effective the anomaly or the metaphor is in terms of interacting with existing conceptions it cannot be expected to 'work' if it is not part of a more general effort by teacher and student to exceed the boundaries of conceptual stability. It is often suggested that this effort should be orientated towards enfeebling existing ideas. The notion
being that anomalies and metaphors result in a level of
dissatisfaction which reduces the status of conceptions within the
child's ecosystem and strengthens the case for change. However,
given the resilient character of ecosystems, it may be essential
for teachers first to facilitate the amplification of these
conceptions in order to make them explicit and co-active with 'new'
ideas. If existing notions are to have their explanatory adequacy
tested and measured against scientific theories, then they must be
allowed to 'live out their lives' to the fullest extent. If the
learner is to test his conceptions against experiences, no single
factor such as conflict or anomalies will cause this to happen.
What is required is the convergence of learning strategies to
produce a learning environment which promotes and sustains the
activities of student's conceptual ecosystems.

8.5 Teaching Styles and Strategies.

Teaching that is designed to facilitate change within
conceptual ecosystems requires students to be aware of their
existing conceptions. This also means that learners must exhibit a
willingness to articulate and explore their conceptions. Learning
environments which provide this sort of opportunity for reflective
and reflexive thought take many forms.

Small problem solving groups seem to have the potential to
nourish students' awareness of their own conceptions. Group work
increases the opportunities for verbal involvement and interaction
as well as opening up feedback channels originating from within
the peer group. Small group work means that individual children take responsibility for their own learning but also that of their peers. The helping behaviour that is commonly observed when children work together involves the 'helpers' in the explanation and the articulation of conceptions. In these circumstances it is not easy to decide who gets the most out of these exchanges, the helper or the helped.

Sawada and Caley (1985) describe how group work may contribute to conceptual change.

"This far-from-equilibrium environment was facilitated by focusing on open-ended projects in which children had extensive free choice in identifying and pursuing interests usually with the aid of a computer using LOGO. The child, as a "pursuer of projects" was not so much a "pursuer of learning" (Being) as he/she was a "pursuer of knowing" (Becoming). The child was a knower or better still, an epistemologist in the sense of Papert (1980); it is the "child as epistemologist" that consciously propels the child toward new realms of Becoming. Freedom to pursue is thus the first guideline towards knowing/Becoming. Sensitivity on the part of the teachers and students is the prime consideration when children as epistemologists extend themselves into an actualization of the unknown by choosing one path of pursuit over another thus opening more domains of Being through Becoming at each decision point."

Certainly problem solving groups have considerable potential in bringing about conceptual change in the individual. In the past there has been a tendency to make group work the ultimate form of constructivist learning strategy (usually by non-constructivists) however, a much more fundamental issue is not so much the specific strategy used but the general learning climate created by the students and teachers.

Whether in the context of a class discussion, or an experimental project, teaching and learning should make it possible
for students to experience the sorts of conditions which are likely to promote conceptual change. Teaching strategies which encourage active learning and student participation, will be more effective in this respect, than the teacher dominated, 'knowledge transmission' type of lesson. In this respect the most critical factor in creating a learning environment capable of facilitating change is not the particular strategy used, but the development of a supportive climate in which conceptual ecosystems can mature and grow. If children are to be encouraged to make their conceptions explicit, and if these ideas in turn will be subjected to private and public scrutiny, only a supportive classroom environment will make this a positive learning experience for the student. The creation of an environment where learners can feel confident that their ideas will be respected and valued by teachers (and fellow students) can help promote conceptual change. Watts and Bentley (1986) have considered the role of non-verbal communication in the creation of non-threatening learning environments. The implications of this work is that teachers may have to be more aware of their own actions before expecting children to engage in the activities which may lead to conceptual change.

"From our evidence it would seem that youngsters are highly attentive and sophisticated interpreters of teacher behaviour. Within a supportive atmosphere they are looking for high levels of trust, warmth and enthusiasm. They know they have found such attitudes when teachers engage in frequent eye contact, are alert, with quick body movements, listen carefully to youngsters criticisms, and act on them. Such teachers laugh, with others and at themselves, stand close, touch from time to time, and use quick, bright voice tones that convey warmth and above all, respect for their co-learners."

(Watts and Bentley, 1986)
Given the prevailing social climate in some classrooms, these observations highlight how the metatransitions of the conceptual change process may be all too easily disrupted by dominant forces which interact with children's ecosystems. These forces may well take the form of restrictive interpersonal relationships in which the teacher or a fellow student is interested only in imposing their ideas (overtly or covertly) on others. In these circumstances individual ecosystems may be denied the opportunity to develop the level of openness (heterogeneity, flexibility and engagement) which results in conceptual change. The image of the dictatorial teacher or the 'know all' student may spring to mind in this context, but the real problem associated with promoting conceptual change is not so easily identified or remedied.

The imposition of scientific 'fact' lies heavily over most classrooms. Curricular science gives teachers and students little in the way of freedom to develop their intuitive conceptions, and what little that they have is often controlled by examination requirements and the expectations of parents, students and society. The learner is so busy with the agenda of curricular science there is little time for the sort of personal exploration which results in conceptual change. Equally the teacher is concerned to develop the potential of her students to the full, but there isn't time to allow ecosystemic processes to bring about change and therefore change is imposed (often un成功lessly). Caught between what seems to be two extremes, the teacher tries to provide a rich, supportive learning environment on the one hand but cannot afford the 'luxury' of giving her students absolute freedom to develop their own ideas.
in their own time. Student's are encouraged to 'discover' and to make sense of their world, but all the time their activities are being guided by the template of curricular science. Teachers and students are caught in a viscious circle of cultural forces which act in such a way as to inhibit conceptual change.

At another level, the teacher who is committed to a constructivist view of learning and seeks to facilitate the conceptual change process, is also caught up in the dilemma of how to teach in such a way as to help and not enfeeble the activities of the learner. Such teachers have no desire to be neutrals when it comes to their students' learning activities. However, they may have become aware that in order to give students the freedom to change their conceptions, they must first not deny them that freedom. By determining the direction and the route that conceptual change should follow we may preclude the very possibility of change. If children are to be given the opportunity to change their ideas then teachers and fellow students need to ensure that their actions are 'ecosystemically friendly', ie. they resonate with the learner's existing ideas and that they increase rather than decrease the creative potential of the learner's ecosystem. Metaphorically speaking, science teaching becomes not the exploitation and organization of children's ideas in order to align them with scientific views, but the conservation of ecosystems of conceptions which have an inherent potential to change and to assimilate new ideas and experiences.
Having described the wider issues of how conceptual change might be facilitated in classrooms, it would seem appropriate at this point to consider the specific strategies used in teaching inheritance and to compare these with the model of conceptual change developed in this thesis. If we consider the methods used by teachers to introduce students to inheritance concepts, then it is possible to build up a general picture of classroom practice.

The first formal contact that many students have with inheritance concepts is when they are asked to think about the observable traits and characteristics of 'classical' genetics organisms such as mice, fruit flies, pea plants or fungi. In the light of my researches it would seem highly desirable that this list of organisms be extended to include a greater number of familiar organisms such as domestic cats, dogs and Homo sapiens. Classic genetics organisms are not chosen on the basis of their familiarity to students but on the basis of biological criteria such as high fecundity, short generation times and ease of experimental manipulation. These latter characteristics may be extremely important to research geneticists, however, many of these convenient organisms are unfamiliar to students. This makes it difficult for the student to reconcile existing conceptions of inheritance, which may be bound to specific everyday examples, with 'school genetics'. The use of more familiar organisms such as mice or cats might overcome this problem. Another advantage of extending the range of exemplar organisms is that it would make it
possible for teacher and student to move away more easily from the 'black and white' world of Mendelian genetics. For example, domestic cats exhibit all the classic Mendelian characteristics but also show polymorphism, multiple allele effects and co-dominance. The considerable variation to be seen in cat phenotypes would allow students and teachers to discuss and debate existing notions of "mixed breeds", "half-casts", and "blends". These effects are often thought to be too difficult as they involve complex gene combinations, but at a descriptive level they have considerable potential in allowing students to make the connection between their everyday experiences of inheritance and school genetics. Examples drawn from human inheritance patterns would also have the same potential to generate anecdotes, analogies, metaphors and anomalies from within individual ecosystems. On this basis learners can actively engage with inheritance phenomena and begin to test their intuitive ideas.

A classic strategy associated with genetics teaching is the use of problem solving activities. Children are introduced to the genotypic underpinnings of inheritance through problems which require the student to predict offspring and parental phenotypes/genotypes. The 'Punnett Square' typifies this form of problem solving. Problem solving is an ideal way of facilitating conceptual change. This thesis has described how problem situations provide a focus for student discussion, raise conceptual awareness and give learners the opportunity to test their conceptions privately and publicly. Unfortunately, genetics problems do not tend to encourage these behaviours, for they rapidly develop into
pseudo-mathematical exercises where the student is encouraged to get the 'right' answer by following a problem solving algorithm. Many students find genetics problems straightforward but in the majority of cases this is achieved by 'ritualising' the content of the problem and separating it from real world inheritance phenomena that they have experienced. If problem solving in genetics is to have any impact on the reconciliation of existing ideas with genetics concepts, then there is a need to delay the introduction of Mendelian explanations until students have had a chance to try out their own predictive theories. Failure to do this means that problem solving is confined to school based genetics which may have little to say about why "the cat next door had three brown kittens and one white one".

This thesis has indicated that many 12 year old children have thoughts about inheritance and can construct conceptual ecosystems which allow them to theorize about inheritance phenomena. It is unfortunate that these children will have to wait several years before any of these ideas might be used again. Traditionally, genetics is a topic which is taught to senior students (a Piagetian scar on the syllabus?). However, if conceptual change involves a series of metatransitions based on the learners growing awareness of the relationship between existing conceptions and new ideas, then it may be advantageous that he is given time to make these adaptations. It would seem more desirable in this respect that rather than squeeze genetics into two weeks of teaching and learning, children might be given the opportunity to make the links
between existing conceptions and new ideas over a longer period of time.

8.7 Future Research and Development of an Ecosystemic Model of Conceptual Change.

To enlarge our understanding of conceptual change it would seem profitable to develop the small group setting as a focus for research. Teacherless groups provide a fruitful model system for observing theories in action. Indeed in the light of what I have said above about non-threatening environments, they may be one of the best contexts in which to observe active conceptual ecosystems. Much research remains if we are to find out more about how to maximise the benefits of group work for the individual. The combination of boy/girl ratios, group size, age, status, and friendship characteristics, which yield the greatest benefits for individuals is a research question that remains open. In this study it was observed that where one student is in the minority by sex or by their level of engagement, this student can become isolated and detached from the group's activities. We need to know more about the personal and interpersonal reasons for this behaviour.

The technique of video-recording group activities would seem to be a particularly fruitful research technique. Not only does it afford the opportunity to analyse cognitive and interpersonal activities, but given considerable resources of time and equipment, it could also be used to analyse the effects of non-verbal communication within the group and give cognitive and social
analyses another dimension. Video recordings of group activities can provide a multidisciplinary focus for researchers interested in conceptual change.

Future research efforts might also examine the generalisability of the ecological framework to other content areas within science curricula. The influence of social settings, different problem solving tasks and various sex/age combinations might be examined. In the context of this research it is acknowledged that the design of the inheritance problem is specific to this biological topic. However, at a more fundamental level it is not difficult to imagine the same sorts of problem solving activities taking place in a sixth form physics laboratory or in a primary school playground. Certainly the boys and girls involved in this study cannot be seen as being representative of every social class or family background, school system or ethnic group. Future research might continue to look at the effects of these variables on the origins and the use of children's intuitive beliefs. It is possible to speculate that although one might expect these factors to have significant effects on children's conceptualising, there will be many more instances of commonality and similarity between groups of children. Whether this would be a reflection of common cultures, common languages or fundamental cognitive processes, the representativeness of student's involved in research is probably a more salient issue when researchers try to utilise educational resources in order to implement 'solutions' to learning problems in the classroom.
In addition we need to know more about the response of teachers and students to learning environments which encourage variability, uncertainty and disturbance within conceptual systems. In a rapidly changing world where unknown experiences seem to be around every corner, is it more likely that learners will ultimately seek out or insist on conceptual stability rather than look for ways of maintaining their openness to change. The consequences of such a response may have a very considerable effects on the ways that students reconcile existing ideas with scientific conceptions. Equally, can teachers accept that their role in bringing about conceptual change may not be one of 'inducing conflict' in the minds of their students but facilitating and supporting children in their conceptual activities. This research has highlighted the problems of generating conceptual conflict and change in group settings. The lack of effectiveness of cognitive conflict strategies has considerable bearing on the productivity of group discussions and teacher-pupil interactions. What role does the teacher perform if his challenges, disagreements and arguments carried out in the best Socratic fashion fail to have an impact on his student's conceptual ecosystems? 'Deliberate' attempts to bring about conceptual change may have to take the form of preparing learning environments, illuminating and eliciting conceptions and fostering the growth and maturation of each student's alternative conceptions.
Appendix I

Inheritance Cards
Appendix II

Comprehension Task: Text Content
The coat colour of a mouse depends on the genes it receives from each of its parents.

* Genes are bits of biological information which control the way the mouse looks, eg. the colour of its coat, the length of its tail etc.

The colour of a mouse's coat is determined by pairs of genes. The mouse receives one gene from the father and one from the mother, to make up a pair of genes.

There are a number of pairs of genes which control the colour of a mouse's coat.

Black Mice
The gene B controls the development of the black coat colour in mice. If a mouse receives a black gene B from each parent, the mouse will have a black coat.

Brown Mice
The gene which produces black coat colour can occur in another form called the brown gene b. A mouse which receives a brown gene b from each parent will have a brown coat.

Black Mice/Brown Mice
If a mouse receives a black gene B from one of its parents, and a brown gene b from the other parent, the mouse will have a black coat. This is because the black gene is dominant over the brown gene.

Mice with Coloured Coats
The colour gene C is the gene which decides whether a mouse will have a coloured coat. If a mouse receives a colour gene C from each parent, the mouse will have a coloured coat.
Albino Mice

The colour gene C can occur in another form called the albino gene c. A mouse which receives an albino gene from one parent and another albino gene from the other parent, will have no colour at all in its coat. Albino mice are pure white and have pink eyes.

Coloured Mice/Albino Mice

If a mouse receives the colour gene C from one parent and the albino gene c from the other parent, the mouse will have a coloured coat. This is because the colour gene C is stronger than the albino gene. (The colour gene is said to be dominant over the albino gene)

Mice with Dark Coloured Coats

The gene L has the effect of making the colour of a mouse's coat darker. If for example, a brown mouse receives an L gene from each of its parents, its coat will be a dark chocolate colour.

Mice with Light Coloured Coats

The gene L can occur in another form called l. The gene l has the affect of making the coat colour lighter. If for example, a brown mouse receives an l gene from each parent, its coat colour will be a milk chocolate colour.

Light Coloured Mice/ Dark Coloured Mice

If a mouse receives an L gene from one of its parents, and an l gene from the other parent, the mouse will have a dark coat colour. This is because the gene for darker colours is stronger than the gene for lighter colours (L is dominant over l).

Agouti Mice

Agouti mice have grey coloured bellies and a coat made up of two colours. This gives the coat of an agouti a speckled look. For example, agouti mice can have a mixture of black and brown in their coat. The agouti gene A produces the agouti pattern in the mouse's coat. If a mouse receives an agouti gene from each parent the mouse will also have an agouti pattern.
Non-Agouti Mice

Non-agouti mice have coats of only one colour, eg. solid black. The non-agouti gene a is another form of the agouti gene A. If a mouse receives a non-agouti gene from each parent the mouse will have a coat made up of only one colour. Sometimes mice can have the gene a¹ which gives non-agouti mice tan bellies.

Agouti Mice/Non-Agouti Mice

If a mouse receives an agouti gene A from one parent and a non-agouti gene a from the other parent, the mouse will have the agouti pattern. This is because the agouti gene is dominant over the non-agouti gene. (A is stronger than a).
Appendix III

Family Tree Problem
Appendix IV

Summary Diagrams of each Group's Family Trees
Symbol Key

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<thead>
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<th>Symbol</th>
<th>Phenotype</th>
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<tr>
<td>Br</td>
<td>Brown</td>
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<tr>
<td>Ag</td>
<td>Agouti</td>
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<tr>
<td>Gr</td>
<td>Grey</td>
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<tr>
<td>Al</td>
<td>Albino</td>
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Care Study 2
Appendix V

Videotape Recording Equipment
Appendix VI

Shorthand Summaries of Case Studies
Symbol Key

○ Like Begets Like

▲ Variation in the Offspring

□ Blending (Sue and Tracey)

● Sibling Similarity

■ Blending

‡ 'Dominance'/Blending

◊ Albino Frequency

♦ Grandparental Influence

♦ Random Offspring (Odd Ones)

□□ Gender Based Like Begets Like

△ Mixtures (Tracey)
<table>
<thead>
<tr>
<th>Susan</th>
<th>Sarah</th>
<th>Tommy</th>
</tr>
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<tbody>
<tr>
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<td></td>
<td></td>
<td>Competitive Collaboration</td>
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<td>●</td>
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<td>▲</td>
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<tr>
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References

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